Co-operation models

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Abstract:
This deliverable presents research and development on architectural concepts selected as candidates for next-generation open access based network infrastructures. The deliverable presents research performed within the scope of OASE concerning specific challenges of the different open access aspects. Such aspects include different open access models, monitoring, traffic studies, and access and aggregation/metro architectures. The deliverable is finalized by a short list of open access concepts which will be evaluated in WP5 and WP6.

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Executive summary

The main goal of the deliverable is to evaluate and develop access and aggregation/metro network architectures for cooperative scenarios, and to analyse traffic patterns and its implications on next generation optical access and aggregation/metro networks. The work in the deliverable has the full OASE scope defined in D3.3, i.e. from a gateway at the customer premises to the core network edge.

Open access networking is a business model where the aim is to share an infrastructure in order to lower the costs to the entities utilizing the open access infrastructure. Such a business model has implications on the design of the network architecture. This affect is realised across three different levels; 1) fibre, 2) wavelength, and 3) bit-stream. In order to visualize where and on which level open access is supported, an open access reference model has been developed and used when describing the different varieties of open access architectures.

The main impact on the physical infrastructure provider (PIP) is due to the opening of the wavelength layer since this creates an opaque PIP that needs to manage optical devices (e.g. optical splitters, arrayed waveguide gratings (AWGs), and wavelength selective switches (WSSs)). Wavelength open access also requires an entity that manages and coordinates the usage of the optical spectrum (wavelengths) between the entities that share it, i.e. the network providers. It is possible that the PIP, NP, or even a totally separate entity may coordinate this. Based on discussion with WP6 it was decided that the most likely and neutral entity would be the PIP.

A transparent PIP, which offers dark fibre infrastructure access, is of course also possible. The scope of OA within OASE is larger than that which is normally considered. In addition to access to fibre and wavelengths within the final mile, we also consider the problems of end-to-end fibre and wavelength access all the way up to the core. In so doing we must also consider the problems of access to points-of-presence along the path and issues of floor space and power supply when considering the possibility of multiple network and service provider's equipment at these locations.

When it comes to bit-stream open access the main focus has been to increase the isolation between network providers and service providers utilizing the shared infrastructure on an electrical forwarding level, and on the control and management level. The latter focuses on alleviating the current "black box" problem in open access networking where the operator of the shared infrastructure has full control over the network while the service provider usually has little insight in to the state of the shared infrastructure. This can lead to very high support costs when customers are reporting problems while the service provider does not have the tools to trouble shoot or locate the cause of the reported problems. In this deliverable a more evolutionary approach based on virtualization has been suggested, where more disruptive approaches are studied in other FP7 projects such as SPARC.

Also included in this work are studies related to traffic flows which have a focus on video content distribution and the locality and caching of such traffic flows. If there is such a locality aspect in the nature of the traffic flows then this would tend to offset some of the potential gains from extreme consolidation scenarios. The reason would be that it would not be optimal to send traffic into the core and back when it could have been switched more locally in the access. The locality study shows that even though not utilizing a highly distributed caching infrastructure there were at least 18% simultaneous users of the same video content. With caches this figure would go up and architectures that allows for such traffic flows would then off load the core network to a fairly high degree.

The evaluation and development of open access architectures lead to a number of different possibilities; six different versions of WDM PON, five different versions of Hybrid PONs, and a single of each of the two stage PON and NG AON, and this does not include bit-stream open access which is possible over any of the different architectural versions. However, based on discussions with WP5 and WP6 a short list of architectures was drawn up that included four different WDM/Hybrid PONs and AON based architectures that fulfilled the requirements.

In summary the main contributions of the deliverable is the work on different open access models, open access reference model, optical monitoring in multi network provider scenarios, traffic studies, the large variety of wavelength open access architectures, evolutionary virtualization based open access architectures, and the short list of open access architectures based on discussions with WP6.

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Abbreviations

AON	Active Optical Network
API	Application Interface
AWG	Arrayed-Waveguide Grating
BBF	BroadBand Forum
BGP	Boarder Gateway Protocol
BS	Band Splitter
B-VLAN	Backbone VLAN
C	Client
C&M	Control and Management
CAN	Consolidated [or Central] Access Node
CapEx	Capital Expenditure
CDN	Content Distribution Network
CPE	Customer Premises Equipment
C-VLAN	Customer VLAN
CWDM	Coarse WDM
DHCP	Dynamic Host Configuration Protocol
DEMUX	DEMUltipleXer
DoW	Description of Work
DSLAM	Digital Subscriber Line Access Multiplexer
DWDM	Dense WDM
EWAM	External Wavelength Adaptation Module
FF	Feeder Fibre
FSR	Free Spectral Range
Gbps	Giga bits per second
HTTP	Hypertext Transfer Protocol
ID	IDentifier
IP	Internet Protocol
IPTV	IP TeleVision
I-SID	Instance Service IDentifier
IX	Internet eXchange
LAN	Local Area Network
LL	Link Level
LSP	Label Switched Path
LX	Local eXchange
LXC	Linux Containers
MAC	Media Access Control
Mbps	Mega bits per second
MPLS	Multi-Protocol Label Switching
MPLS-TP	MPLS Transport Profile
MUX	MUltipleXer
NDP	Neighbour Discovery Protocol
NG	Next-Generation
NGA	Next-Generation Access
NGOA	Next Generation Optical Access
NP	Network Provider
NS2	Network Simulator 2
NT	Network Termination

OA	Open Access
OAM	Operation, Administration, Maintenance
OAN	Optical Access Network
OASE	Optical Access Seamless Evolution
OCh	Optical Channel
OLT	Optical Line Termination
OpEx	Operational Expenditure
ODF	Optical Distribution Frame
ODN	Optical Distribution Network
ODU	Optical Data Unit
ONU	Optical Network Unit
OSPF	Open Shortest Path First
OTDR	Optical Time Domain Reflectometry
OTN	Optical Transport Network
OTU	Optical Transport Unit
OUI	Organizationally Unique Identifier
P2P	Peer-to-Peer
PADI	PPPoE Active Discovery Initiation
PADR	PPPoE Active Discovery Request
PADT	PPPoE Active Discovery Termination
PB	Provider Bridges
PBB	Provider Backbone Bridges
PBB-TE	Provider Backbone Bridges Traffic Engineering
PCP	Physical Connection Point
PIC	Photonic Integrated Circuit
PIP	Physical Infrastructure Provider
PON	Passive Optical Network
POP	Points of Presence
PoU	Point of Unbundling
PPPoE	Point-to-Point Protocol over Ethernet
PtMP	Point-to-Multi-Point
PtP	Point-to-Point
OSF	Optimal Split Factor
QoS	Quality of Service
S	Server
SFP	Small Formfactor Pluggable
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol
SP	Service Provider
SQL	Structured Query Language
STB	Setup Box
S-VLAN	Service-VLAN
TCM	Tandem Connection Monitoring
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
ToC	Table of Content
UD	Ultra Dense
UI	User Interface
VLAN	Virtual LAN

VOD	Video on Demand
VRF	Virtual Routing and Forwarding
VSF	Virtual Switching and Forwarding
VSI	Virtual Switch Instance
WDM	Wavelength Division Multiplexing
WR	Wavelength-Routed
WS	Wavelength Selective
WSS	Wavelength-Selective Switch
XML	Extensible Markup Language

1. Introduction

The goal of the deliverable is to evaluate the impact of co-operation models, or open access networking, on the OASE network architectures. The scope of the deliverable is the end-to-end OASE scope, i.e. from a core node to the customer premises.

In this deliverable there are a multitude of different versions of the OASE architectures that can be developed for open access scenarios. An evaluation of these is included in this document. It is assumed that the same aggregation network architecture can be used for all access architectures. However, it is not necessarily true that the aggregation part of the network is open. There might be cases where there are multiple, in parallel, vertical networks from the core to the access while the access is shared, where sharing can be done on the fibre, wavelength and bit stream levels.

Connecting to an open access network can also be done on multiple levels and through multiple types of interfaces. The open access reference model, introduced in this deliverable, tries to convey where to connect, and on which layer, for the various architectures. It corresponds to the reference model that was introduced in D3.1. Other open access architectural considerations covered in this deliverable are isolation and virtualization, energy-efficiency, CapEx and OpEx, and point of open access in these types of co-operation environments.

The deliverable also includes a section on traffic measurements and analysis in order to predict future traffic patterns and the impact that they might have on the next generation optical access. The focus of these studies is to see if there is a localized nature of large volumes of the traffic since this could act as a counter balance to extreme consolidation.

1.1 Overview of activities covered in the deliverable

The list below shows the related co-operation model activities in the DoW, and also indicates where within the deliverable the work addressing each activity is to be found. All activities in WP3 T3.2 are finalized by this deliverable.

- A3.2.1: Open access network (M13-M35)
    - Fully covered in chapters 3, 5, and 6. Chapter 3 includes work on the open access reference model and other aspects of open access, chapter 5 is where architectures of open access are described as well as the end-to-end open access mapping onto the reference model, and chapter 6 which focuses on open access implications on the OASE common aggregation network.
- A3.2.2: Traffic and service models (M13-M35)
    - Covered in chapter 4 by analysing current traffic patterns to predict future locality of traffic demands, and through simulating locality aspects in peer-to-peer networks. Work in the activity is also covered by aspects like the shared IX which is covered in chapter 3.2.6.
- A3.2.3: QoS guarantee and monitoring (M13-M35)
    - QoS aspects are covered in chapters 3 through work on virtualisation/isolation and SLAs, and chapter 5 which includes an analysis of this on a per co-operation architecture variety level. Monitoring work is covered in chapter 3.2.5.

2. Open access background

Open access concerns the design and operation of a network or architecture such that it supports a degree of freedom in some conceptual sphere, see e.g. [1]. For example, an open access network may be utilised to offer a choice of services to the customer (for example, allowing them to choose between internet service providers). This is a boon to customers and promotes competition and market diversity. In addition, open access networks allow companies to collaborate in the undertaking of the deployment of a network, mitigating risk. For example, the supply of an internet connection to a customer could be divided up into the civil works, network architecture design, deployment and operation and service provisioning tasks. By dividing these tasks between different companies in a collaborative arrangement the risks and investment (at each level) can be compartmentalised, potentially reducing the barrier to market entry to new market entrants outside the initial collaborative agreement.

As the open access mechanisms to be discussed involve the close cooperation of various businesses this topic has therefore been the subject of study within Work Package 6 (WP6). Within this section we will include, where appropriate, a brief outline of some WP6 work which will facilitate understanding of the concepts presented here. The canonical source for information related to business modelling will remain WP6, however, and we would therefore direct the reader to the WP6 deliverables D6.1, D6.2 and D6.3.

Delivery of internet service to customers will involve the interaction of multiple actors, which may be performing multiple roles. For example, a NP may need to lease dark fibre from a PIP. This may be a self-contained entity (for example, see the Stokab scenario detailed in D6.2) in which a municipality has installed a dark fibre network, or alternatively it may be only a part of a large vertically integrated monopolist telecommunications provider. The roles that must be performed in order to provide a service to a customer are shown in Figure 2-1 below

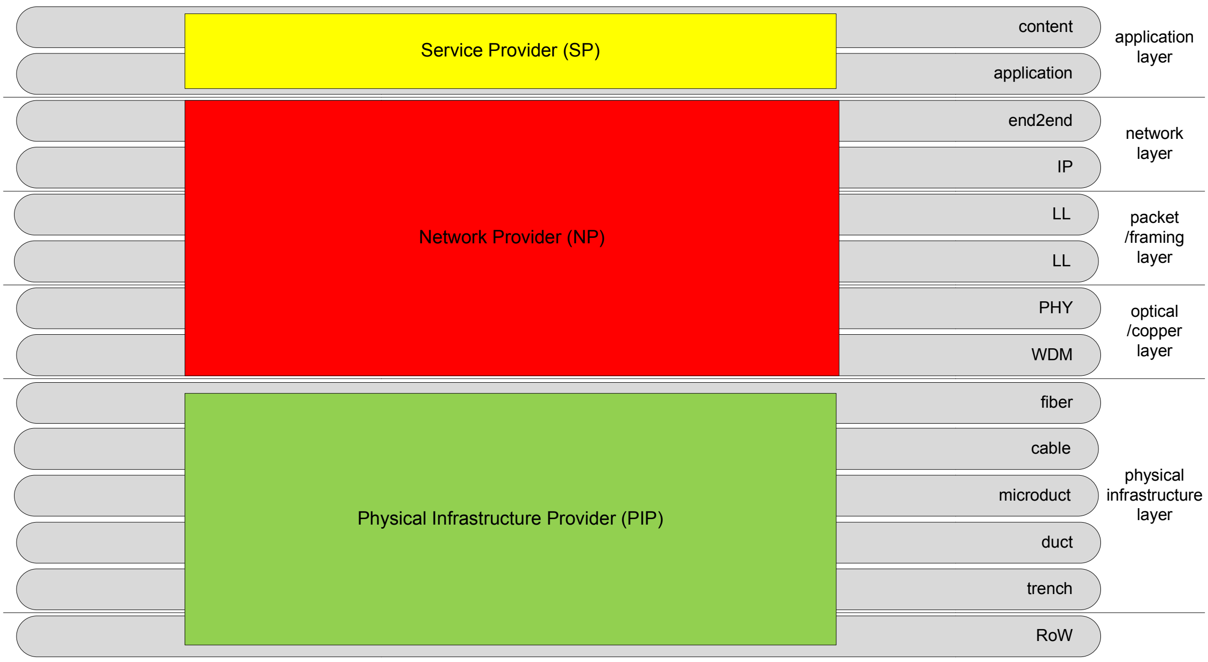


Figure 2-1: Roles by network layer

This shows the functions that are performed by the different roles as you traverse the network stack.

Depending on the scenario, many of these roles will be contained within a single business entity. These scenarios are shown in Figure 2-2 below, and can also be found in D6.1.

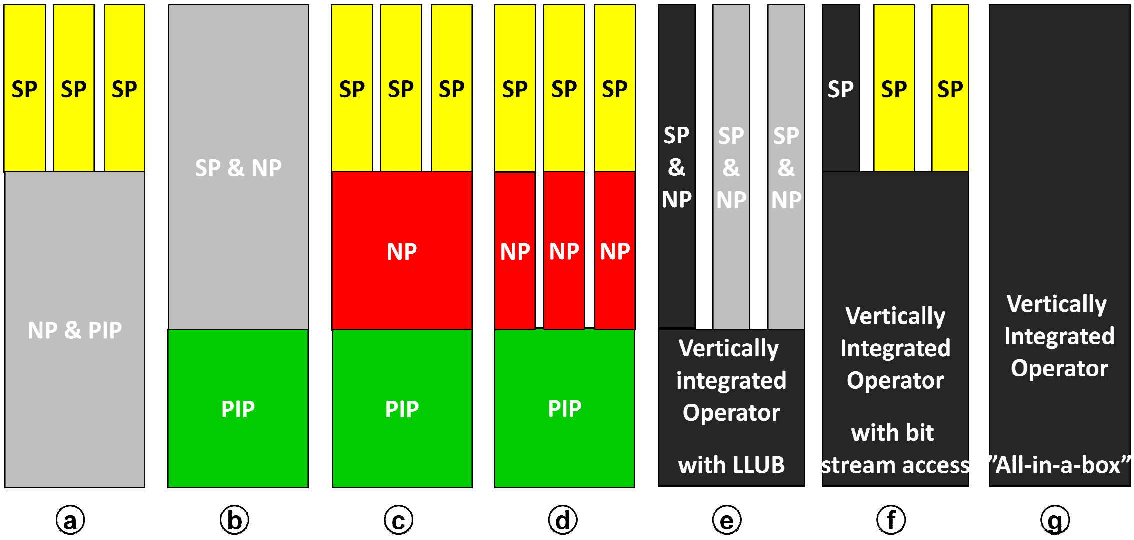


Figure 2-2: Examples of vertical and open access network scenarios. Service Provider which is indicated by SP can be in plural, i.e. the figure is not locked to a maximum of three SPs or a single SP per NP in case "d".

Scenario "g", that of a large vertically integrated operator, is possibly the most traditional in the European context. However, it supports no open access and is therefore only relevant within the context of other research areas. Most of the incumbent operators have currently been regulated into an unbundling of its copper infrastructure, i.e. model "e". Scenarios "a" through "f" however all display some degree of cooperation in order to provide service. At the most extreme, scenario "d" shows a scenario of a single PIP supporting multiple NPs that in turn support multiple SPs.

Open access is possible on two distinct levels (i.e. between physical infrastructure provider [PIP] and network provider [NP], or between NP and service provider [SP]) utilizing three mechanisms (i.e. fibre, wavelength or bit-stream). Note that in this deliverable, the term open access is used to refer to opening the network in general. Strictly speaking, however, there is a difference between open access and unbundling. Unbundling refers to the case in which a single actor is exploiting both a particular layer and the layer on top of that, while still allowing co-existence of other actors on top of its own (models "e", "f" and "g" in Figure 2-2). Open access refers to the situation in which the lower layer is provisioned in a non-discriminatory way to different actors on the layer above (model "b", "c" and "d" in Figure 2-2). In this case, the actor in the lower layer does not act in the layer above.
Open access can be enabled by allowing NPs to utilize deployed but unutilized fibre capacity (i.e. fibre open access), or it may be enabled by utilizing a wavelength-multiplexing system to allow signals from multiple NPs to be carried on one (or more) fibres, depending on the abundance of fibre (i.e. wavelength open access). Open access means that the end customer can choose different services between different SPs, for example internet access from service provider A and IPTV service from service provider B. We can further distinguish between wavelength and bit-stream open access, where the former refers to architectures with

individual wavelengths per SP, whereas the latter refers to the case where SPs are differentiated on layer-2 or layer-3, using one common network infrastructure.

2.1.1 Fibre open access

Fibre open access scenarios consider the possibility of utilising deployed (but unutilised) fibre capacity within the fibre network. This provides the possibility of scenarios “b”, “c”, “d” and “e” at the junction of the PIP and NP.

The likelihood of such scenarios is based around two main criteria. Firstly, in order to support fibre open access, there must be sufficient fibre deployed. Secondly, a PIP (or vertically integrated NP + PIP) must exist that is willing (or regulated) and able to allow access to its fibre network. Should these criteria be met, then the fibre open access system is the most flexible of the potential open access solutions. It imposes no restriction on the network providers which are able to co-exist in parallel utilising potentially heterogeneous network technologies.

However, there may be a significant additional cost associated with this mechanism due to the fibre rich deployment and associated costs for optical distribution frames as well as due to the replication of equipment and manpower (for both the NPs and PIP) that is required. Fibre open access is generally described in chapter 3.1.1 and further discussed with an architectural view point in chapter 5.1.

2.1.2 Wavelength open access

Wavelength open access refers to the ability for every network provider / service provider to access to one or more dedicated wavelengths within individual fibres to reach customers. This is naturally predicated on the availability of Wavelength Division Multiplexing (WDM) over some (or all) network segments. This provides the possibility of scenarios “b”, “c”, “d” and “e” at the junction of the PIP and NP, although with greater restrictions imposed on the NPs by the PIP than in the fibre open access scenario above.

Wavelength open access is technically the most complex and varied of the open access schemes (when looking at the individual architectures), and conveys some interesting challenges. One of the key issues is the coordination of access to the optical spectrum. If a user is willing to receive different services from different service providers, he must be able to fast tune over different wavelengths or must possess multiple receivers or colourless receivers. This will require that services from different service providers must be properly coordinated. The spectrum can be managed by a third party who may be responsible to allocate spectrum in a neutral and efficient way. However, despite these challenges wavelength open access allows for the re-use of equipment, points of presence, and personnel. For example, by unifying the management of the passive devices in one actor there are decreases in cost through economies of scale, and it is possible to re-use some points of Points of Presence (POPs) to house equipment from the different NPs, resulting in savings in rental, power, cooling and maintenance costs, amongst others.

Wavelength open access also poses interesting questions. The most significant of these is how it will be achieved. For example, in a scenario where the PIP is decoupled from the NPs above it (according to the diagram in Figure 2-2), then it is possible that the PIP will also own the passive optical devices (such as Arrayed Waveguide Gratings [AWGs] and power splitters) necessary to facilitate open access. However, as this will make part of their network fixed to a particular architecture, it may be unlikely. If, however, the fibre is rented from the PIP by a

NP who installs their own passive devices, then it is uncertain whether this NP will be amenable to allowing access to other NPs. Doing so introduces the risk that problems will be introduced by the new NP (by, for example, utilising a laser power which is too high), and requires access to areas of their network which are sensitive and normally highly secured. Similar problems exist for the scenario of a vertically-integrated network operator.

2.1.3 Bit-stream open access

The implementation of this service-level open access (hereafter referred to as bit-stream open access) may be done in different ways, and this provides the opportunity for scenarios “a”, “c”, and “f”. In this section we will shortly discuss who is in control of the infrastructure and issues connected to this and the technologies that can be applied.

In current architectural open access solutions the customer choice is implemented by the NP, who configures the network according to the customer’s choice. The SP then delivers the service at the edge of the NP’s network which is where the SP’s control ends. This leads to an issue commonly known as the “black box” problem: the SP has little-to-no control or monitoring of the inner workings of the NP’s network and therefore cannot troubleshoot errors end to end. This issue results in a conflict when a customer reports service problems - as the SP cannot see the inner workings of the NP’s network it commonly lays the blame for the problem on the NP. The NP may in turn put the blame on the SP. This increases the cost for both NP and SP and increases the problem resolution time. Similar issues can be found in the other open access scenarios (fibre and wavelength), where e.g. optical monitoring functionality could be utilised.

A partial solution for the “black box” problem is to increase the ability of the SP to see and control parts of the NP’s network. In its simplest form this may be for the NP to share network information about a slice of network to the SP.

More advanced solutions are to give the SP control of the slice. One method to provide this is through network virtualization. With network virtualization the NP can separate the network into virtual slices of the network and give control of a virtual slice to a SP. The SP can then freely configure and integrate that slice into its private network. Each virtual slice must be separate from other virtual slices to avoid resource and configuration problems between SPs.

There is little flexibility available with bit-stream open access. The technologies, architectures and even vendor choices are restricted by what has already been chosen by the NP. In addition, within the choice of technology made by the vendor it is unclear the level of freedom that will be provided. For example, if an IP system is utilised, is there Quality of Service (QoS)? If so, will the Open Access (OA) operator be able to define their own priority classes?

It is likely that bit-stream open access will be possible on four levels. The lowest of these (with reference to the OSI model), and specific to one architecture, is the Time Division Multiple Access Medium Access Control (TDMA MAC) layer. The next lowest is Ethernet, which is likely to be ubiquitous. In the middle is Multi-Protocol Label Switching (MPLS), which is currently widely deployed in the core network and could therefore see an increase in usage as it is pushed out toward the edge. At the top is Internet Protocol (IP) which, like Ethernet, is likely to be ubiquitous in either is version 4 or version 6 form.

3. Architectural aspects

This chapter includes information on a number of architectural aspects of open access infrastructures, and focuses on open access models, control and general aspects.

3.1 OPEN ACCESS MODELS

This section describes on which layer one can open up or unbundle the network infrastructure in order to establish an open access infrastructure. As discussed previously, the possible levels are fibre, wavelength and bit-stream. Also discussed are different NP/SP scenarios, i.e. where in the OASE landscape these entities act. An open access reference model is presented, which aims to describe the characteristics of the different architectures.

3.1.1 Fibre open access model

In a fibre open access model (see also chapter 2.1.1) it is possible to provide open access to single fibres, fibre bundles or fibre cables in different network sections of the access and aggregation/metro network. The Physical Infrastructure Provider can provide a continuous or single hop fibre connection between a fibre socket at the user site (Physical Connection Point [PCP2]) and an Optical Distribution Frame (ODF) port at the Central Access Node (CAN) location, as well as between other points in the fibre infrastructure. It should be pointed out that this definition of fibre open access makes the scope larger and different from e.g. copper unbundling which focuses on opening up the copper infrastructure in the last mile ("pure" access).

These point-to-point fibre connections include the Link Levels (LL) 1/2, 3, 4, 5 and 6 as shown in Figure 3-1.

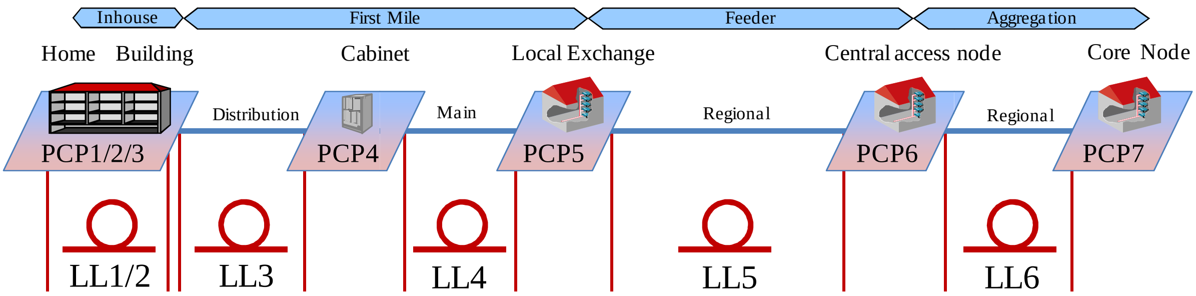


Figure 3-1: Fibre sections of the next generation optical access an aggregation/metro network

This approach allows Network Providers without fibre infrastructure to deploy system technology in the access and aggregation/metro network, e.g. Reach Extender, AWG, Power Splitter, Ethernet switches, IP/MPLS routers etc.

Table 1 shows some possible fibre connections with the appropriate fibre termination at the user and network side and the involved link levels.

Table 1: Possible fibre connections with the appropriate fibre termination at the user and network side

Fibre connection between …	User side termination	Network side termination	Link level
PCP2 and	Fibre socket at PCP2	ODF port at PCP6	LL2 + LL3 + LL4 + LL5

PCP6			
PCP2 and PCP5	Fibre socket at PCP2	ODF port at PCP5	LL2 + LL3 + LL4
PCP2 and PCP4	Fibre socket at PCP2	ODF port at PCP4	LL2 + LL3
PCP4 and PCP6	ODF port at PCP4	ODF port at PCP6	LL4 + LL5
PCP4 and PCP5	ODF port at PCP4	ODF port at PCP5	LL4
PCP5 and PCP6	ODF port at PCP5	ODF port at PCP6	LL5
PCP6 and PCP7	ODF port at PCP6	ODF port at PCP7	LL6

The above definitions are more or less the traditional view of fibre open access even though it has been extended to include the full OASE WP3 scope, i.e. PCP2 to PCP7. The next step is to include aspects introduced by having a fibre open access provider (a PIP) that addresses scenarios which allows for opening up on the wavelength level (see chapter 3.1.2). Such scenarios can put added complexity onto the physical infrastructure operated by the PIP. As will be described in more detail in the next chapter, wavelength open access may require the coordinated access (between multiple NPs) to shared optical spectrum. Together with WP6, it was decided that this coordination would not be handled by any of the competing NPs, but by the most neutral party in the PIP / NP interactions, i.e. the PIP. This leads to the necessity (in these scenarios) of added management and operational responsibility of the PIP due to the need of including optical devices like power splitters, band splitters, and WSSs under the PIP umbrella, which are needed in order to open up on the wavelength level (see chapter 5). This leads to the possibility of the PIP having different types of physical infrastructures:

1. A transparent fibre open access
2. An opaque physical infrastructure which allows for offering an wavelength open access to the different NP and SP combinations in Figure 2-2

The first option is the more traditional one and allows for opening up a pure fibre infrastructure based on ducts, cables, fibres, ODFs, sites etc, i.e. not including any optical devices (e.g. splitters, AWG) which are needed for any specific technology which utilized the fibre for transmission purposes. The second one is similar to the first but includes optical devices managed by the PIP. Fibre strands in the PIP's infrastructure that includes these optical devices are not necessarily technology agnostic to access architecture (e.g. TDMA, Wavelength Division Multiple Access [WDMA] based PONs, and Active Optical Networks [AONs]). It is to these access architectures which the open fibre access can be transparent (technology agnostic) or opaque (not technology agnostic).

3.1.2 Wavelength open access model

Wavelength open access refers to the case when a PIP coordinates the use of the optical spectrum (wavelengths) by a number of network providers over an infrastructure consisting of fibre as well as optical devices like power splitters, Band Splitters (BS), and Wavelength Selective Switches (WSSs), as described in the end of the previous chapter. The Point of Unbundling (PoU) in a wavelength open access is the reference point between the Physical

Infrastructure Provider and Network Provider, whereas the interconnection to the user site is named the U_W interface. Note that this PoU is more generically referred to as Provisioning Interface in WP6 (and covers therefore both unbundling and open access cases). For a broader and higher level discussion see chapter 2.1.2.

In general, we can distinguish between Point-to-Point (PtP) and Point-to-Multipoint (PtMP) wavelength open access:

- PtP wavelength open access:
  A PIP offers use of optical spectrum that results in a dedicated wavelength connection between reference point PoU at the network site and reference point U_w at the user site (PCP2) as shown in Figure 3-2a. PtP wavelength open access can be realized using active or passive wavelength multiplexers (e.g. AWG or WSS) in the Optical Distribution Network (ODN).
- PtMP wavelength open access:
  A PIP offers use of optical spectrum that results in a wavelength connection between reference point PoU at the network site and multiple interfaces at reference point U_w as illustrated in Figure 3-2b. In this case several users have access to one wavelength. PtMP wavelength open access can be realized using power-splitters in the ODN.

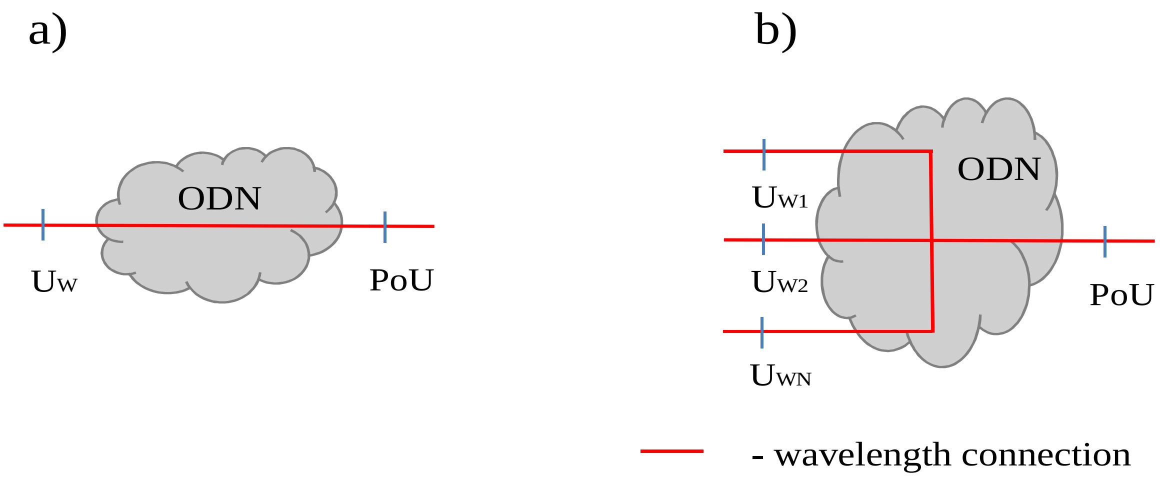


Figure 3-2: PtP and PtMP wavelength connectivity

As shown in Figure 3-3 the interface of reference point PoU can be realized at different locations. Figure 3-3shows a scenario where the NP controls a wavelength connection between PCP2 and PCP6. Service Providers with their own or rented fibre infrastructure have access to that wavelength capacity via an interface at PCP6. Figure 3-3b shows a scenario with the NP/SP interface at PCP5. More information on how the connection between the NP and SP can be found in e.g. the next chapter or in chapter 3.3.1.

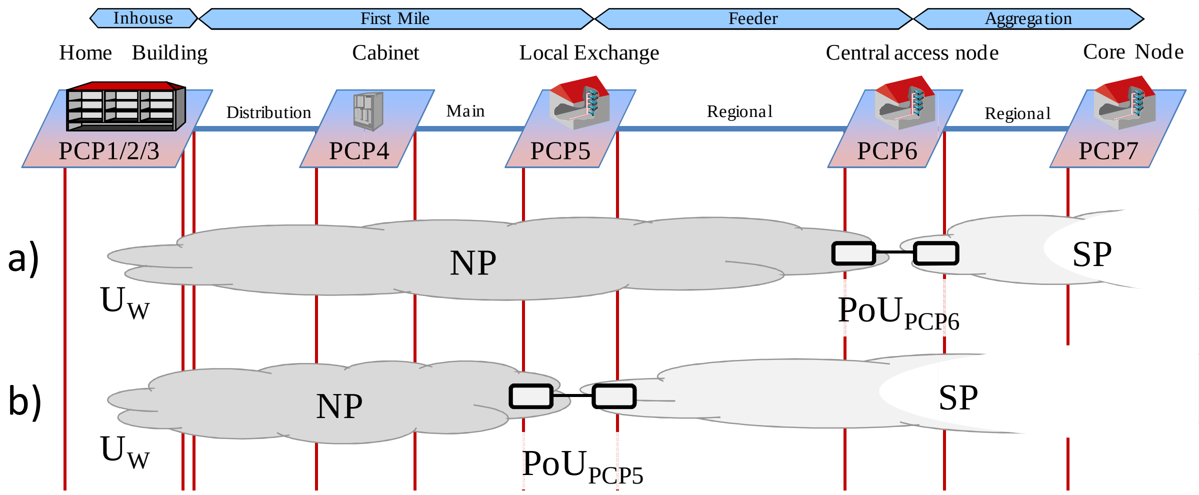


Figure 3-3: Wavelength open access options

3.1.3 Bit-stream open access model

The following bit-stream access and aggregation/metro reference model (introduced in chapter 2.1.3) is based on the Broadband Forum definitions described in the Technical Reports (TR) TR-101 and TR-156 (Figure 3-4) [2][3]. The interface between Network Provider and Service Provider is referred to as A10 in the figure but in this document we will call it the NP/SP interface, whereas the interconnection to the user site is named U interface, or the User Interface (UI).

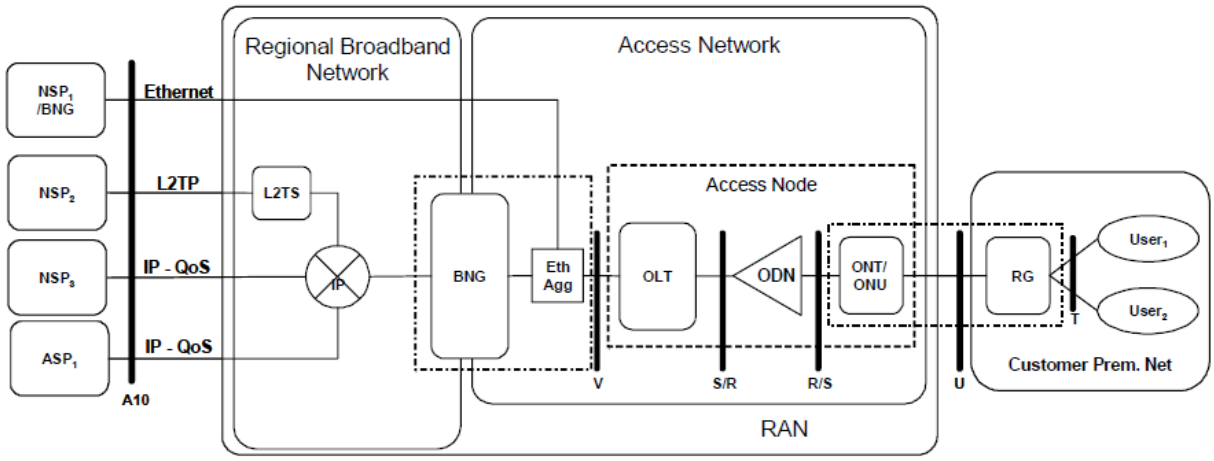


Figure 3-4: Network architecture for Ethernet-based GPON aggregation [3]

Figure 3-5 shows three architectural options which differ in location of the NP/SP interface. The NP is responsible for the provision of the active and passive access/aggregation infrastructure. In addition, the NP is in charge of the transport of the end-user service between user and NP/SP interface. The Service Provider is responsible for service creation and the transport between NP/SP interface and service creation point.

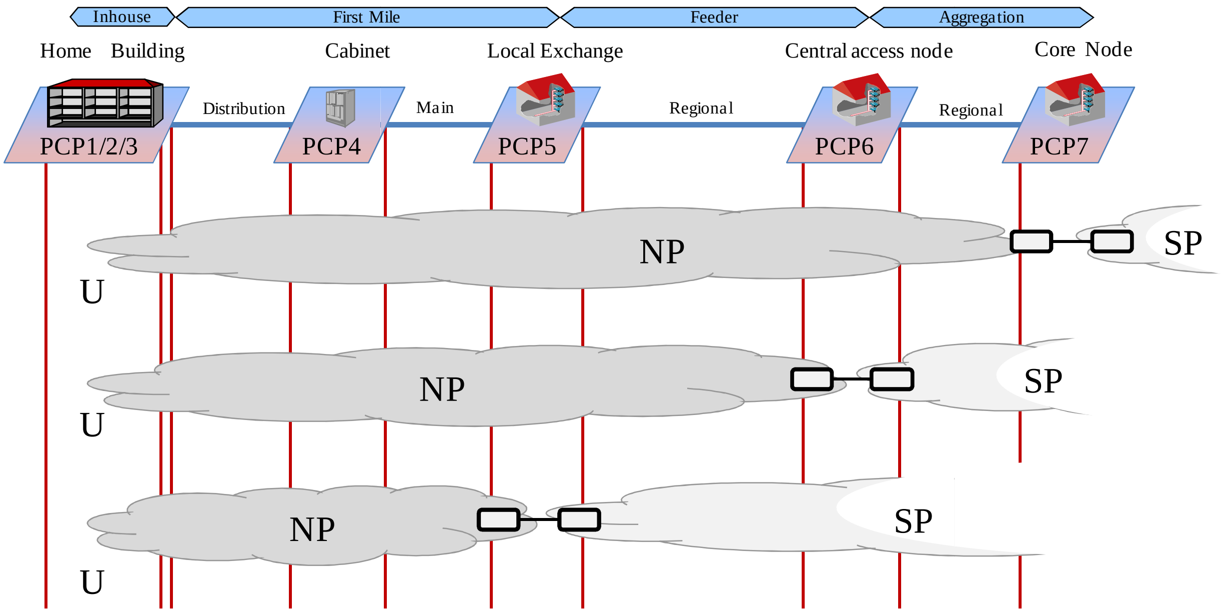


Figure 3-5: Bit-stream Access architecture options

In this deliverable, chapters 5.5 and 6.2 have a higher focus on next generation bit-stream open access. It is assumed that bit-stream open access can be applied to all basic variations of the Next Generation Optical Access (NGOA) architectures described in e.g. OASE D3.2, as well as to the wavelength open access variations described in chapters 5.2, 5.3, and 5.4.

In chapter 3.1.5 we will give a more in depth discussion on these NP/SP scenarios depicted in Figure 3-3 and Figure 3-5.

3.1.4 The Open Access Reference Model

In order to show which OA mechanisms that are possible within each architecture an open access reference model has been developed. The OA reference model is visualized by a grid such as the one in Figure 3-6. The layers are indicated on the left, and the PCPs are indicated on the bottom.

The goal of the OA reference model is to show on which layer and in which physical point in the network one can access an open infrastructure, creating a client/server relationship between the one accessing and the one offering.

The different entities that can access the open access are: the service provider, the network provider, a backhauling service, and the end user. Also included in this is the physical infrastructure provider, which only acts as a server layer. This creates a number of Client/Server (C/S) interfaces between SP/NP and NP/PIP.

In order to indicate that open access is possible at a particular PCP and layer, a circle will be added in the respective location. The circle indicates the layer on which the client can assume their traffic will be forwarded on, i.e., it indicates the presence of an interface at this location, which is capable of providing network services using the relevant protocol or mechanism.

Arrows are used to indicate the direction (upstream or downstream) which a client connects to an underlying open server layer. Within PCP2 (and perhaps PCP3), yellow arrows are common which indicate that residential user interfaces are expected at this location and on this network technology and that these are available for open access. Red arrows indicate points at which backhaul traffic may be admitted. Light blue and blue arrows indicate points at which a network provider and/or a service provider may access an open server layer. In the case of NP and SP the open server layers would be the PIP and the NP respectively, i.e. NP/PIP (C/S) and SP/NP (C/S).

An example would be an NP accessing an open fibre architecture operated by a PIP. This would render a “fibre interface” circle (i.e. the fibre level) in a site (e.g. PCP5) with light blue arrow pointing in both upstream and downstream directions since the NP connects both to an end user, as well as to its own equipment in a PCP6 location or PCP7.

A more advanced example would be a wavelength open access scenario (please see chapter 5.2 for an example of a wavelength open access architecture). Here an NP connects to an opaque PIP that is offering wavelength open access, but it is the NP that is generating the wavelengths coordinated/admitted by the opaque PIP’s open wavelength access infrastructure. This would then render a “wavelength interface” circle in e.g. PCP5 on the wavelength level. The light blue arrow should in this case point downstream since the NP connects to a downstream facing fibre port that might end up connected to an AWG in PCP4.

Network Layer	IP									
Packet / Framing Layer	MPLS									
	Ethernet									
Optical / Copper Layer	PHY	Eth								
		TDM								
	WDM*									
	All optical devices									
Physical Infra-structure Layer	Fibre									
	Cable									
* Not necessarily present			PCP1 In-home	PCP2 Homes	PCP3 Buildings	PCP4 Cabinets	PCP5 Local Exchange	PCP6.1 Central Exchange	PCP6.n Aggregation Sites	PCP7 Core Sites

Service provider interface
Backhauling service interface
Residential user interface
Network provider interface
— Most likely
--- Less likely but possible
0 Fibre interface
1 Wavelength interface
2a Time domain interface
2b Ethernet interface
2c MPLS interface
3 IP interface

Figure 3-6: Differentiation grid for an idealised Open Access network. PCP6.1 and PCP6.n indicates the possibility of having multiple aggregation level hierarchies (see D3.1) which depends on e.g. the physical infrastructure topology and the NP network topology on top of that.

Open access represents a broad study area, and while some types of OA will not differentiate between the architectures under study, there remains a wide variety which will challenge them on many levels. In chapter 7.2 of this deliverable a qualitative evaluation will be done of the different access architectures based on a general discussion as well as requirements based on business model studies performed in OASE WP6.

3.1.5 PIP/NP/SP scenarios

The business model scenarios that are of most interest have been outlined in Figure 2-2, and in this section we will focus more on where the points of unbundling between open access entities can be located in PCPs of the reference model.

We first show an E2E type fibre open access model in which a PIP will own the fibre infrastructure in the end-to-end scope (PCP2 to PCP7), see Figure 3-7. The network either opens up at the customer side, in PCP2 (home), or at the network side, typically in PCP 6 (central exchange) or 7 (core). However, depending on the node consolidation scenario, it can also be done in PCP5.

In case of bitstream E2E open access, the entire access and aggregation network (PCP2 till PCP7) is covered by the single PIP/NP. Here the network opens up in PCP 2 (home) and PCP7 (core). This is similar to the previous case, but here we have a single PIP/NP, where in the previous case we have a single PIP and potentially different NPs (covering the entire OASE scope). When, in case of open access at the fibre level, we see different NPs, the fibre network is opened in an intermediary PCP. This can be considered a *local loop unbundling type of open access*. Here the network opens up in PCP2 (home) and PCP5 (local exchange). In case of *local loop unbundling* on the wavelength layer, the network opens up in PCP 2 (home) and PCP5/6 (depending on consolidation scenario).

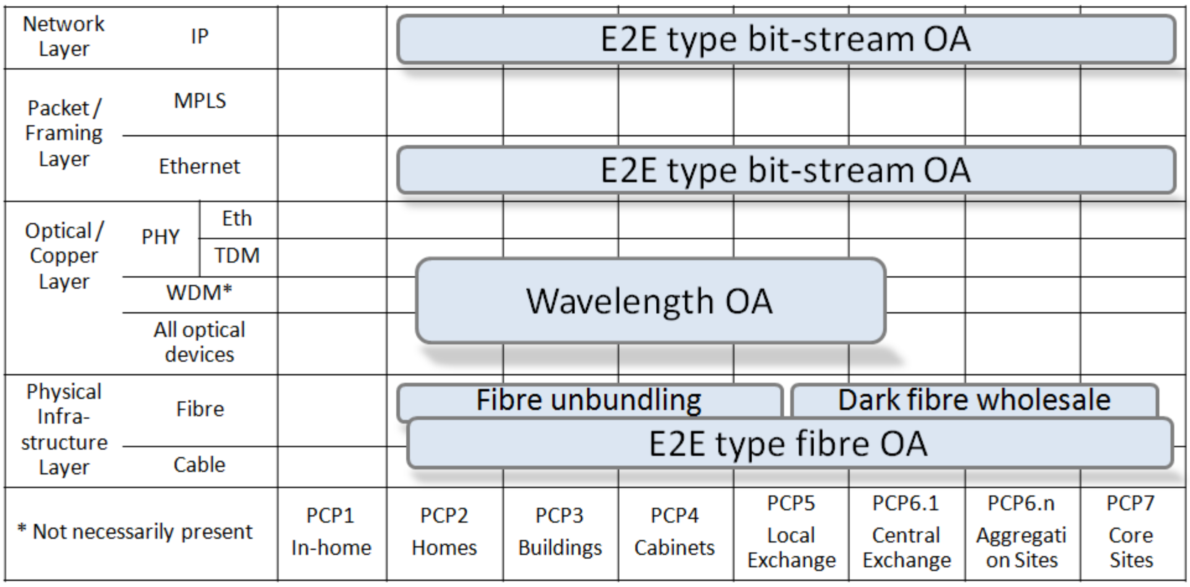


Figure 3-7: The figure indicates between which points and on which level some of the more common open access infrastructures exist. Some are utilising the full OASE scope physical connection points (PCPs), while other have a focus on the pure access.

CONCURRENT NP/SP

In addition to the physical location of different PIP/NP/SP entities and how they relate, the user may want to connect to multiple NP/SP at a same time. For example, a user can request voice, data, TV and multimedia service each from a different NP/SP. This is referred to as a “Concurrent NP/SP” scenario. While the network is more open with the facilitation of such concurrency in the NP/SP connectivity, there are challenges and disadvantages in this approach. For the fibre and the wavelength open access, the concurrent NP/SP scenario requires more than one receiver at the Optical Networking Unit (ONU); this will increase the cost, the power consumption, the complexity and the failure probability of the ONU. Thus, most likely, the concurrent NP/SP scenario is not pragmatic at the fibre or the wavelength level. The concurrence NP/SP scenario is most feasible at the bit stream level. However, there remain challenges of providing concurrent open access at the bit stream open access. Normally, the services of all SPs will be multiplexed in the same L2 and L3 channel, and the ONU needs to filter out its relevant part. As it requires processing of whole data, it will increase processing overheads, and power consumption. Thus, proper MAC protocols that allow for the slotted transmission of data from different SPs should be developed, so that the ONU can choose any one slot to receive its data, rather than processing the whole chunk of data.

3.2 CONTROL ASPECTS

In this section we will discuss aspects of open-access related to control of the network. This is an aspect that is even more important in a network with potentially several network and service providers.

3.2.1 Isolation

A fundamental requirement when providing open-access in a network is good isolation between services and the operators in the network. The strength of this isolation and how it is implemented depends fully on what layer the network is opened up on.

Isolation is built in when open-access is provided on fibre level, as each NP is utilising fully separated fibre strands. This thereby guarantees that no interferences are created between NPs.

If the access and aggregation/metro network is opened on the wavelength level it also has the possibility of offering a high degree of isolation. In this case, it may be possible to separate a set of network providers through the use of different wavelengths. It is very important to understand that this is not necessarily true depending on the architecture that is used to realise open access on the wavelength level. If the architecture is based on the use of optical splitters care must be taken not to introduce the possibility of affecting other NPs services. Wavelength filtering or even routing devices (e.g. AWGs or WSSs) can instead be used in order to keep a high degree of isolation.

In bit stream based open access, isolation is much bigger issue since there is a higher degree of sharing, i.e. data belonging to different service providers will be sent over common forwarding resources in the electrical domain. In order to handle contention of such resources a technique called hierarchical QoS can be used. Hierarchical QoS is implemented through the use of a hierarchical token bucket architecture. It is currently used in multi-layer Ethernet (IEEE 802.1Q) where one can have different levels of QoS on Service Virtual Local Networks (S-VLANs) and Customer Virtual Local Networks (C-VLANs) (see D3.1). A benefit of using this scheme is that the open access network provider can have access to the lowest level(s) of this hierarchy in order to control QoS behaviour between multiple service providers utilizing the open access infrastructure, while a SP could have access to additional levels of the hierarchy in a transparent manner. Here we can see that there is a connection between QoS and the degree of isolation, but there is also a connection with the concept of virtualization (which is discussed in more detail in the next chapter).

To summarise, isolation and Quality of Service is an important issue for open access networks. The quality of service issue can be addressed in two ways: 1) There are issues related to the architecture in which a potential malicious and rogue user can disrupt the services of others. Thus, there should be proper monitoring services which can take immediate restorative actions to resume proper services to affected users, or there has to be high enough degree of isolation so that this is not possible. 2) The second issue is to maintain fairness between the end users and the service providers. Generally, the problem of assuring QoS from the perspective of the MAC layer is a two dimensional problem in open access, where the fairness between the users and at the same time between the SPs has to be maintained. The users may want to receive different services from different providers and this will only complicate the bandwidth-scheduling problem.

3.2.2 Virtualization

In bit stream based access a problem for both service providers and network operators are the lack of integration between the service provider's network and the network operator's network. This creates what is known as the "black box" problem: the service provider does not see the internal network of the NP and can therefore not detect problems in that part of the service delivery chain. This may cause situations where the SP and the NP put the blame for customers problems on each other, with both side arguing that the problem is located in the others network.

One solution for this problem is the introduction of network virtualization [4], where the SP gets a slice of the NPs network which the SP is free to configure and manage in the way the SP desires. This means that one entity can monitor and configure the whole chain of service delivery, and therefore simplifies the troubleshooting process.

Network virtualization can be implemented in a variety of different ways and with differences in the amount of control given to the SPs, but the most important aspect is that each slice of the network needs to be isolated. A high level view of what will happen in a network forwarding element can be seen in Figure 3-8.

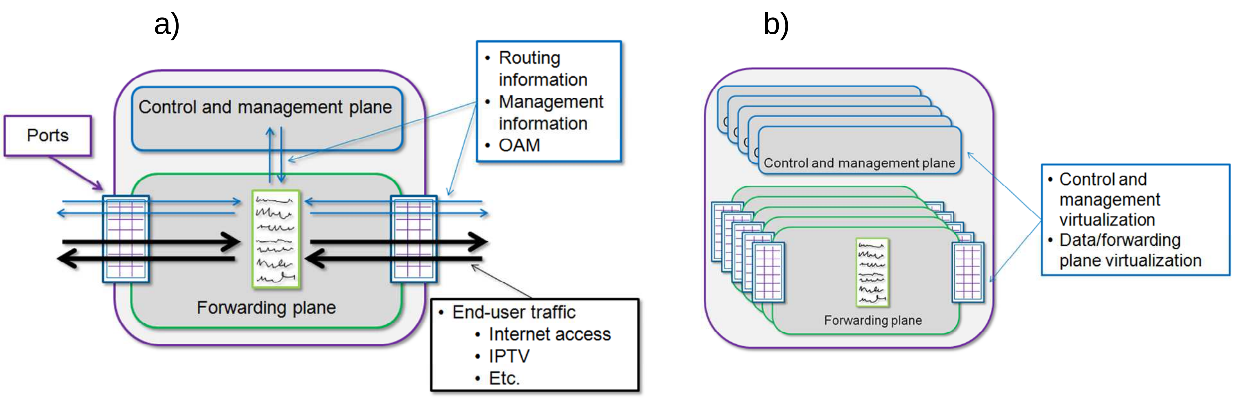


Figure 3-8: a) depicts a schematic model of a network forwarding element, and b) the segmentation of such into a number of virtual slices.

With currently deployed technologies virtualization could be implemented in various ways, using built in virtualization functions such as "Virtual Routing and Forwarding" (VRF) and Virtual LANs or deploying devices with support for running multiple instances of the control plane.

Virtual LANs operate by tagging Ethernet frames with an identifier that defines to which virtual LAN this frame belongs to and ensures that they are handled accordingly [12]. The VRF technology is similar to VLANs but operates on layer three and is more node specific than link specific. Each VRF instance has an isolated routing and forwarding table which is independent from other VRF instances. As the VRF instance operates on layer three each VRF instance needs to have exclusive access to an interface in order to map traffic to the correct VRF instance. This interface is either a physical interface, or a logical interface such as a VLAN or MPLS tagged interface. This is necessary as the normal IP header does not include fields to distinguish between VRF instances. These techniques are currently mostly use to increase scalability of the networks and to improve the operation of the networks. Most commercial solutions which support these techniques does not provide separate Control and Management (C&M) instances or isolation on the management interfaces, such as providing separate logins.

In the case of emulating layer two Ethernet connections over an MPLS network the Label Switched Path (LSP) terminating device utilizes a Virtual Switch Instance (VSI) in order to emulate an Ethernet switch. A similar type of function could be employed in pure Ethernet forwarding elements, which would then correspond to the more node specific VRF function but for 802.1Q Ethernet network elements. This would allow for creating an open access network slice controlled and managed by the SP. Depending on the link virtualization used (i.e. the flavour of 802.1Q , e.g. QinQ, MACinMAC) this would give the SP full control over the virtualized identifier space, e.g. if the open infrastructure is Provider Backbone Bridges (PBB – IEEE 802.1AH) based and therefore utilizes S-VLAN tags then the SP would fully control the C-VLAN space and could utilize all 4096 VLAN IDs. PBB allows for a hierarchical use of S/B-VLANs and MAC addresses, i.e. S/B-VLANs in S/B-VLANs and MAC in MAC, which means that the SP could also have full control of the S/B-VLAN ID space and the open access infrastructure provider would not need to populate its forwarding tables with SP specific MAC addresses. Special care is needed at the edge of the open infrastructure in order for the open infrastructure network provider to be able to multiplex/demultiplex traffic (basically Instance Service IDentifier (I-SID) mapping) from the different SPs, see chapter 3.3.1 for more details.

3.2.3 Bootstrapping

Bootstrapping refers to the processes that need to take place when a Customer Premises Equipment (CPE) device is initialised and needs to become part of a network, in order to receive access to a set of network (e.g. Dynamic Host Configuration Protocol [DHCP]) and end-user (e.g. IPTV) services. These processes are very important since it automates, to some degree, the processes of provisioning and service delivery, and failure to do so leads to high Operational Expenditures (OpEx) and/or support costs. These processes are initiated by first allowing a network device (ONU) to get bit-stream access, and then configuring services running on top of this bit-stream access. How these two steps are performed depends on the technology used and what type of open-access offered in the network.

The process of bootstrapping in the open-access network can be more demanding than in a vertically integrated network. The reason for this is that the network operator and services are normally selected a head of time and the process of connecting the device and activating the services can be pre-configured both in the network and on the device before the customer connects the device.

BOOTSTRAPPING IN NETWORK WITH MULTIPLE NPS

The process of bootstrapping in a network that potentially provides several NPs could be performed in several general ways. The simplest would be that the customer selects a network provider a head of time, and that the customer port is configured to support this pre-selected provider. But the selection of a network provider could also be done in a more dynamic way, where the customer selects one (or perhaps several) network providers when the device is first connected to the network. In this scenario the ONU would detect the available network providers either by dedicated control channel or for example via active probing the network for operators. How this is specifically handled depends on the architecture and is discussed in chapter 5. When the ONU has ascertained the available network providers the ONU could present this information for the customer who then selects the network provider to use.

BOOTSTRAPPING IN NETWORK WITH MULTIPLE SPS

Bootstrapping of services can, like NPs, be pre-configured (where the customer selected services ahead of time) or detected and selected on the fly. For the second case the procedure is that the customer selects services when they first connect to the network. Specifically, the customer would start the computer and get a default network address for the network operator, and then redirect the customer to a special “service selection” web site. The possible services and their costs would be presented on this page, and the customer would have the option to select and pay for these services. Once selected the network operator would provision these services, either automatically or based on manual configuration.

3.2.4 Location and identification

A clear assignment of an access line termination point to a specific postal address is an important operator requirement. This assignment enables the implementation of service features which require the postal address information, e.g.:

- Emergency call: The caller location must be ascertainable even if the caller is unable to talk and therefore cannot give his name or location.
- Legal interception: Communications network data of a specific postal address must be forwarded to a law enforcement agency for the purpose of analysis or evidence gathering.
- Service Provisioning processes
- Fault localization processes

As illustrated by Figure 3-9 the assignment of a Network Termination (NT) at the subscriber site to a specific postal address can be easily implemented by providing a dedicated fibre or wavelength connection. A fixed Virtual Private Network (VPN) between NT and Service Creation Point (SCP) is another alternative to localize the source of data traffic received at the SCP site.

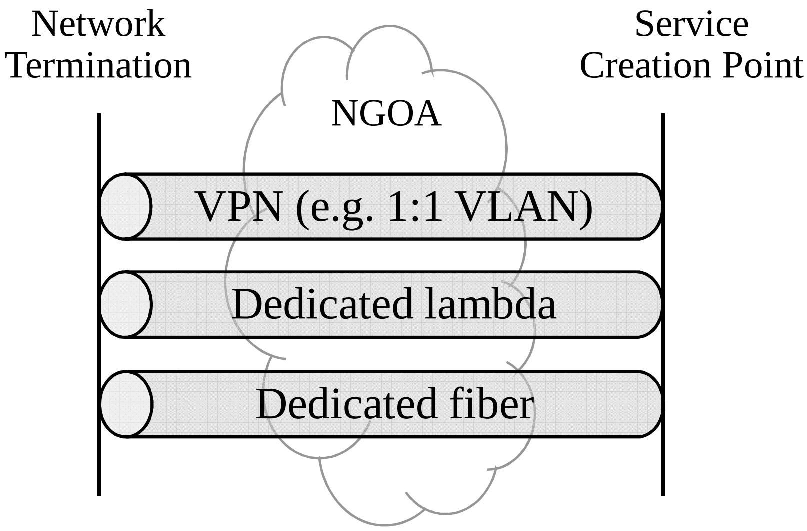


Figure 3-9: Examples of dedicated connections between NT and SCP

As illustrated in Figure 3-10a a fixed VPN can be realized with a 1:1 VLAN approach in an access network with a point-to-point architecture, e.g. AON. The subscriber traffic is transported by a dedicated VLAN pipe that is assigned to a point-to-point access line and terminated at a specific postal address enabling the localization of the data source. This means that the postal address can be linked with the VLAN Identifier (VLAN-ID) number. However, the VLAN-ID cannot be used in an N:1 VLAN architecture as shown in Figure 3-10b. In this case the data traffic of multiple subscribers is transported within the same Service VLAN (S-VLAN) which makes it impossible to identify an individual subscriber location on the basis of the VLAN-ID.

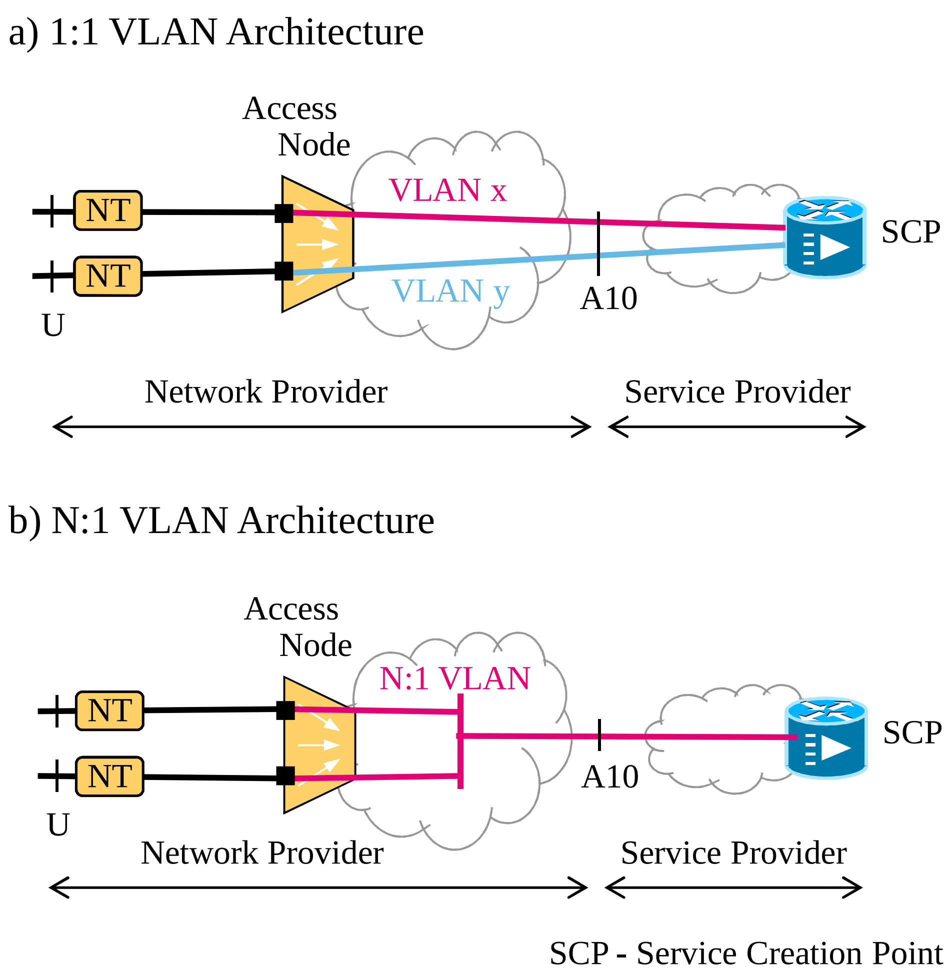


Figure 3-10: Overview of 1:1 and N:1 VLAN architecture

In addition a VLAN-ID based subscriber localization is difficult in a shared PON architecture (e.g. TDM-PON), since the clear assignment of a VLAN to a specific access line cannot be implemented due to its point-to-multipoint nature. In a TDM-PON deployment, therefore, the ONU has to provide additional information (e.g. ONU-ID [ONU Identifier], serial number) during the configuration process in order to enable localization. However, the ONU is an un-trusted device from the Operator's point of view. For example, the Operator is not able to detect when a subscriber connects the ONU to another power-splitter port of the same PON that is assigned to another postal address (see Figure 3-11).

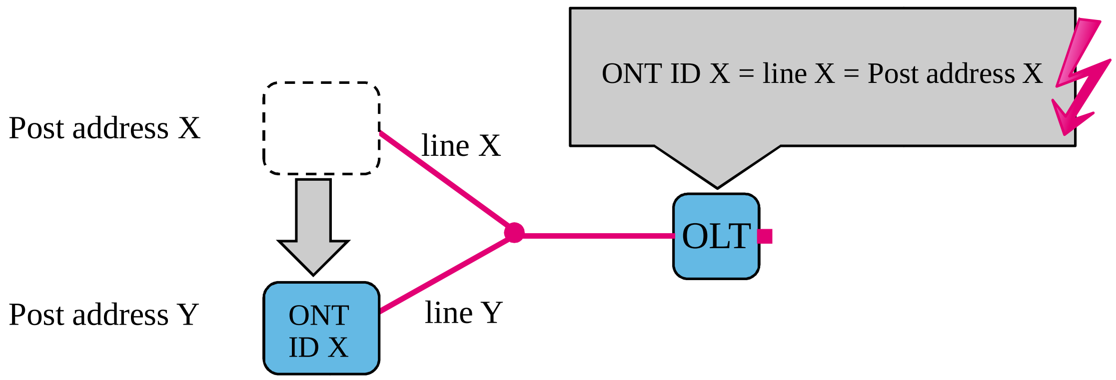


Figure 3-11: Problem of nomadic access in shared PON architectures (Example)

LINE-ID CONCEPT

As described above, the VLAN-ID is not the best option in all cases to identify an access line. The Layer-2 Bit-stream Access recommendation of the NGA (Next Generation Access) Forum [5] suggests the use of a technical key that is called Line-ID. The NGA-Forum, led by the Bundesnetzagentur, is a working group of representatives from German regional and national telecommunications companies with the target of defining broadband access products including the technical and operational interfaces, along with the key business processes necessary for interoperation.

Definition

The Line-ID clearly identifies the physical subscriber access line and represents the network section between network termination (NT) at the subscriber site and the first active port of the Network Operator. The Line-ID will be generated by the Network Provider and is unknown to the subscriber (end customer).

Benefits

The Line-ID replaces the telephone number as access line identifier in All-IP networks and enables a clear identification of the subscriber access line which is a key requirement for Open Access architectures and is the basis for simple IT interfaces between Network Provider and Service Provider. The Line-ID concept allows for the separation of a service from network resources (e.g. VLAN pipe, wavelength) which simplifies network operation (e.g. switchover an Access Node to a new Network Edge node). In addition, the Line-ID enables a fully automatic authentication and access line configuration.

Syntax

The Line-ID is composed of the Country Code, the Carrier Code and the Line Code as illustrated in Figure 3-12. The Carrier Code defines the Network Operator. The value is predefined by ITU M.1400. The Country Code defines the country where the individual access line is located. The Country Code is based on the specification ISO 3166. The Line Code identifies the individual access line.

The Line-ID consists of capitals (“A”…”Z”) and numbers (“0”…“9”) only. Country Code, Carrier Code and Line Code are separated by a “.”.

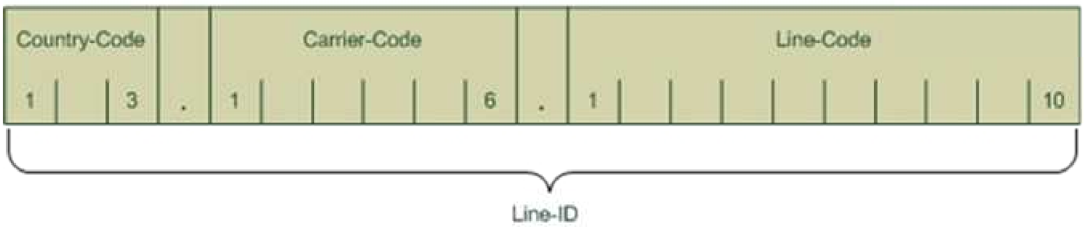


Figure 3-12: Line-ID structure

Implementation

The Broadband Forum (BBF) recommendations TR-101 and TR-156 define the Agent Remote-ID that can be used for describing a subscriber access line at the logical access port. The Network Operator can use up to 63 Bytes (ASCII code) of the Agent Remote-ID field.

The Line-ID can be written into the Agent Remote-ID field during the session auto-configuration process on the basis of Point-to-Point Protocol over Ethernet (PPPoE) or IP over Ethernet (IPoE) (DHCP).

- PPPoE:
  As illustrated by Figure 3-13a the Access Node (e.g. OLT, DSLAM) supports the "PPPoE Intermediate Agent" function which is able to write the Line-ID into the Agent Remote-ID field of the control frames PADI, PADR and PADT during the session auto-configuration [TR-101 [2], Appendix C].
- IPoE (DHCP)
  The Access Node supports the functions "DHCP Relay Agent Option 82" and "Layer 2 DHCP Relay Agent" according to TR-101. As shown by Figure 3-13b the Access Node writes the Line-ID into the DHCP control frames (DISCOVER, OFFER, REQUEST and ACKNOWLEDGE) during the session auto-configuration [TR-101 [2], Appendix B].

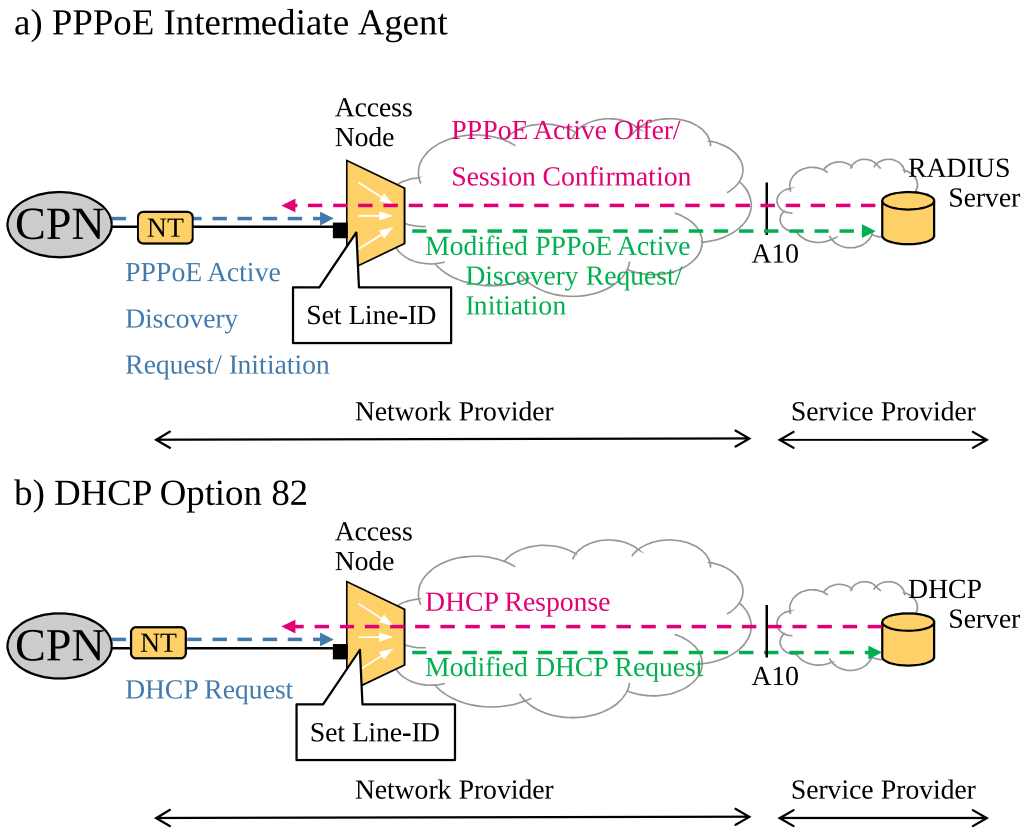


Figure 3-13: Line-ID implementation for PPoE and IPoE (DHCP)

Weaknesses

The Line-ID concept is not able to solve the problem of nomadic access in shared PON architectures as described above. Since the ONU is an untrusted device the PPPoE Intermediate Agent/ Layer 2 DHCP Relay Agent function should be implemented by the OLT. However, a clear assignment of an ONU to a specific postal address is not possible at the OLT site, since multiple access lines are concentrated on one PON port.

3.2.5 Monitoring

Rapid troubleshooting becomes very important for NGOA, which support large amount of traffic to/from thousands of users, in particular for mobile backhaul systems as well as business access. Centralized and automatic monitoring contributes to operational expenditures

(OpEx) savings thanks to remote operation. No hardware upgrade on user side should be required (e.g. demarcation components) due to high hardware and manpower costs per drop line and monitoring functionality should be shared over the complete NGOA network to provide high sharing factor of the investment. Furthermore, the effective fibre-fault detection and localization scheme should not affect data communication [6][7] and be sensitive to as low power fluctuations as 1 dB [8].

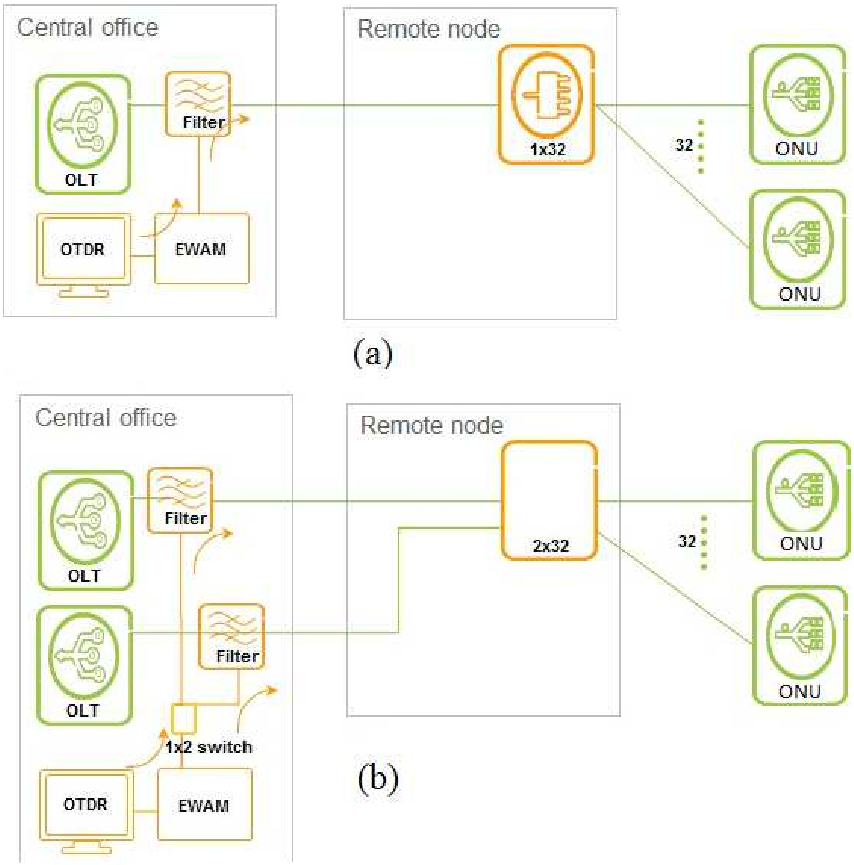


Figure 3-14: supervision solutions for WDM PON with (a) single FF [8] and (b) multiple FFs [11].

Many existing monitoring techniques have been proposed, e.g. [8][9][10]. However, to the best of our knowledge, most of them only focused on the basic NGOA architecture. Take an example of WDM PON. A typical WDM PON architecture has a single feeder fibre (FF) deployed for the connection between ONU at Central Office (CO) and Remote Node (RN). Figure 3-14(a) shows the supervision approach presented in [8] for a basic WDM PON architecture. It should be noted that for other purposes, such as open access, resilience and so on, the basic architecture with single FF may need to be changed to the one with multiple FFs connecting to e.g. several OLTs which are used for working/backup or different SPs/NPs. It in turn requires some modifications on monitoring approaches. Figure 3-14 (b) presents the modified supervision scheme proposed in [11] for a WDM PON with multiple FFs and OLTs.

In the basic case with single FF (see Figure 3-14 (a)), a commercial optical time domain reflectometer (OTDR) device with external wavelength adaptation module (EWAM) is installed at the central office (CO) and is shared by a number of optical line terminal (OLT) ports. Here, EWAM provides external wavelength tuneability of OTDR in order to monitoring distribution fibres, separately. It is also possible to use an internally tuneable OTDR as an alternative. To perform the measurement an OTDR pulse is sent from CO towards ONUs and is backscattered or back reflected to the CO. The wavelength-adapted OTDR signal is injected into the FF by means of a filter at CO and reaches a passive RN (the design of EWAM refers to [8] for more detail). In case of duplication of the OLT and FF (see Figure 3-14 (b)) an optical switch (OS) is required to be implemented. It is used to switch both OTDR signals between multiple FFs. Due to the cost issue, all the OLTs located in the same CO can share one OTDR device by using an OS to monitor different PONs. For some certain approaches supporting resilience or open access with multiple OLTs for one WDM PON at the same CO, instead of placing an extra OS an inherent one can be used to switch OTDR signals between different FFs. By using the scheme proposed in [11], the extra deployment cost to monitor multiple FFs could be limited.

3.2.6 Shared Internet Exchange

A possible issue in large bit-stream open-access networks, where there exists a large degree of isolation between SPs, is that all traffic needs to be transported to a point where the SP exchanges traffic with other SPs (e.g. an Internet Exchange point (IX) or through direct peering). This point is normally in a single location and potentially far away from the end customer.

This can lead to a scenario where traffic between two customer (with different SPs) will be transported large distances, from the first customer trough the NPs network to the first SP, through the SPs backbone to the other SPs network, and finally from the second SP through the NPs network back to the second customer. This is in comparison to a vertically integrated operator's network, where the route of the packet could be much shorter, perhaps over just the shortest multi-hop path (to the closest shared routing/bridging point) between the two customers since both are located in the "same" network.

Clearly this open-access traffic case represents a sub-optimal situation, which leads to high capacity use, longer latency, and overall higher costs. One solution to this issue is to introduce a common interexchange point between SPs in the NPs network. In these locations several SPs could interchange packets, similar to how it is done higher up in the network hierarchy, where it is often called an Internet exchange point.

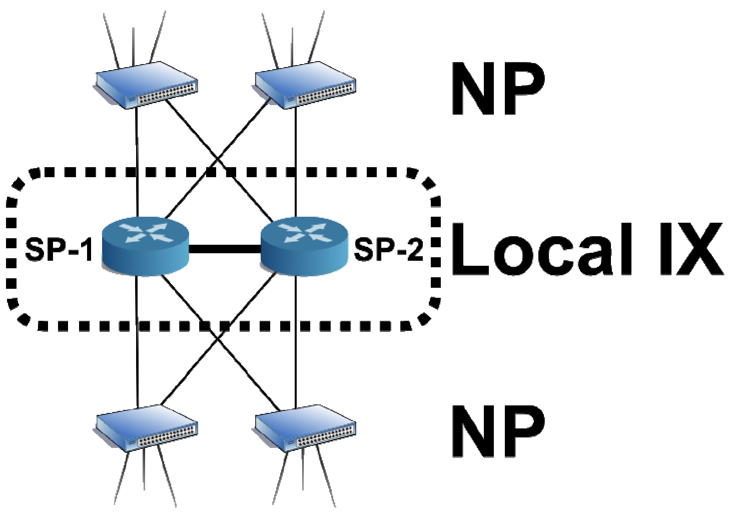


Figure 3-15: Local Internet exchange point

In an open infrastructure with a low degree of sharing, e.g. with parallel aggregation/metro networks this can be handled in a traditional manner where the SPs agree to exchange traffic, thereafter connects a reasonably dimensioned link between them, and configures it to allow forwarding of local traffic flows (see Figure 3-15). In an open infrastructure with a high degree of sharing this has to be handled in a different way since the traffic that belongs to two different SPs actually is transported in the same physical infrastructure belonging to a single NP, and the shared IX in Figure 3-15 could be realized within a network element. If the shared infrastructure is based on current access/aggregation architectures (see chapter 6.1) this could be achieved by introducing simple filtered forwarding where traffic between local addresses are allowed a local shortcut instead of being forwarded on a sub-optimal path. If the open access infrastructure would be based on next generation virtualized open infrastructure architectures (see chapter 6.2), then the shared IX would need a similar function for leaking of traffic but between the different virtual slices of the NPs infrastructure.

3.3 General Aspects

3.3.1 External interfaces

The interface between service providers and the network providers is a crucial point on both the data plane as well as on the control plane. Several possibilities exist on the data plane, both at the selection of layers (i.e. on which level the traffic is terminated and forwarded on in the NP network), as well as how services are separated within that layer (e.g. VLAN or MPLS tagged).

Data plane interface

The most straight forward solution on L2 is to use IEEE 802.1Q tags (also known as C-tags) for separation of services, as this is supported by virtually all hardware sold [12]. While this method solves the routing and separation issues it does not offer a way for the service provider to map an IP address to a customer. One solution to this issue is to enable DHCP option 82 on the access switches at the NP. This extension will add a field to DHCP requests which then contains an identifier of the switch which is closest to the end-customer and the port on which that end-user is connected, one variation of this is discussed in section 3.2.4. The NP can then provide automatically assembled information about which customer is connected to which switch port. This provides a way for the SP to know from which customer a DHCP request came from, and therefore also know which customer is assigned a certain IP address. This method also requires the service to be bootstrapped with DHCP, which is the case for most services. Only limited amount of cooperation between SPs and the NP is required as they only need to agree upon which VLAN ID should map to which service.

The long term evolution of this Ethernet solution would be to have a NPs network which is based on provider backbone bridges switches (see D3.1), an Ethernet standard capable of encapsulating Ethernet frames and effectively create tunnels in network. In such a network the SP could use arbitrarily values for VLAN ID as well as sending untagged traffic since the NP will encapsulate the traffic at the borders and does not need to understand the contents. The NP would then switch the SP traffic to all the access ports where the SP has an active user. This solution would also improve the scalability of the NP network as it can use VLAN IDs in an unrestricted manner as well as reducing the resources used by Ethernet learning procedure.

A similar approach could be to base the interface off MPLS instead of Ethernet, which could integrate better in to the network of the SP. This interface can be designed in several ways, but perhaps the simplest would be to implement the same basic pattern as in the VLAN technique. Instead of VLAN ID, the SP tags the traffic with MPLS labels. A more advanced approach would be to use separate labels per customer and service instead of having an ID per service. This is possible since the label space is larger and MPLS labels can be stacked. This interface could also be implemented as MPLS pseudo-wires in the NP network, so the SP could send Ethernet frames into the MPLS tunnel, providing a L2 interface to the customer. This would then address the identification of customers as there would be a one-to-one mapping between MPLS label and a customer, the mapping between label and customer would be provided by the NP if needed. In such scenarios the ONU would need to have some support of MPLS. The MPLS OAM functions, as well as the upcoming MPLS Transport Profile (MPLS-TP) Operation and Management (OAM) functions could be enabled for the SP. This could provide the SP with a method for doing limited fault detection and troubleshooting, for example LSP Ping, even inside the NPs network.

An interface based on L3 requires potentially more cooperation, depending on how the services from the SP operate and if IPv4 is used. The most common model today is where the NP manages all assignments of IPv4 addresses, including distribution of them via DHCP. This also makes routing easier since the NP can route the traffic in its network with normal routing protocols (e.g. Open Shortest Path First [OSPF]). The NP will then simply route the different traffic out to the appropriate SP as normal IP traffic. The SP will then detect what type of service its receiving based on the destination address or other properties of the packet. That the NP needs to have full control of the address spaces used is critical if several SP are using private address spaces for the delivery of the services, since there can otherwise be conflicts in the address spaces between SP. The use of private address spaces is common for services that terminate inside the SP network, like for example IPTV. A long-term solution for this is the use of IPv6, where the address space is so large that all services can have a public (globally routable) address. In this case the client may be configured without DHCP and no pre-configured address handling is needed in the NP. In this case the routers between the NP and SP would disseminate the routes needed for that SP.

All these interfaces would also be improved by the SP providing information on what speed caps and QoS requirements exists for the services provided by the SP. This enables the NP to throttle the customer traffic at the ingress point instead of at the border between the NP and SP. This mitigates local denial of service attacks that could be possible if the traffic is only throttled when the flow reaches the SP.

CONTROL PLANE INTERFACE

One important possibility on the control plane is sharing partial topology information which could be used by both sides to identify errors. This function should be compared to the function in chapters 3.2.1 and 3.2.2, where the SP gets full access to the control plane. The function described here would be a more evolutionary path which would alleviate some of the problems mentioned on these chapters. This could, for example, be that the NP “leaks” selected SNMP information to the SP, which give the SPs support operation a method to verify that the NPs network is working as normal. This is important for support reasons as this will simply the interaction and minimizes the amount of trouble shooting between the two.

Depending on the type of data plane this interface will also need to transfer routing information, for example via Border Gateway Protocol (BGP) or OSPF. Also if the data plane offers a virtualization option to the SP then this interface needs to handle the communication in a secure way between the two networks.

SERVICE HANDLING

Some additional information is needed between the NP and SP (for example ID to customer information as mentioned above) and this kind of information could be transported via manual interaction or via digital interface. This could for example be implemented as an Application Interface (API) offered by the NP to SPs. This would give the SP the ability to query the NP about information about a customer, such as the port ID that the customer is connected to. This could also be used as a way to inform the NP about the services offered by SP, both about the service metadata (such as type, description and price of the service) and transport information (such as service separation information, for example VLAN ID for a service).

What information that is exchanged via the API would depend on how services are provisioned, e.g. if the NP is responsible for provisioning a service for the customer or if the customer needs go to the SP. For example, if a customer would like sign up for service can it sign up for the service directly via a NP controlled page or does it to go to the specific SP page to sign up? Both models exist in open-access networks, where NP controlled provisioning allows for faster provisioning as it can trigger the network changes automatically. In this case the NP would provision the service and then notify the SP about the action with the appropriate details. This also requires deeper knowledge about the service that is offered by the SP, including cost of service and technical information. If the service provide is the responsible for the provisioning then it needs to trigger the network changes of the NP, which could be performed using the same API as described above.

3.3.2 Energy efficiency

An open-access network implies some amount of sharing; what is shared and how depends on the specific flavour (fibre OA, bit-stream OA, etc.) and the architecture (WDM PON, AON, etc.). This often lead to a scenario where an open-access based network infrastructure needs less equipment compared to a scenario where these providers had parallel networks. This is especially the case in bit-stream open-access as used in an E2E type scenario (see Figure 3-7 and Figure 6-1), where parallel NP network infrastructures are minimized between PCP2 to PCP7.

If addressing the same set of end-users, the total volume of traffic is the same in both a full scoped OASE bit stream architecture (end-to-end sharing passive and active infrastructure) and one that is only open on the fibre level while the active layers are not shared. A fully shared infrastructure needs to be dimensioned higher since it will handle the full traffic load, while parallel architectures needs lower dimensioning which depends on the number of network providers. Here it is assumed that network elements with a higher number of ports and line cards can be built more energy efficient than ones with a lower port and card count.

The result of this sharing, and the subsequent reduction in number of network elements, is that the overall energy use can be lower compared to several, in parallel, vertically integrated operators. This saving leads to overall reduction in OpEx, besides the more obvious reduction in CapEx. There is therefore a clear benefit from this perspective to maximize the amount of sharing in the network, while balancing the amount of sharing to the extra costs incurred by the sharing. See WP6 D6.2 for business model calculations on open access scenarios.

3.3.3 Service-level agreements

The transmission of SP data in the NPs network could be configured in several ways. The use of network protection could, for example, be used depending on the type of service and the network provider's capabilities. For example, the service provider could request network protection for a service, while at the same time not providing network protection for other services from the same service provider. This could result in a higher fee from the network provider; this fee could in turn depend on the cost of providing network protection.

Protection could therefore be a Service Level Agreement (SLA) configured aspect of the services, and not a generic attribute of the network. This opens up business options to the network provider, who can sell protection services to other service providers. For the network provider this could also reduce the cost of providing network protection as not all services running in the network would need protection, and in case of a failure only the SPs which paid for protection would continue to run without their service being affected. This means that the NP does not need to dimension the network to handled full protection of all services, reducing the dimensioning requirements incurred by the need for protection equipment.

From a customer service perspective it is logical that only important services are protected, for example eHealth or telephone services. Entertainment services, for example IPTV, are less important; a service outage could be acceptable for a limited time

3.3.4 Physical infrastructure aspects

As we go higher up in the layers to provide open access, both the flexibility and the complexity of the solution decrease. There is an increasing price associated with the flexibility of open access solutions. In general, fibre OA provides flexibility but the issue of smooth customer migration may be problematic. OA at the WDM layer is difficult; dimensioning of the AWGs on the WDM layer may have to be altered to offer and support open access, becoming larger and more expensive. Network management will have to be executed more careful – with multiple optical signals sharing the same fibre there is the potential for one operator to adversely influence the signals of another (this is not necessarily true for wavelength unbundling described at chapter 5.3.2 where network management is handled in a fully automated way since operating on the electrical domain). Bit-stream open access will likely be simple to implement on any of the system concepts under study and may therefore provide simple solutions to SPs not concerned with a high degree of control of network resources. We will now see each flavour of open access and how it influences CapEx and OpEx.

If traffic is handed off at layer 1 (e.g. dark fibre), the NP/SP that gains access to that fibre would not only have a monopoly on that household, but also on all premises connected on that network, thus preventing competition. The NPs may adopt different heterogeneous technologies, and this will prevent smooth customer migration. Fibre open access is possible in a fibre rich scenario, where the PIP overprovision the fibre within the network. In addition to the overprovision of fibre within the network that is necessary to offer open access on the fibre level, it is also necessary to provide optical distribution frames that are not only larger but also more complex, allowing cross-connection between the network operators. It remains to be seen by work in WP5, however, exactly how significant this increase in cost proves to be when considering the cost of trenching. The architectures with low fan out like WDM PON will be most probably hit more with lower layer open access.

The challenges to provide open access on wavelength level are numerous. For wavelength open access, the PIP may need to own the open access element in order to provide access to every NP. Since, the PIP will own the network element, it ceases to be technology agnostic. The point of unbundling can also be owned by one of the NP. This scenario is most likely in case of unbundling. If the NP owns the point of unbundling, it is referred to as the master NP. For pure open access, the scenario with Master NP should be avoided to ensure neutrality. The wavelength open access scenario, with the PIP owning the point of unbundling, can further scale the business case if every customer can connect to every NP. This will require that all NPs should use the same technology. However, we will see that such scenarios are very complex and will not be cost effective. Moreover, NPs should be guaranteed isolation from each other. Over the power splitter based infrastructure, this therefore poses further challenges. In view of all this, the scenarios with wavelength open access will have high complexity to implement. In wavelength OA, there are many options to choose a point of unbundling. The point of unbundling could be a manual patch panel. The architectures that allow manual open access will have tremendously high operational cost as every time a user wants to connect to a different service provider, connection has to be manually configured using fibre patch panel. Nowadays, there are automatic fibre robots, which minimize the human error in fibre patching. Moreover, the architectures using an active switch like a WSS will have higher energy consumptions and operational cost. Nevertheless, they have the potential to support dynamic spectrum sharing between service providers. In addition, there will likely be costs associated with connecting or disconnecting clients, as this will require either manual intervention from an operator to re-patch (manual re-wireing) or the use of expensive optical switches. Some network architectures are, however, better than others in this respect and there is therefore the potential for both optimisation and differentiation between the system concepts in this regard.

If, on the other hand, the NP hands off traffic to the SP at layer 3 (i.e., IP packets), the network will have to manage all the problems of providing open access at layer 3. Providing open access at layer 3 involves lot of complexities such as address assignment, implementing routing protocols, managing peering with SPs, migration to IPv6, and implementing IP multicast protocols. Therefore, layer 2 (Ethernet frames) connectivity between the NP and the SP is most suitable as it combines flexibility with low complexity. These reduce the barrier of entry for new SPs which should therefore result in greater competition.

4. Traffic and service models

This chapter includes work on traffic studies and simulations with a focus on the local nature of the traffic, i.e. how much of the traffic could go between two peers who are "close" as measured by topological distance. Another focus is on cache assisted networking, which looks into aspects of distribution of caches etc. and their potential benefits.

A3.2.2 of the OASE DOW includes and specifies that work on "different traffic patterns and service characteristics will be studied in order to construct representative traffic and service models". The implications of this work on the open access models are mainly on the bit-stream level, but also on the fibre open access level.

Traffic patterns that are highly local or distributed in nature are governed by end-user content-request concurrency requirements, i.e. how often end-users are interested in the same content in a similar time window. This can either be implemented by a protocol connecting end-user resources/caches and/or network assisted resources/caches. The impact of this on network design is basically the ability of the network to connect/route/bridge the resulting flows of two concurrent or near concurrent requests of a particular content as topologically close to the end-users as possible. This traffic driven requirement has the possibility to balance consolidation requirements and has a big impact on where to allow for routing/bridging points in the access and aggregation/metro network.

Also in an open access environment these distributed routing/bridging points need to adhere to, or at least try to relevantly meet, the locality requirements of the traffic transported. The impact on an OA infrastructure is then similar to networks in general but on an inter-NP level, i.e. NPs need to allow for traffic exchange to a certain level. The inter-SP traffic exchange can be composed of routed/bridged traffic between SP segment overlays (e.g. see chapter 3.2.6) on NP infrastructures, and/or the understanding of OA network wide cache locations. On lower levels this would lead to a requirement e.g. of the physical infrastructure which would need to allow for fibre connections between co-located NPs and not only in a PCP up-/down-stream direction.

The traffic studies of this chapter can have a large impact on how to design future access and aggregation/metro networks in general as well as open access equivalent infrastructures.

4.1 LOCALITY OF CONTENT IN ACCESS NETWORKS

This section presents a novel study of the locality of content in access network by analysis of the content distributed with BitTorrent. In the study we investigated how many content downloads could be kept local in the network, if the client had locality knowledge. This was accomplished by collecting BitTorrent tracker information from two access networks and analysing the content download per each client and content file. It is, however, important to note that the use of BitTorrent as distribution method is a means to investigate the locality of content, not to study the specifics of the protocol. The results showed that between 19% and 25% of content bandwidth could be saved by only using these techniques. To complement this study we also performed initial work on the effects of a simple cache.

4.1.1 Introduction

In order to design architectures for future access and aggregation networks we first need to understand how the current network behaves. This will give us a better base from where we can estimate how the future network will behave and therefore identify how to build the future network to accommodate these behaviours.

The purpose of this work is to investigate how content in the network (videos, music etc.) is distributed among the users, and to see if there are locality patterns to the content. For example, how common it is that several customers are interested in the same content during the same time period? It is then possible to estimate the benefits of mechanisms that utilize these facts. For example, if several customers are interested in the same video, then the traffic that this video represents could be kept local in the access/aggregation network.

Several methods could be extended in order to keep the content more local, for example using peer-to-peer offloading, caches or Content Distribution Networks (CDNs). With peer-to-peer offloading the content is distributed fully or partly by software running in a distributed fashion, most commonly on client devices. These solutions could be modified to be aware of where the other peers are located and therefore allow clients to prefer peers that are close to themselves. Caches could be deployed in the network where devices may store data and where other devices may fetch the content from, or via transparent caching proxies. Using CDNs the content that is most popular can be placed in CDN nodes that exist in the local access/aggregation network.

These solutions have benefits for all parties in the content distribution chain, from the content provider, through the network operator and finally to the end customer. The content provider reduces its bandwidth costs as less traffic flows from its own servers. The network operators will have reduced peering costs as less traffic is sent to other network operators. Furthermore if the network operator will allow for more local bridging of traffic flows it will offload its core network, which leads to reductions in the cost of the central parts of networks. Finally the end customer may experience better QoS in the form of lower delay and higher throughput as the content is fetched from a location in the local network.

In this work we seek to answer some of these questions and quantify the potential benefits by analyzing the content distributed via BitTorrent. The reason for choosing Bit Torrent is that it is a very commonly used P2P file sharing protocol, and that its share of the total traffic in high speed access networks is very large [20]. There also exist several proposals for extending the protocol for locality awareness.

4.1.2 Related Work

A similar study was performed in [18] where a university network, with relative low BitTorrent usage, was monitored for a short time span. This study found that 10.4%-18.2% of the content files could be downloaded locally. Our study presents an updated view, with a longer monitoring period in modern access networks with a different methodology. Inter Internet Service Provider (ISP) traffic analysis has been presented in for example [24], where the focus in on traffic flows between ISPs and not the actual content.

It is shown in [21] that up to 88% of the traffic for a Peer-2-Peer (P2P) video distribution can be held locally within an ISP if the P2P application uses a locality–aware peer selection scheme. To avoid unnecessary transit of P2P traffic among multiple ISPs, different locality–

aware content fetching solutions have been proposed, with or without assistance from ISPs [15][25][22][14][16][28].

Caching for peer-to-peer applications has been studied, where the cache also functions as a peer in the network [19]. Further, various measurement studies on P2P applications have shown that there are large bandwidth gains for ISPs if caches can be implemented in the networks, see for example [19][18][27][23].

4.1.3 Post processing and identification of locality

The first step when investigating the locality of content is to select a distribution method to measure. As discussed in the Introduction, the content distribution method that represented the highest amount of traffic in the access networks available was BitTorrent, with about 70% of traffic volume on both networks [20].

BitTorrent is therefore an appropriate distribution method to study, both because the large amount of bandwidth that could be saved and the large amount of content that could be identified from it. BitTorrent is also easy to study as the content can be identified using the info-hash described in the next section.

It is however important to note that the use of BitTorrent as distribution method is a way to investigate the locality of content, not to study the specifics of the protocol. Other methods could have been selected but, as described above, BitTorrent is both easy to study and has a large user base. It is likely that the same general content and usage patterns hold true for other types of content distribution, because of the large amounts of BitTorrent users and the variety of content that it distributed with it.

BitTorrent Info-hash

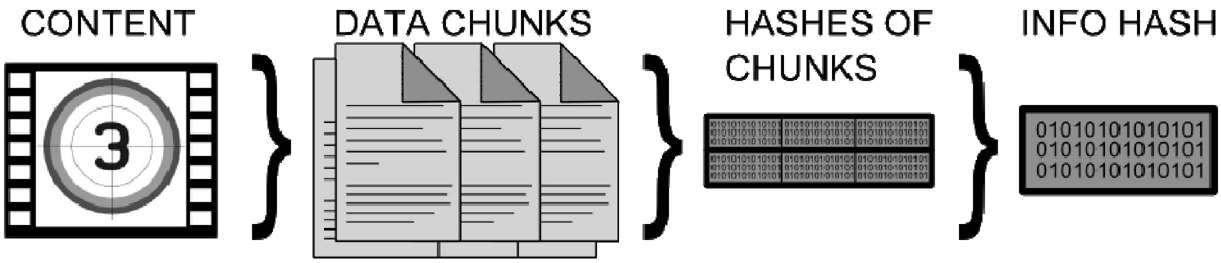


Figure 4-1: The info-hash is build based on hashes of chucks of the real content; this means that the same content will always have the same info-hash.

Each file distributed with the BitTorrent protocol is described in a “torrent” file which contains information about the content and information to bootstrap the download of the content. The content information includes a list of files and a list of hashes; these hashes were in turn calculated from chunks of the original content. By hashing all the file chunk hashes, a unique hash of the content is obtained, known as the info-hash as seen in Figure 4-1. This means that the info-hash uniquely identifies the content, and it is therefore possible to know that two clients with the same info-hash are downloading the same exact content.

BitTorrent Tracker

Traditionally each client in the BitTorrent system would contact the BitTorrent Tracker to receive new peers that participate in the distribution of a BitTorrent file. This is still partly the case today, but only as one of several possible sources of peers, for example modern clients also exchange peers directly between each other. However, most clients still contacts a

Tracker, which means that this traffic can be intercepted by a packet analyzer. In the two studied access networks a packet analyzer was present at the border between the access network and the rest of the Internet, which means that this device can pick up all traffic between a peer and the Tracker.

A BitTorrent client will send information to the tracker via HTTP GET messages, containing a set of parameters encoded in the request URL [17]. The most important of these parameters for this work is the "info_hash" parameter which specifies the info hash, which as explained in section 3.1 identifies the content that the client is downloading. Other interesting parameters for our usage is "left", "downloaded" and "uploaded", which respectively specifies amount left to download, amount downloaded and amount uploaded.

Important to note is that encrypted HTTP traffic makes the analysis described above impossible, but fortunately this seems to be quite uncommon among BitTorrent trackers1. The results of this study should not be greatly affected by this, even if some traffic is left out because of encryption. This lost traffic will result only in a smaller amount of BitTorrent users, the locality results will still remain the same for the traffic captured.

DATA COLLECTION

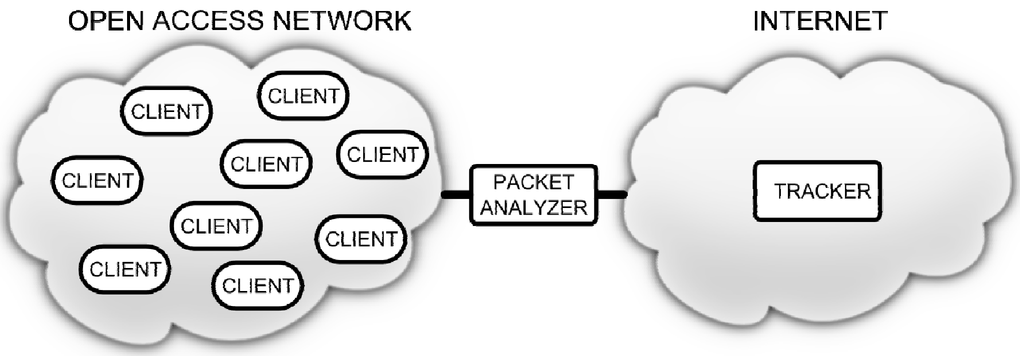


Figure 4-2: We placed a packet analyzer between the access network and the Internet, and could thereby capture all communication between the clients and the torrent trackers.

The first step is to collect the information transmitted from the BitTorrent client and the Tracker. This is done by using a packet analyzer (deep packet inspection based - DPI) between the access network and the Internet, as can be seen in Figure 4-2, which means that external traffic can be collected. The packet analyzer was configured to store all packets matching BitTorrent tracker traffic into Packet Capture (PCAP) packet dump files.

These files where then downloaded and converted to XML based information using the packet analyzer Wireshark [26]. Using this XML information, the following parameters were extracted:

- Timestamp, when the request to the tracker was made
- Source IP address of the client, hashed and salted to reduce identifiability of the user
- The info hash that the request was for
- The amount downloaded, uploaded and left to download
- The Trackers host name

The extracted information was inserted in a Structured Query Language (SQL) database, and used in the next step as described below. Using the captured information an approximation of the size of the BitTorrent files was calculated, based on the maximum value of the "left" parameter reported by the BitTorrent clients. This gives a good estimation of file size, since a starting client will report the full size of content, as it has not yet started the actual download.

4.1.4 Measurement of locality

The goal of measuring the amount of locality in the current access networks was implemented by collecting the information transmitted from the BitTorrent client to the BitTorrent Tracker. The date and time stamp when each BitTorrent client where active with a given content is estimated using this collected data, which is referred to as a session in this work. The session information can then be used to estimate (through a concurrency analysis) which downloads could be made internally in the network and which must have been downloaded externally. The same session information was also used to simulate a simple caching scenario. The analysis of this will be described more in detail in the following sub-chapters.

SESSION CALCULATION

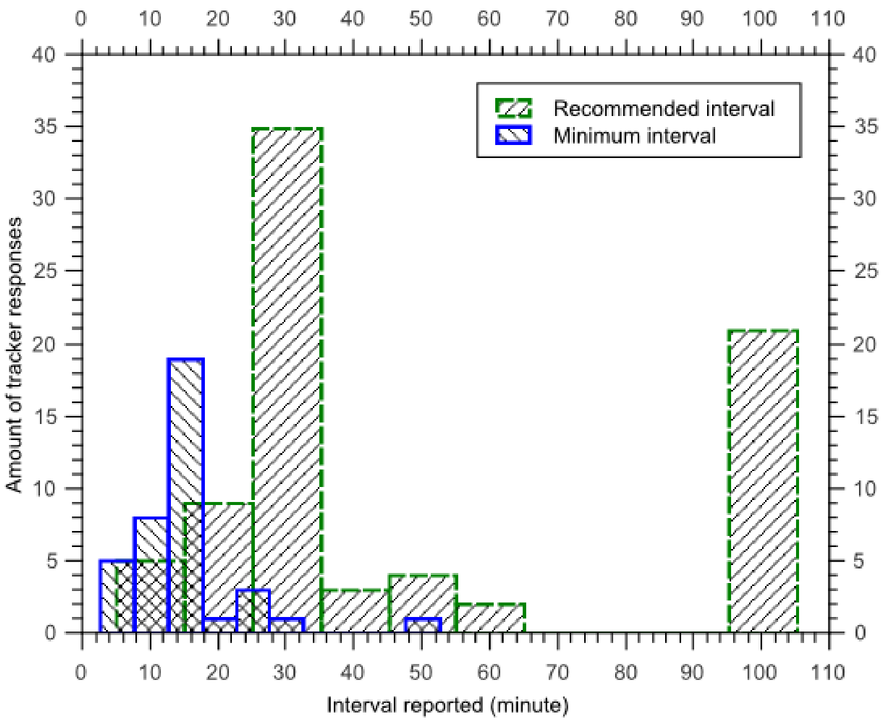


Figure 4-3: Recommended and minimal tracker update interval based on responses from 80 unique trackers

To calculate detailed user activity, either downloading or uploading with a specific piece of content, one needs to calculate the active session of the user+content combination. This includes at least the time when the client started and stopped, and a content identifier. User sessions were created from the extracted data in the following manner:

1. Extract all data points for client A and info hash X, sorted by ascending time.
2. Start a session from first new data point
   (a) Analyze next data point
   (b) Is the next data point within a time period α from the last data point?
   (c) If so assume that the session continues, go to a.
   (d) If not add a time period β to the session and insert the session in to the database and go to 2.

This calculation requires two tuneable parameters α and β, where α represents the maximum time period between a data point in a session and the next data point that can be considered to be part of the same session. And β is an estimated time period to add to a finished session to compensate for possible lost data points at the end of the session.

These two values depend of the "interval" parameter reported from the tracker which specifies the recommended interval between tracker updates. A small survey of the different values was therefore preformed, and the result is shown in Figure 4-3. It can from the figure be observed that the most popular choices for update interval are 30 minutes and 100 minutes. The α value should also be at least twice the interval value to overcome at least one lost tracker update, or when the client select an interval which is higher than the recommended value. Lost tracker updates where observed, either because of packets not captured by the packet analyzer or because of problems in the BitTorrent clients. A fixed value of α =2h and β =2.5h was selected based on the intervals reported by the trackers. It would also be possible dynamically calculate appropriate values for each torrent based on the tracker interval response for the specific torrent and could be performed in future work. Adding 2.5 hours on short sessions might affect the results slightly, but most short sessions will be downloads of small files which have limited affect of the overall bandwidth gain. Furthermore, the initial analysis of the results indicates that large files are the ones most likely to be downloaded concurrently.

CONCURRENCY CALCULATION

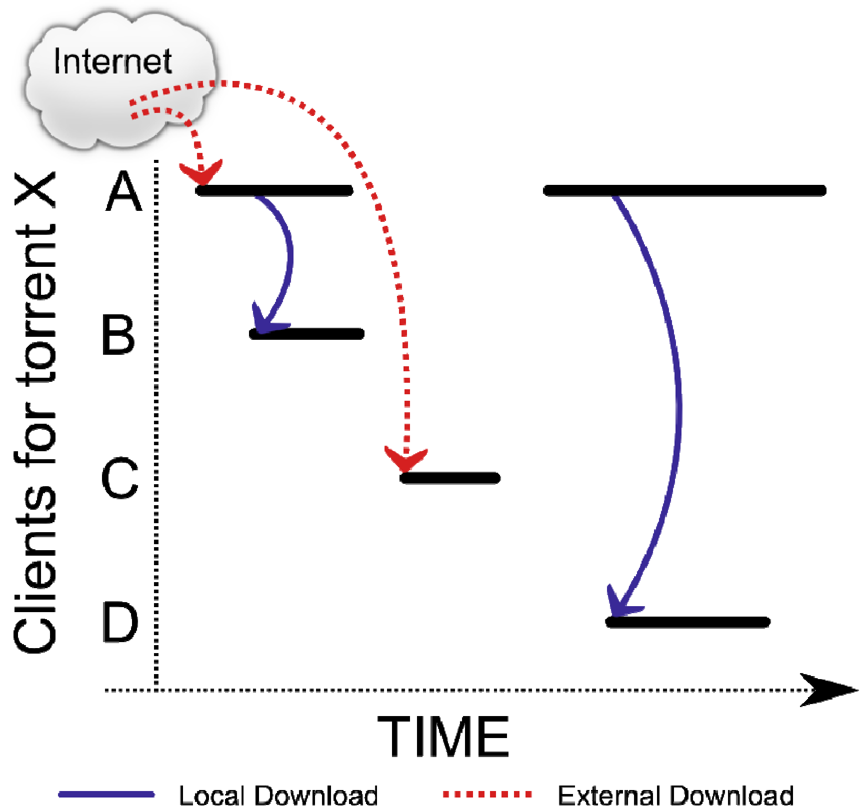


Figure 4-4: Example of calculation of concurrent downloads, for client A-D for a torrent X.

Given the calculated session information we are now able to evaluate which downloads must be fetched from outside of the access network as opposed to downloads that could have been kept local if the BitTorrent clients knew about each other. In order to quantify this, every session associated with a BitTorrent download was analyzed to determine which clients were active and if they previously had downloaded the file.

Consider Figure 4-4, in this example four clients (A-D) are active with the BitTorrent file X. The first active client is A, who has to download the content externally as no other clients are active inside the access network. Sometime later client B starts to download the file, but can now instead download this content from client A since client A is both active and has previously downloaded the file. When, later, client C starts it must download the content externally as no other local client is active. At the time when the last client D starts it can download the content from A as it became active again after a time of inactivity.

This procedure was used to calculate the amount of local and remote downloads. The number of downloads was also translated to bandwidth, using the approximated sizes of the content as described previously.

IDEAL CACHE

To increase the efficiency of the content distribution a local cache may be placed in the network. This cache would automatically store content transmitted in the BitTorrent distribution system. A very simple variation of this cache was therefore simulated; a cache which stores all content that has been downloaded at least twice. Even if this cache represents an unrealistic best scenario it gives an idea on what is the best possible result that a cache could achieve. Later studies could give insight to how close a more realistic cache could get to this best case scenario.

This ideal cache was simulated using the same method as described in the section above, with a few modifications. The number of downloads per torrent file was counted and when the caching limit was hit (two hits used in this work) the torrent was marked as being in the cache. The simulation preferred to download from other clients, and downloads from the cache was only preformed when no other active clients where available.

4.1.5 Results

Table 2: Attributes of the two access network measured

	Subscribers	Access technology	BitTorrent Percentage	Concurrent Ratio	Cache Ratio	Total Downloads
Small Access Network	~1500	FTTH, DSL	~70%	18%	43%	493 Tbits
Medium Access Network	~1500	FTTH	~70%	23.5%	46%	1337 Tbits

The analysis was performed in two different open-access networks, both located in Sweden. The same procedure was used in both networks, with the exception that port numbers where used to identify customers in one network as compared to hashed IP addresses. The detailed results are presented in Figure 4-5 and Figure 4-6, where the statistics for each day is displayed. Presented is the number of downloads that could be performed internally in the network (intra), and the number of downloads that required an external download (inter). Also presented are number of downloads that could be handled locally with the assistance of a cache (cache+intra), and the ratio between intra downloads and the total amount of downloads. The figures also present the number of users for each day as well as markers for the last day of the weekend.

SMALL ACCESS NETWORK

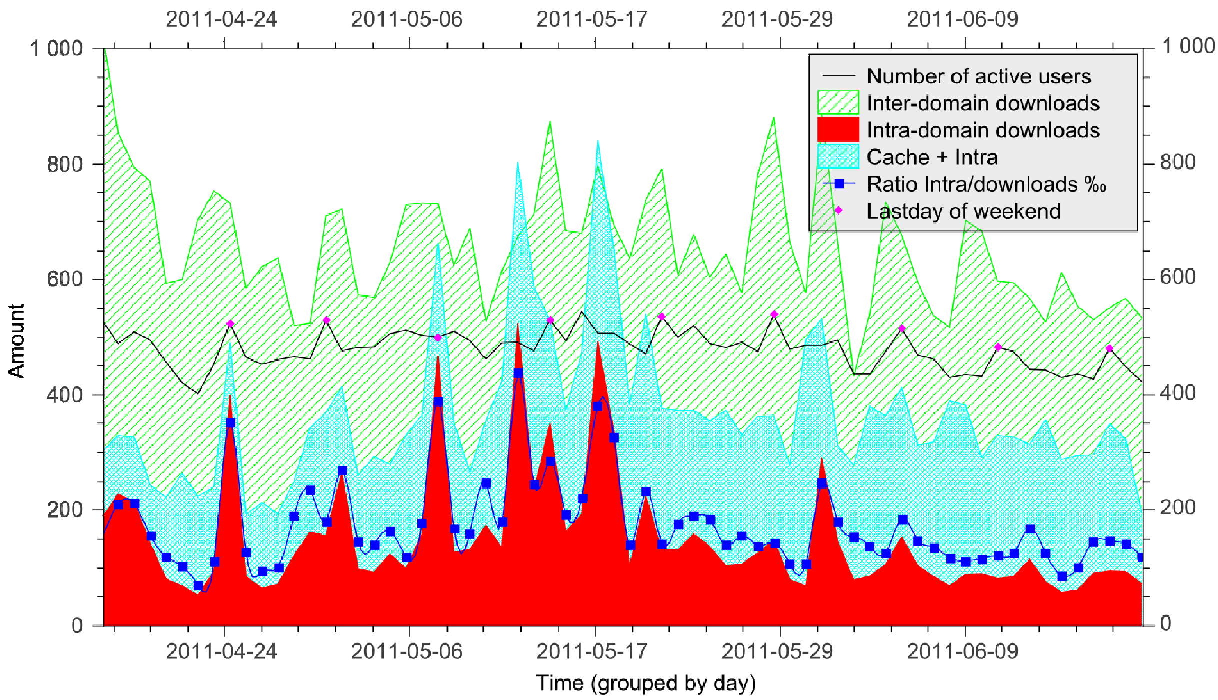


Figure 4-5: Results of the locality study in the smaller access network.

The results seen in Figure 4-5, are from a small open access network with around 1500 subscribers. This open access network has a high on average connectivity per end subscriber, majority connected via fibre. On average 18% of the content downloads could be handled by the local peers ("concurrent downloads"), with 19% in terms of bandwidth. With the simple cache the average percentage that could be kept local was 43% in terms of content downloads and 46% in terms of bandwidth. During the period the total amount of downloaded material equals 493 Tbits, where 94 Tbits were concurrently downloaded, and 230 Tbits were kept locally when assisted by the simple cache.

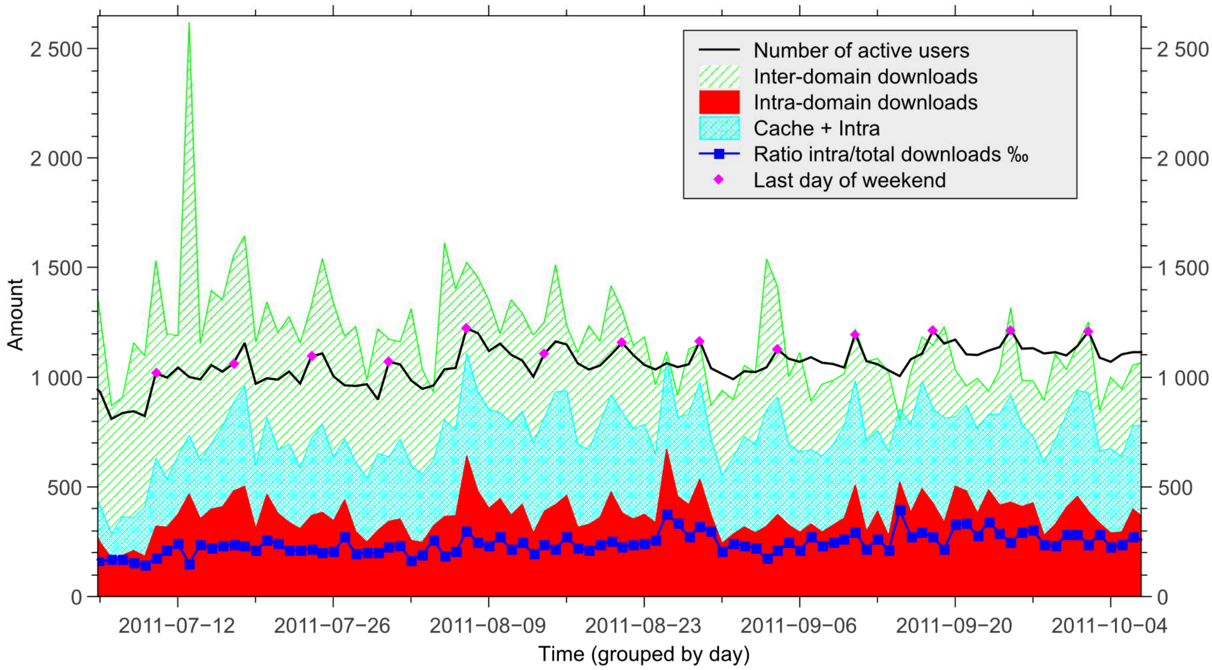


Figure 4-6: Results of the locality study in the medium access network.

In Figure 4-6 the results from the second mid-sized access network are presented. This open access network serves around 5000 subscribers, largely with FTTH connectivity. In this network we found an on-average concurrent download ratio of 23.5% and in terms of bandwidth 25%. For the simple cache we got 46% and 51%, for download and bandwidth respectively. During the period the total amount of downloaded material equals 1337 Tbits, where 339 Tbits were concurrently downloaded, and 687 Tbits were kept locally when assisted by the simple cache.

4.1.6 Conclusions and analysis

The medium sized network showed a higher percentage of potential local downloads (intra-domain) compare to the smaller network. This is expected, as the number of user will improve the likelihood that several users are interested in the same content during the same time period. However it is not possible to say to what extent this will change for smaller and larger networks. It is likely that the relationship between network size and locality potential is not linear and that there exists a point in the range in network sizes which is the most effective.
The percentage of saved downloads is lower compared to the amount of saved bandwidth in both networks, which is probably an effect of larger files being seeded for longer times compared to smaller files. This results in a larger chance for these files to be used by other peers in the network.

It can also be observed in both networks that the number of active users, and therefore content downloads, clearly rises on the last day of the weekend. This probably reflects the common content consumption patterns and could probably be exploited with pre-caching.

The results found in this research show that a large percentage of the BitTorrent traffic can be kept local simply by modifying the behaviour of the BitTorrent client software. Improvements to these results could be obtained if the users were to keep their BitTorrent clients active for longer times but only for popular content. Even higher savings could be realised by introducing active caches, even if the feasible quantity in a realistic scenario needs to be determined in a future study.

FUTURE WORK

The analysis in this work used a fixed timeout constant when calculating session lengths. While this probably provides a good estimation, future work could calculate the size of this timeout variable based on the information sent by the tracker. This may improve the accuracy of the session calculations and therefore slightly affect the final locality results.

The types of content were not taken into consideration when performing the simulations, and future work could focus on different kinds of content. It would be possible to roughly estimate the type of content based on the size of the files as for example movies and TV-shows differ in size. This could provide interesting results as the user behaviour of viewers of TV-shows is probably different from, for example, movies.

The cache in this work was an unrealistic ideal cache and a more realistic cache could be implemented which would give a more accurate view of the caching possibilities. The size of the network could be changed to investigate on which aggregation level the locality effects are the most effective, and on which level the benefits of network size flattens out.

Concurrent study of several networks could give insights into similarities and differences in content demand behaviour, for example will the same content be popular in both network or is content popularity local? A similar analysis of other distribution systems could provide insight if there is an aspect of the locality of content that differs from the behaviour found in this study.

4.2 PEER-2-PEER SIMULATIONS

In this section we analyze via simulation the possibility of offloading traffic from the aggregation part of the network by localizing the traffic using peer-2-peer applications. The traffic measurements presented in the previous section (i.e. Section 4.1) show that there is common interest in some certain content among the users subscribed to the same access network, which can be engineered to lead to a potential bandwidth saving on aggregation links via P2P file sharing, especially for video files that are generally huge in the volume. It should be noted the P2P application itself does not care about the geographical or topological location of the peers and hence the data might be downloaded from the nodes far from the requesting node where the same content is available just in the vicinity. In order to offload traffic from the aggregation network as much as possible, we consider a modified version of the bit torrent algorithm which takes into account the distance of the peers from the requesting node while selecting the list of IP addresses to be used as seeds [29]. Our simulation results have confirmed that a significant reduction in the bandwidth usage of the aggregation/core network can be achieved for both passive and active NGOA network architecture options.

4.2.1 Network architectures and locality awareness scheme

Figure 4-7 shows the general view of the physical topology of a hierarchical network including the metro and access nodes. This figure is used to describe the locality awareness peer selection algorithm used in the simulations. As you can see a ring of routers is connected to layer2/layer3 (L2/L3) switches, except one that is connected to the tracker. At the next level, one L2/L3 switch is connected to several access switches, each of which covers multiple end users.

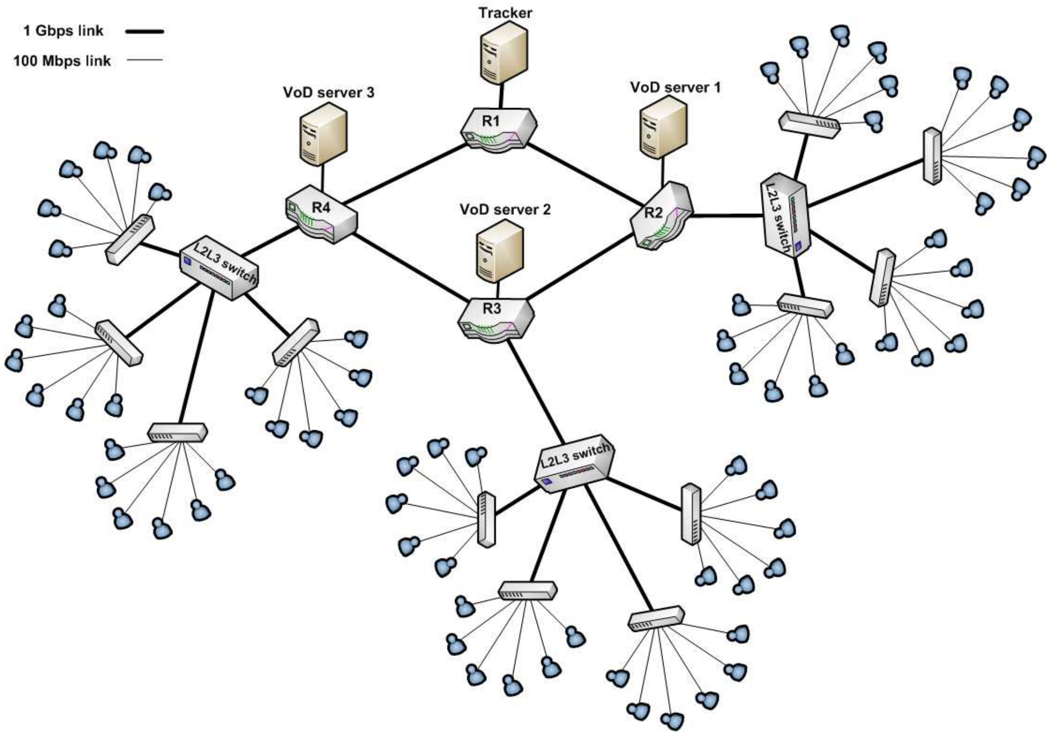


Figure 4-7: General topology of network [30].

The network demonstrated in Figure 4-7, is divided to four zones by the distance from requesting node. Peers are in region zero when they are connected to the same access switches. If they are under same L2/L3 switch but in different access switches, they are in Region 1. Peers belonging to the same router but not the same L2/L3 switch have a distance of 2 (region 2). The longest distance is with peers connected to a different router than the initiator node, with a distance of 3. Our considered bit torrent algorithm chooses the peers with distance as short as possible [30]. To take the topology shown in Figure 4-7 as an example, peers between the users under the same access switch are first selected.

We employed the same algorithm as presented above in two different network architectures, namely PON and AON, to compare their ability to offer traffic locality.

Figure 4-8 shows our considered PON architecture, where four XG-PONs are utilised. It could also be imagined as a hybrid WDM PON with four 10G TDM PONs. The downstream traffic in one TDM PON is broadcasted to all connected ONUs, and the upstream is shared among users via TDMA technique. Starting from the right hand side we have the POP which can be considered as the router in Figure 4-7 connected to three central access nodes through the aggregation links. Each CAN contain four XG-PONs, each of which is connected to a 1:32 power splitter in the cabinet. Router, L2/L3 switch and access switch in the Figure 4-7 are replaced by POP, CAN and power splitter in this architecture. As the power splitter in this architecture is a passive component, peers in region zero do not help to offload the traffic in feeder fibre link.

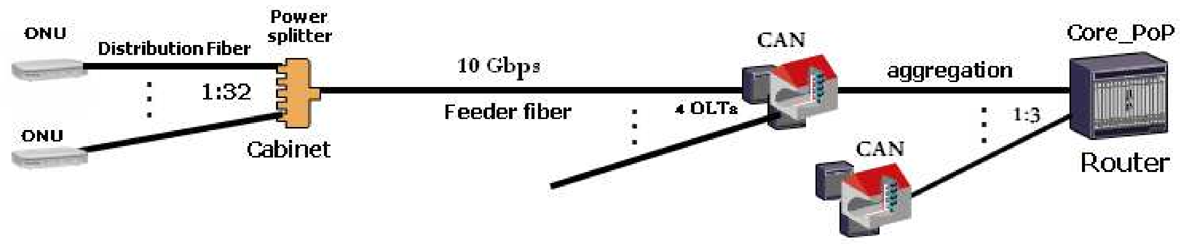


Figure 4-8: PON based architecture.

Figure 4-9 depicts the topology used to implement an active optical network in an active star configuration. This is very similar to the topology presented in Figure 4-7, where each CAN accommodates an active OLT. There are also Ethernet switches located in the cabinet translated as the access switches in Figure 4-7.

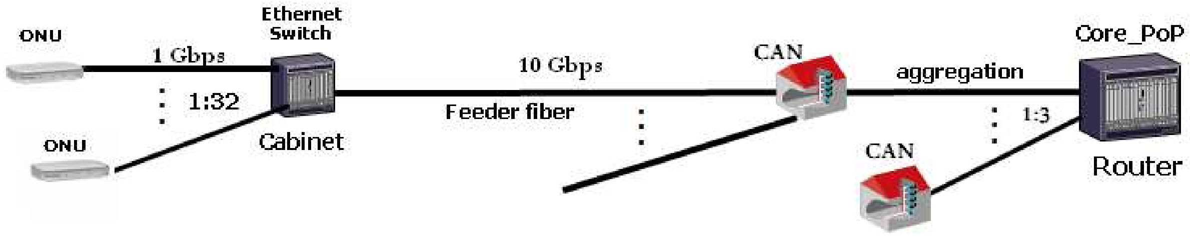


Figure 4-9: Active star based architecture.

The number of nodes used in our simulations at each level is summarized in the Table 3. We set the same number of ONUs served by each CAN for both PON and AON in order to have a fair comparison.

Table 3: Distribution of nodes in the network

	POP	CAN		Cabinet		ONU	
		Per POP	Total	Per OLT	Total	Per RN	Total
PON	2	3	2*3 = 6	4	6*4 = 24	32	24*32= 768
AON	2	3	2*3 = 6	4	6*4=24	32	24*32=768

The main difference between the architectures is the type of device located in the cabinet. In the PON based architecture the cabinet is passive and lacks switching capability, so region 0 and 1 can be merged as a single region in the locality awareness scheme mentioned above. However, in the AON based architecture, the traffic can be switched at the cabinet level, meaning that peers belonging to two nodes connected to same cabinet do not have to travel back to the CAN.

4.2.2 Simulations tool and set up

Network Simulator 2 (NS2) was utilized to run the simulations. NS2 is one of the most popular simulators as it is an open source tool and constantly updated by its large user base [31].

One Video on Demand (VoD) server was connected to each router to be used as the local cash or video server and this was populated with all the content which might be of interest to the users. Each user has a Setup Box (STB) with sufficient storage capacity to store several movies and act like seeds if needed. Each end user that is scheduled to watch a movie or is used as a seed is called a peer. The peers will share the content as soon as they start the download and have some slices available.

There is also a tracker for the P2P application. The tracker is responsible for peering between the nodes in the network. It has a list of all the peers with their IP addresses. The IP addresses of the nodes are ordered in such a way that the tracker can distinguish the physical location of each node to keep the traffic as local as possible. It also has other necessary information about the end users such as their Table of Content (ToC) and the number of downloads and uploads of each node. During the simulation, the tracker updates the peers ToC periodically by sending ToC requests to each peer.

When it is time for a peer to start watching a movie, it sends a request to the tracker via the pre-established Transmission Control Protocol (TCP) connection. The tracker processes the request and acts upon it by searching for peers who have enough of the requested content: the tracker checks both the locality of the peers and their content, and it tries to choose the nearest peers that have sufficient upstream capacity according to their physical distance. To keep the traffic as local as possible, the tracker first tries to find peers in region zero as the requester. If it cannot find enough nodes in this stage, it searches one level higher in the nodes hierarchy. It continues this process to find the maximum number of seed for the peer (which is equal to 5 in our case).

We ran two series of simulations for each architecture. In the first scenario all the nodes download their content directly from the video server and P2P functionality is deactivated in the network (this is referred to as the VOD scenario). This will be used as the benchmark to be able to define the amount of bandwidth that can be saved when considering the possible gains from exploiting locality of traffic. In the second set of simulations, the bit torrent algorithm (referred to as P2P) is enabled for the downloading the same content as in the first set of simulations. In order to keep simulation time to a reasonable scale, each STB will download and watch a movie with the duration of 3 to 5 minutes, and the simulation records the bandwidth usage for the first 3 minutes.

4.2.3 Bandwidth usage on the links

In this section, we compare the upstream and downstream bandwidth usage of both scenarios for a selection of links in the network. In all the graphs, the blue curves represent the VOD scenario and green curves show the traffic when P2P is used. Figure 4-10 (a) and (b), demonstrate the links between the router and one of its connected CANs, which is called the aggregation link. The results show that traffic load of the network in the absence of P2P in the VOD scenario is considerably higher than the scenario with P2P applications in both architectures.

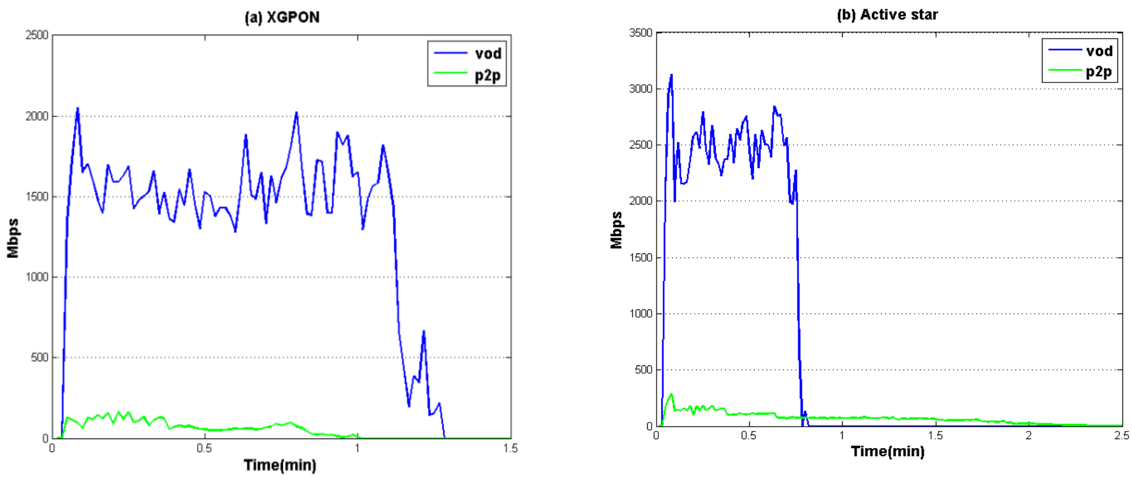


Figure 4-10: Bandwidth usage on the aggregation link for (a) XGPON and (b) Active star.

Figure 4-11 depicts the bandwidth usage on the link between the CAN and the cabinet for both PON and AON. As Figure 4-10 (a) shows, the amount of traffic is similar in case of 10GPON, as the passive splitter in the cabinet cannot offload traffic in the feeder fibre. However in the case of active star, the link usage remains much lower using P2P compare to the pure VOD case (See Figure 4-11 (b)). The reason is that in case of AON some packets can directly be routed to other user at the switch in the cabinet.

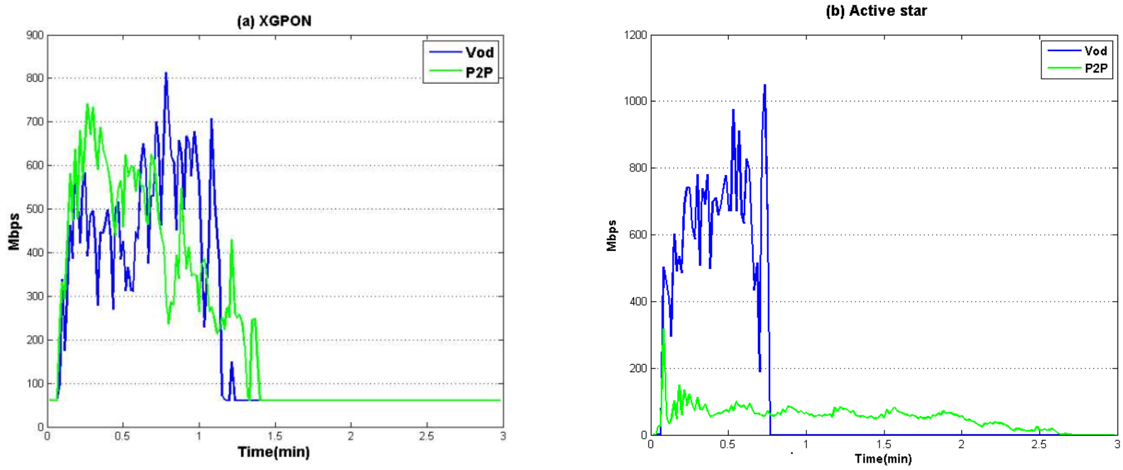


Figure 4-11: Downstream bandwidth usage on the feeder fibre link for (a) XGPON and (b) Active star.

On the other hand, in the P2P scenario, upstream capacity needs to be used to decrease the amount of traffic on the downstream direction. Figure 4-12 shows the traffic from the cabinet toward the CAN. It can be seen that the P2P scenario uses much more bandwidth in this direction compared to the VOD case. The upstream traffic increases more in XGPON, due to the lack of switching function in its passive cabinet compared to an AON based architecture.

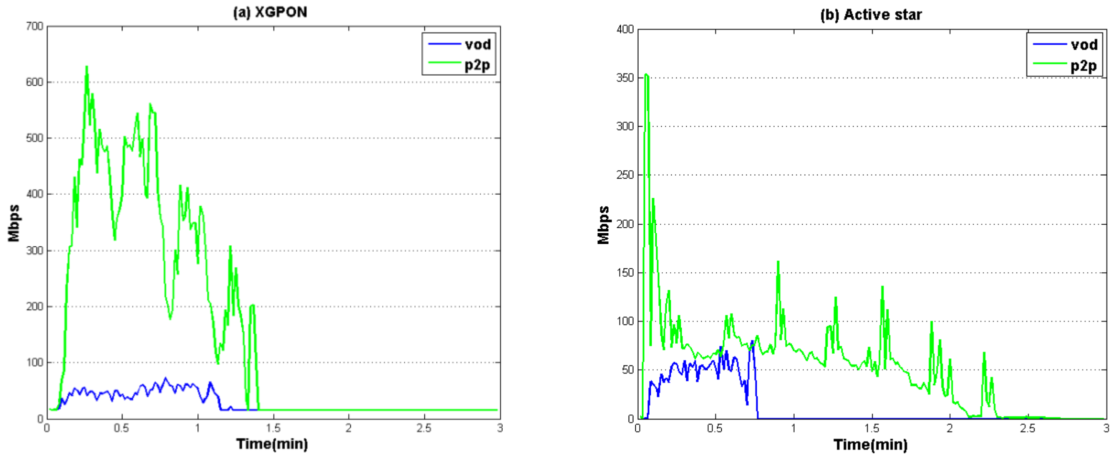


Figure 4-12: Upstream bandwidth usage on the feeder fibre for (a) XGPON and (b) Active star.

Our simulation results confirm a huge potential saving on bandwidth in the aggregation links between the CANs and routers by pushing the traffic more towards end users via localizing the traffic inside the same service area. Although it should be noted that some traffic will be shifted to the upstream direction instead, which is not a problem due to the fact that this upstream resource is available and lowly utilized in the access networks.

4.2.4 Peering statistics

Looking at the end user distribution in the access network, we estimate the probability of peering with a node in another region, if all nodes are considered equal. The calculation shows that the peering probability increases with the distance, as can be seen in Table 4. It means that without having a specific method for locality awareness, traffic in the aggregation network will be directly affected by the one in access segment.

Table 4: Peering statistics without locality-aware scheme.

	Region 0	Region 1	Region 2	Region 3	Total
Calculations	31/768	(3*32)/768	(2*4*32)/768	(3*4*32)/768	1
Percentage	4%	12.5%	33.5%	50%	100%

Table 5 represents the peering statistics from the simulations for the second scenario. It can be observed that there is a huge difference caused by the locality-aware algorithm. There is no rising trend by increasing the distance. In both PON and AON architectures more than 90% of the P2P traffic stay within the same service area covered by a single CAN. The results also show that no P2P traffic passes the POP and hence is localized.

Table 5: Peering statistics per region for each architecture

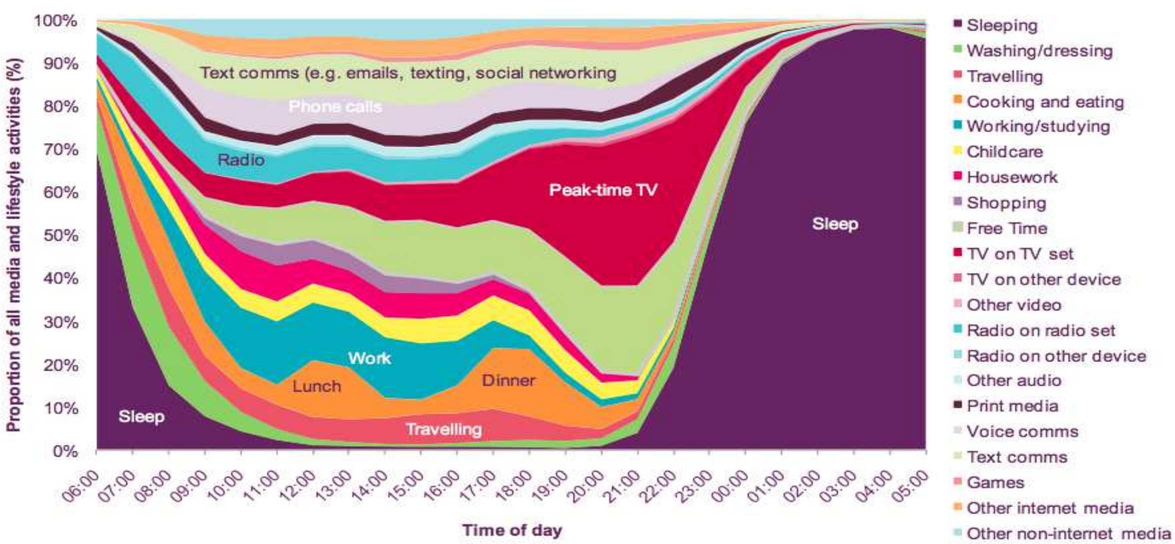
	Region 0	Region 1	Region 2	Region 3	Total
10GPON	97%		3%	0	100%
Active star	69.6%	25.5%	4.9%	0	100%

4.3 Caching of TV Services

The previous sections have demonstrated the benefit that may be expected by enabling clients to connect to local sources of content, avoiding the costs of bandwidth associated with the aggregation and peering networks and potentially delaying upgrades within the operators own network. Within this section we will show how local caching of catch-up TV services may be employed to further reduce costs.

The survey undertaken in WP6 and reported in D6.2 has attempted to identify services that may benefit from delivery over NGOA, and that may drive bandwidth increases toward the 500Mbps OASE target. One of the identified services is delivery of video content.

Online streaming video services are already extremely popular. In the United States, the TV + Movie streaming service Netflix already accounts for 33% of downstream traffic during peak hours. Including other streaming services, this number increases to 60% [32]. This number is likely to increase, with users drawn to the on-demand style of content (as opposed to the traditional “channel” delivery mechanisms through cable or satellite). Figure 4-13 below shows the results of an Ofcom survey to chart the “digital day” – the use of services at various times for the population at large. Peak-time TV represents a large portion of daily activity, with almost one third of respondents saying they engaged in this activity. NGOA provides sufficient bandwidth to deliver this content and this could therefore prove be a significant source of bandwidth demand in the network.



Source: Ofcom research, base = all respondent days: 7966

Figure 4-13: The Digital Day

Optimising this stream is consequently likely to be of high importance to NGOA operators looking to ensure QoS and reduce the costs of their network. However, with the increase in popularity of on-demand services and user-generated content (such as video streaming sites like Youtube) it is in no way certain that popular programmes will be provided through traditional “channels”, which provide a convenient limitation on the variety of content available. Is it possible to predict high-demand video content that may be cached, independent of its origin? In order to evaluate how this may be achieved, we will be analysing traffic data from a UK catch-up TV service provided by the BBC called the iPlayer[1]. In this section, we

[1] This data was collected via a BBC internal data warehouse (BBC iStats). The methodology adheres to industry standard guidelines as defined by JICWEBs and ABCe, with the exception that the BBC data is based on a 25% sample of users and not 100%. The BBC are working towards 100% sample over the coming months.

analyse 22 months of data from September 2010 up to and including September 2012. Data for October, November and December 2011 is unavailable as it was not reported.

The data comprises the total requests per month, as well as the top 10 streamed programmes that month and their viewership. The growth of requests per month, in millions of requests, over time can be seen in Figure 4-14 below. Overlaid is a linear model fitted using an Ordinary Least Squares estimator. The shaded channel gives the 95% confidence interval of the estimation. It is clear from the graph that the traffic is growing steadily, with the current traffic of around 110M requests/month being almost triple the initial value reported in January 2009. It is also interesting to note that the growth in traffic is highly linear, in contrast to the exponential growth reported in other areas of the network. The fitted linear model is significant at the 0.001 confidence level, and suggests that the traffic grows by 2.2 million requests per month. At this rate we might expect to see around 350M requests per month in 2020, rising to 550M in 2030.

It is clear therefore that there is already a significant amount of traffic on this (and other) streaming and catch-up TV services, and growth is continuing apace. However, it may be possible to mitigate the effects of the increasing traffic demand by utilising optimally-placed caches at points in the network. Furthermore, the choice of network technology will affect the places at which a cache may be deployed, and will therefore provide a differentiating factor between network technologies.

4.3.1 Cache benefits

The iPlayer service allows access to content that has already been broadcast on one of the BBC's terrestrial television channels. The service is not utilised for delivery of live content. This means that there is the possibility to pre-distribute popular television (and radio) shows and movies to content caches before they are broadcast. However, there is limited space in the caches and it is important to efficiently use their space in order to reduce the bandwidth demand to the greatest extent. Ideally, this would be achievable without significant operator intervention or knowledge of the series on offer, in order to simplify maintenance. In this section, we will show how such services may be identified automatically.

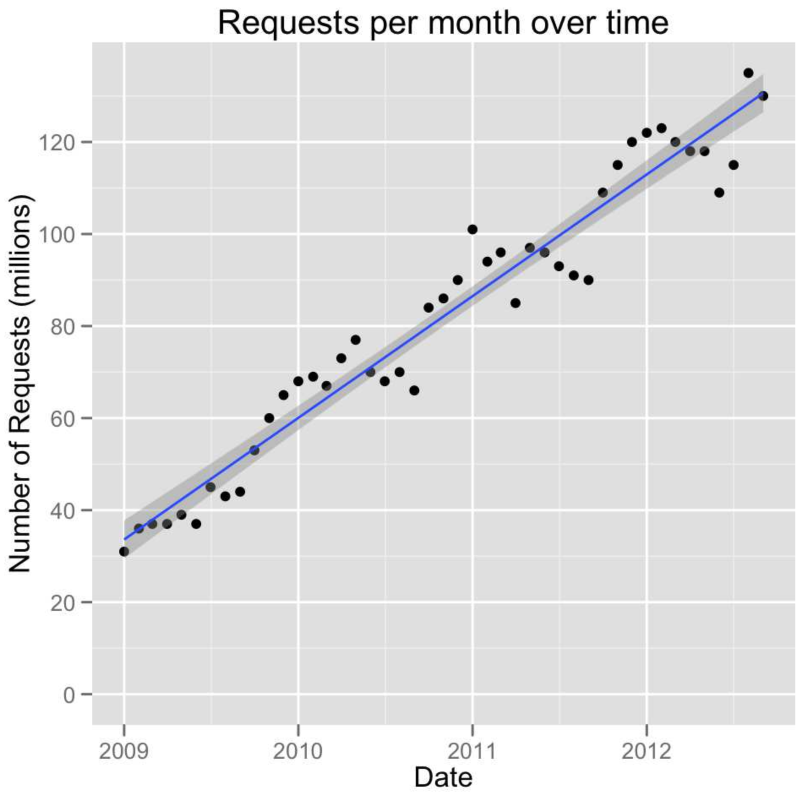


Figure 4-14: The growth of iPlayer traffic, shown by requests per month

The data available comprises the viewing figures for the top 20 shows each month for 22 months. This data was imported and parsed in the R statistical package. Shows which occurred only once in the dataset were removed. These were mostly films, with a selection of sporting events. While these pose problems for demand prediction (as there is limited prior information on which to base a decision), they are frequently know of ahead of time. Sporting events and competitions, for example, are easily identified ahead of time.

In order for a caching algorithm to be able to identify content to distribute to caches, it must be able to accurately predict the demand for content based on past experience (ideally with shows that are significant sources of traffic). If this is random, then the algorithm will be unable to accurately identify popular shows. It is interesting, therefore, to examine to what extent the popularity of shows is invariant. The graph in Figure 4-15 below provides a box-and-whiskers plot showing the distribution of viewers-per-episode of the shows in the dataset.

It is pleasing to note that the distribution of viewing numbers for each show is quite tight for most shows Russell Howard's Good News, for example, is quite invariant – any particular episode has similar viewing numbers to any other. This allows for simple estimation of future demand. EastEnders, a popular British soap opera, demonstrates a looser distribution with two suspected outliers noted. These are likely special episodes which resolve plotlines, or seasonal episodes which typically draw higher viewing numbers. This looser distribution makes it more-difficult to predict. Come Fly with Me shows a very loose distribution.

In general, however, despite variation between shows, all the results could be utilized to predict future demand (in terms of number of viewers). However, we have thus far not identified shows which are sources of significant traffic – shows are of little use if they are predictable but cause little network load. The total viewing numbers, by show, can be seen in Figure 4-16 below. These reflect national demand as they are a result of a national survey with no particular geographic focus. It may therefore be reasonable to expect some minor differences at a local level, caused by differences in socio-economic status, but our data does not provide any insight into this. It may be an interesting area of future study.

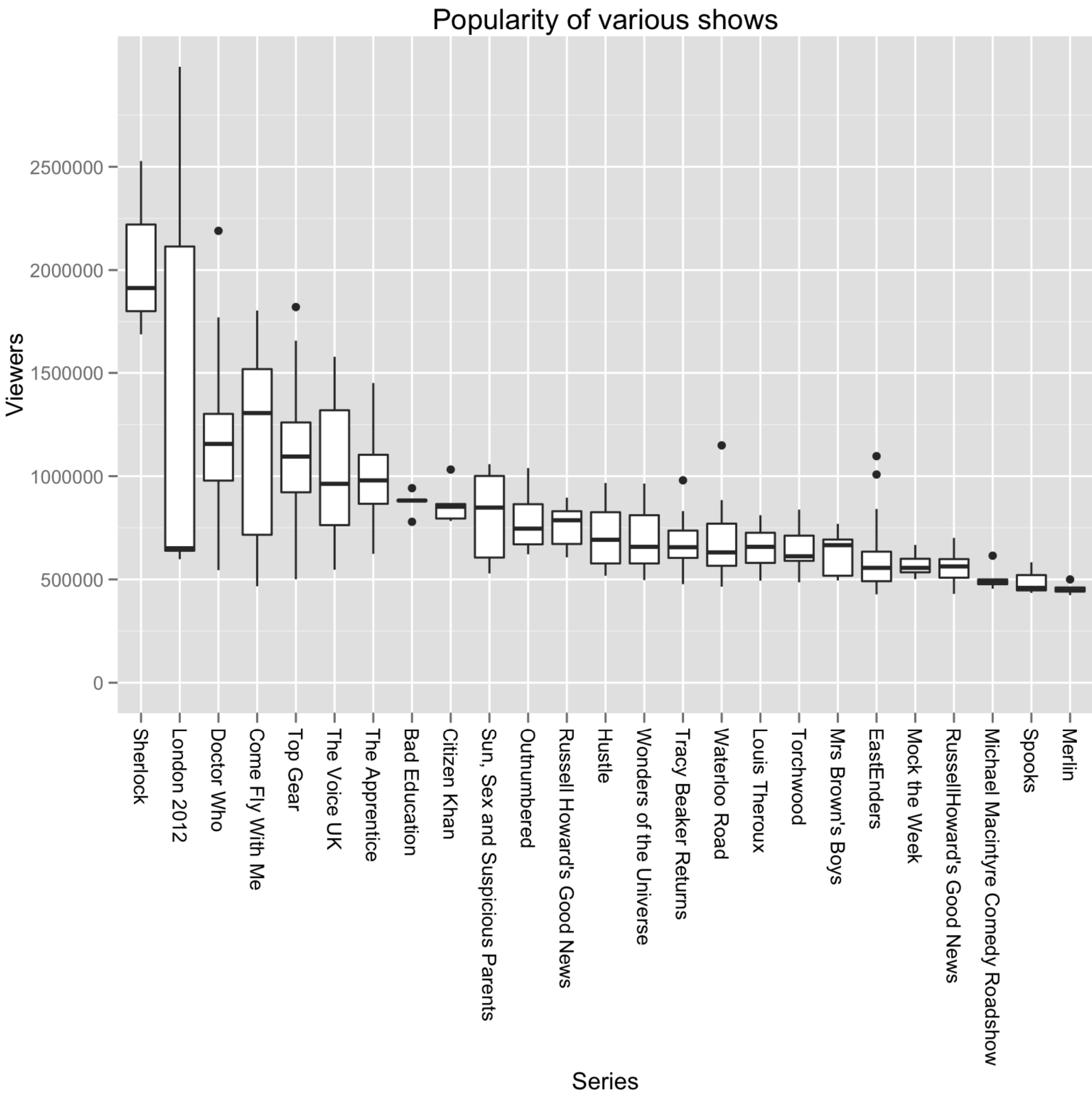


Figure 4-15: The popularity distribution of various shows.

The results here are quite pleasing. EastEnders, previously identified as relatively well-behaved, is also a source of significant traffic. It therefore represents a show which can be accurately predicted, and that will reduce network traffic significantly. In January 2010, EastEnders accounted for 40.4% of the peak time viewing audience. Caching this programme, then, is likely to be both simple to do and achieve high benefit, almost halving the bandwidth demand from IPTV services for that time segment.

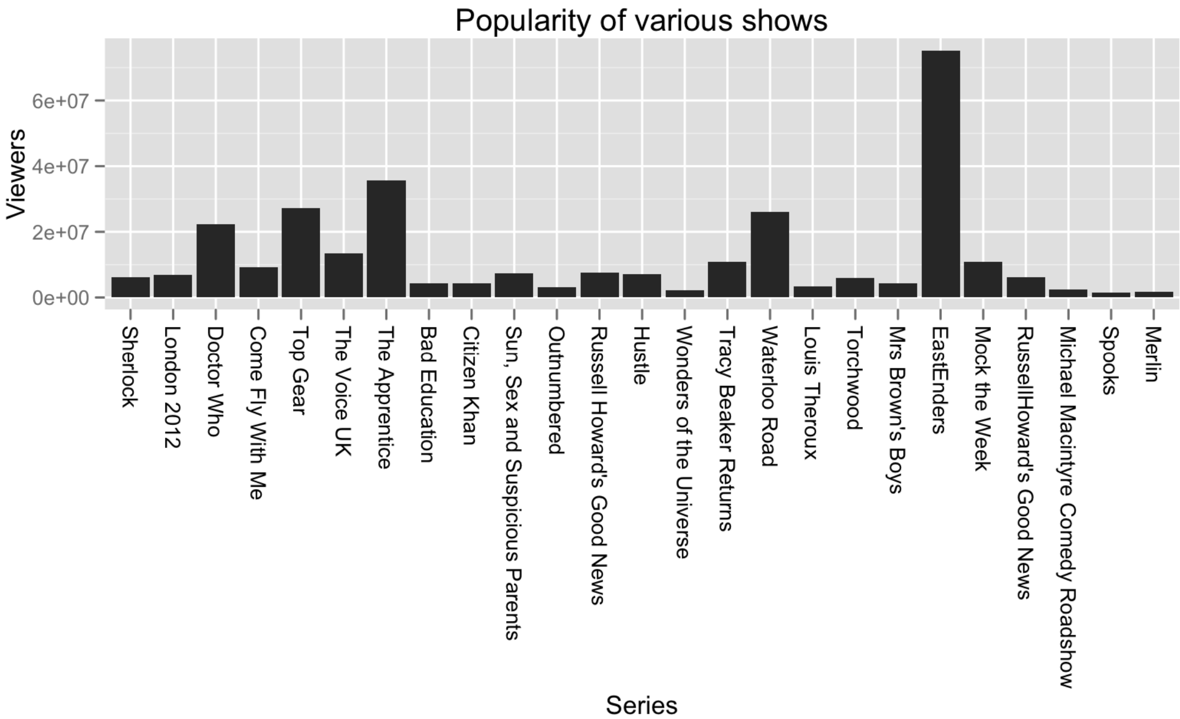


Figure 4-16: Total viewing figures.

In general, pre-caching of content currently available through the 5 major channels in the UK would provide significant advantages. The audience of BB1, BBC2, ITV, Channel 4 and Channel 5 when taken together between 19:00 and 19:30 on 5th May 2010 accounted for 71.6% of the entire viewing audience. This would result in a commensurate decrease in the bandwidth demand at this time for a service which has already been identified as high-bandwidth, high-quality requirement, and watched by approximately a third of the populous at this peak time.

4.3.2 Cache Locations + Technologies

The locations available to install caches depend on the network architecture, and can be seen in the diagram in Figure 4-17. The active star AON case, utilising powered cabinets containing active Ethernet switches, gives the possibility of providing caches at the extreme edge of the network. Due to their placement, such caches would cover only a small number of households (a few hundred at most) but this may be offset by the potential to utilise lower-performance hardware in these locations due to the lower bandwidth demand.

PON variants will depend on the degree of node consolidation being considered. For the "traditional" scenario utilizing existing local offices, this may provide a balance between cache coverage and the performance of the necessary hardware (and therefore system cost). The highly-consolidated scenario implies caches serving a large number of customers, but at the cost of extremely high bandwidth demand.

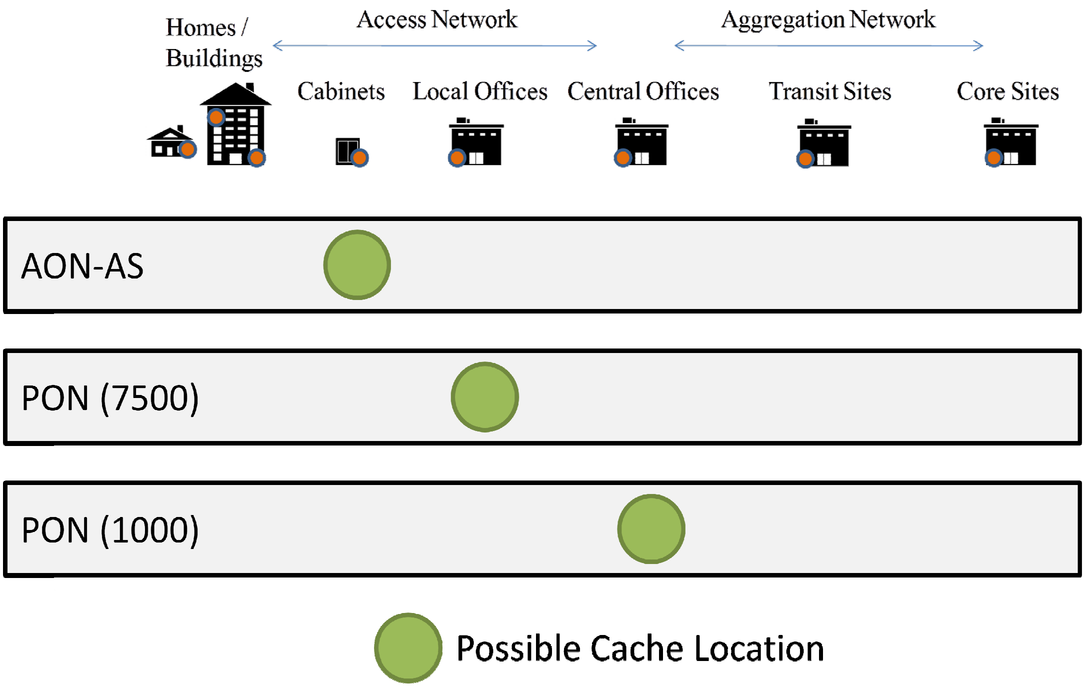


Figure 4-17: Cache location as a differentiating factor between variants.

The active star scenario may have additional benefits, as different shows are frequently targeted at different demographics which are affected by geographical area, allowing an optimization of content that is of local interest.

4.3.3 Conclusion

Streaming video services are likely to be the largest source of traffic in NGOA networks. The high bandwidth available to end-users is likely to increase the appeal of on-demand services to end-users, and we would therefore expect to see some migration away from the traditional "channel" model of content delivery. However, this does not mean that content will be unpredictable. Soap operas will still become available at certain times. Movies will be released on given dates. Therefore, the potential to optimise access to these resources at these times is valuable, especially if it can be done automatically away from the traditional "channel" model. Within this section we have shown that TV shows have consistent viewing figures, and this lends itself well to predictions of future demand and automatic optimisation through caching close to the user, bypassing the aggregation and peering networks. This is an important result as it opens the door to automated caching minimising the need for operator involvement and maximising cost savings and user experience.

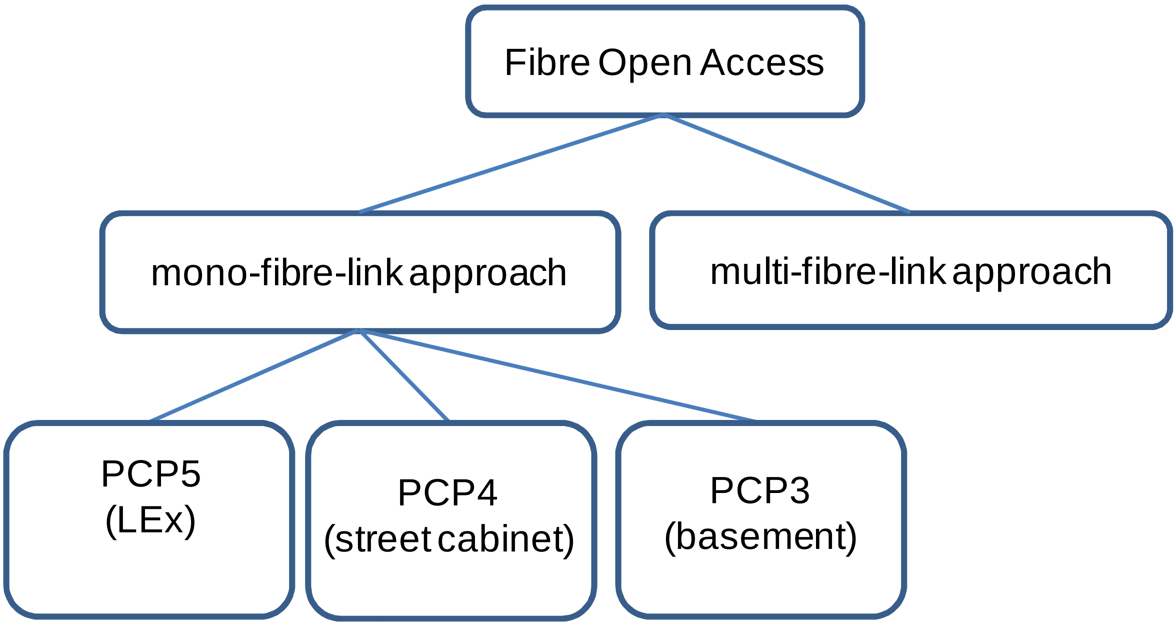
5. Open access architectural configurations

This chapter will begin with a sub-chapter covering the implications imposed on the physical infrastructure by the different higher layer architectures. The subsequent sub-chapters then follow the same structure as previous deliverables (e.g. D3.1 and D.32), i.e. focusing on WDM PON, hybrid PON, two stage WDM PON and NG AON, but modified with the purpose of adding an open access dimension. In doing so, we keep the familiarity of previous work while allowing for a higher focus on the fibre infrastructure.

5.1 Fibre Open Access

5.1.1 Introduction

In principle, physical infrastructure providers can technically provide access to single or multiple optical fibres at different physical connection points. In this chapter a distinction is made between fibre open access with mono-fibre or multi-fibre link approach as shown in the diagram below.



Fibre open access with mono-fibre approach is required in fibre deployments where there is only one dedicated fibre between PCP2 and a PCP enabling access to the fibre. The mono fibre definition is made within the OASE context which has a WP2 requirement on single fibre access. A more general definition would include architectures that have a dual fibre link in the access, e.g. dual fibre AON. Section 5.1.3 describes three fibre open access approaches which differ in the location of open access interface (PCP5, PCP4 or PCP3).

Fibre open access with multi-fibre approach addresses a fibre deployment where several fibres are available at each end-user-site.

5.1.2 *Fibre OA with multi-fibre approach*

Fibre open access with multi-fibre approach allows open access for network providers with or without network infrastructure in the access/aggregation network. The basic requirement of this solution is the availability of multiple optical fibres per end-user-site. This multi-fibre approach enables the support of several NP networks in parallel.

Figure 5-1 shows a schematic overview of fibre open access with multi-fibre approach. It shows that several optical fibres are terminated by fibre sockets at PCP2. A network provider has access to one of these fibres at the optical distribution frame that is located at the PCP enabling fibre access. Theoretically the end-user is able to get access to two or more network providers in parallel. The ODF is managed and controlled by the PIP. In addition, the network provider may use the fibre access offered (dark fibre) by a PIP in order to reach any PCP where fibre access is feasible. The PIP may provide co-location space to the NPs at different PCPs that could be used for installing additional system equipment (e.g. a power-splitter, AWG, Ethernet switch).

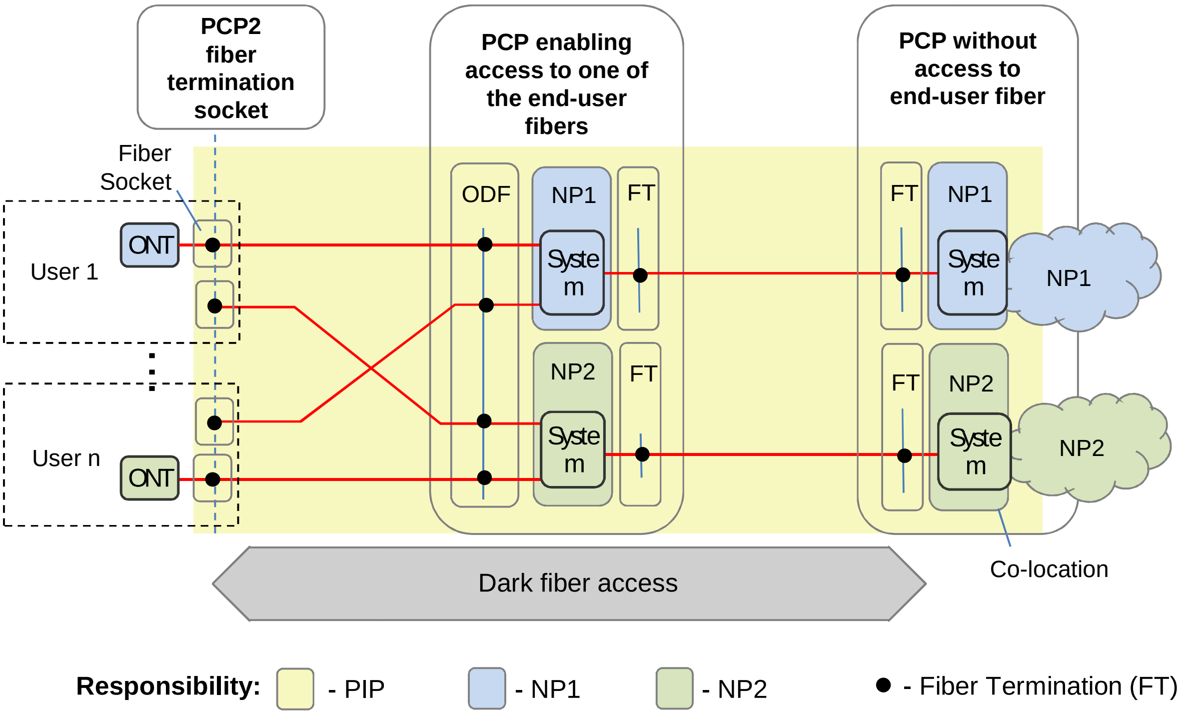


Figure 5-1: Schematically overview of fibre open access with multi-fibre approach

The concept of fibre open access with multi-fibre approach is pursued by some regulatory authorities and operators, for example, in France [34] and Switzerland [35]. Figure 5-2 shows the principle of a physical implementation that is realised by Swisscom in Switzerland. Each household is provided by 4 fibres. The fibres are terminated at a manhole in the field that is accessible by several network providers.

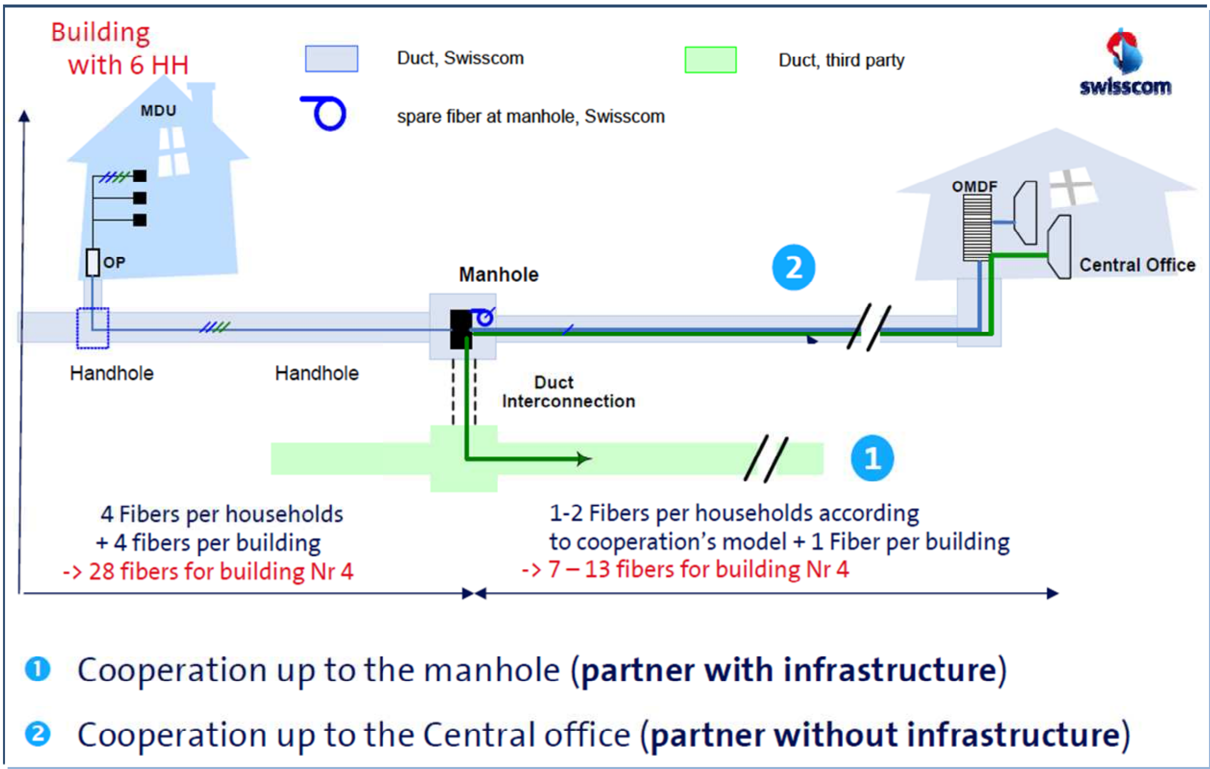


Figure 5-2: Swiss open fibre access model [36]

In principle, all NGOA architectures support this fibre open access approach. However, fibre open access with multi-fibre link causes a very high level of infrastructure duplication in the access network which drives increasing total cost of ownership for all network providers.

5.1.3 Fibre OA with mono-fibre approach

As shown in Figure 5-3, this open access scheme can be realized between PCP2 and any PCP enabling access to a dedicated end-user fibre. This end-user fibre is terminated by a fibre socket at PCP2 and an optical distribution frame at the PCP enabling access to the single fibre. The ODF is managed by the PIP and allows a manual access. In the case of dark fibre access the network provider uses the fibre access offered (dark fibre) by a PIP in order to reach any PCP where fibre open access is feasible.

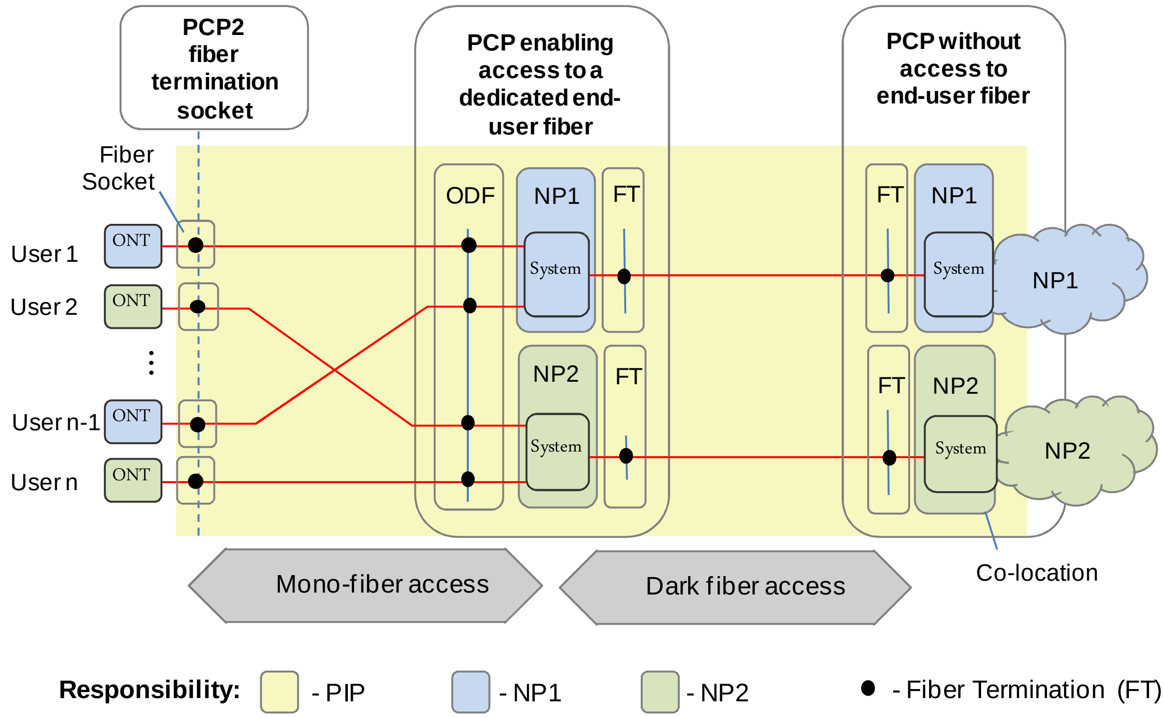


Figure 5-3: Schematically overview of fibre open access with mono-fibre access and dark fibre access

Fibre OA with PCP5 (LEx) interface:
In a co-location space of PCP5 the network provider gets access to a dedicated end-user fibre at the ODF managed by the PIP. This access link is patched from the ODF to NGOA system technology managed by the NP. In addition, the NP may use dark fibres in order to connect the system equipment at PCP5 with system components at other PCP locations.

In principle, all NGOA architectures support this open access approach. However, locating the interface at PCP5 is most qualified for AON home-run since all PON architectures as well as the AON active star approaches target a fibre concentration as closely as possible to the end-user location.

Fibre OA with PCP4 (street cabinet) interface:
Similar to the PCP5 interface the NP gets access to the dedicated end-user fibre at the ODF that is managed by PIP. But in this case the open access is realized closer to the end-user at the street cabinet location. The NP may rent co-location space at PCP4 in order to install additional system equipment (e.g. power splitters, AWG, Ethernet switches). The PIP may provide dark fibres to the NP in order to connect the system technology at PCP4 with equipment at other PCP locations.

The PCP4 interface is suitable for all PON architectures as well as the AON active star approaches. The street cabinet is a typical concentration point in current PON deployments with fibre rich approach (at last one fibre per end-user between PCP2 and PCP4).

Fibre OA with PCP3 (basement) interface:
This fibre open access approach addresses the interface at the in-house wiring. The NP has access to a dedicated end-user fibre between PCP2 and PCP3. Similar to the previously described fibre OA approaches the NP may rent co-location space at PCP3 in order to install additional system equipment (e.g. power splitters, AWG, Ethernet switches). In addition, the

NP may use dark fibres in order to connect the system equipment at PCP3 with system components at other PCP locations.

The PCP3 interface is most suitable for the AON active star architecture with an Ethernet switch at PCP3. In addition, it is suitable for PON deployments in large buildings with a number of apartments in the range of the PON split ratio.

5.1.4 Fibre OA with WDM-PON architectures

This section discusses some aspects of fibre open access for the WDM-PON architectures WR-WDM-PON, WS-WDM-PON and UDWDM-PON.

FIBRE OA WITH WR-WDM-PON

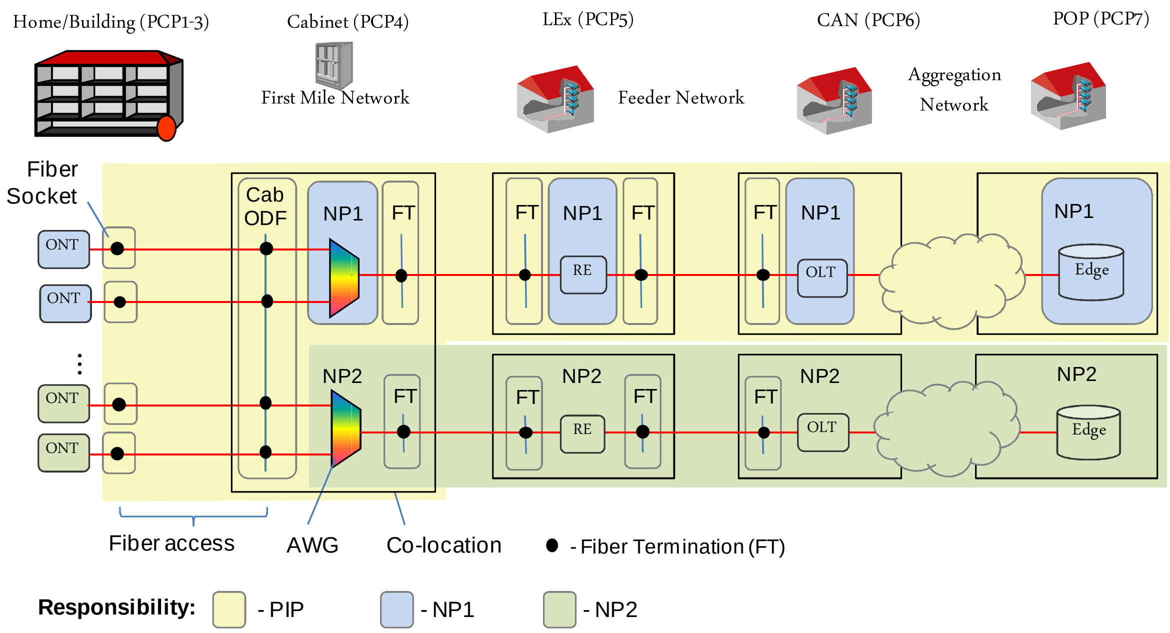


Figure 5-4: WR-WDM-PON fibre OA scenarios (examples)

Figure 5-4 shows an example of fibre open access under the WR-WDM-PON variant for two scenarios which differ in the degree of fibre sharing. The **maximum sharing scenario** refers to the case where the NP (NP1 in blue) has no self-owned fibre infrastructure in the access/aggregation network. In contrast to the maximum sharing scenario the **minimum sharing scenario** aims at the case where the NP (NP2 in green) only needs access to the last fibre link between PCP2 and the PCP enabling fibre access.

Maximum sharing scenario:

- PIP provides co-location at PCP4, PCP6 and PCP7 (PCP5 optionally)
    - NP uses the co-location at PCP4 for installing AWGs
    - PCP5 co-location can be used for reach extender technology
    - PCP6 co-location is used for installing the OLT
    - PCP7 co-location enables access to the aggregation network
- PIP provides fibre open access between PCP2 and PCP4

- NP1 rents dark fibres between PCP4 and PCP6 from PIP and transport capacity from aggregation network provider between PCP6 and PCP7 (dark fibres between PCP6 and PCP7 optionally)

Minimum sharing scenario:

- PIP only provides co-location at PCP4 in order to install AWGs
- PIP provides fibre open access between PCP2 and PCP4
- NP2 utilizes own fibres and facilities (e.g. buildings) between PCP4 and PCP7

Fibre OA with WS-WDM-PON

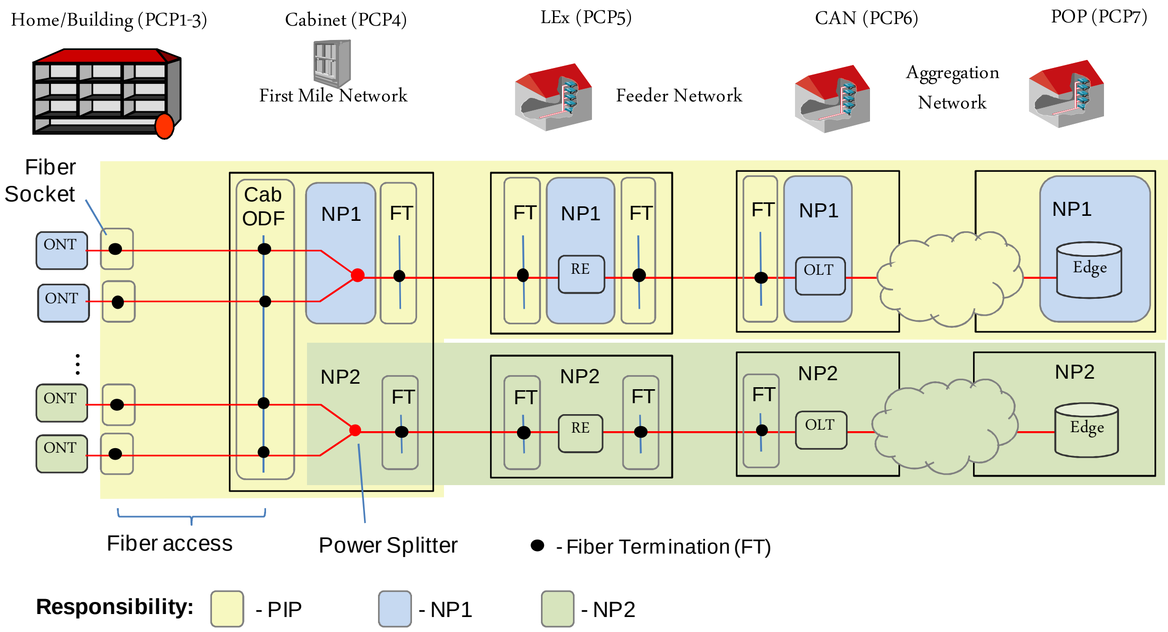


Figure 5-5: WS-WDM-PON fibre OA scenarios (examples)

Figure 5-5 shows an example of fibre open access with PCP4 (street cabinet) interface for the WS-WDM-PON variant in the maximum and minimum sharing scenario:

- Maximum sharing scenario:
  - PIP provides co-location at PCP4, PCP6 and PCP7 (PCP5 optionally)
    - NP uses the co-location at PCP4 for installing power-splitters
    - PCP5 co-location can be used for reach extender technology
    - PCP6 co-location is used for installing the OLT
    - PCP7 co-location enables access to the aggregation network
  - PIP provides fibre open access between PCP2 and PCP4
  - NP1 rents dark fibres between PCP4 and PCP6 from PIP and transport capacity from aggregation network provider between PCP6 and PCP7 (dark fibres between PCP6 and PCP7 optionally)
- Minimum sharing scenario:
  - PIP only provides co-location at PCP4 in order to install Power-splitters
  - PIP provides fibre open access between PCP2 and PCP4
  - NP2 utilizes own fibres and facilities (e.g. buildings) between PCP4 and PCP7

FIBRE OA WITH UDWDM-PON

Fibre open access with UDWDM-PON is similar to the hybrid WDM/TDM-PON or WS-WDM PON solutions.

5.1.5 Fibre OA with Hybrid WDM/TDM-PON

Figure 5-6 shows an example of fibre open access with PCP4 (street cabinet) interface for Hybrid WDM/TDM-PON in the maximum and minimum sharing scenario.

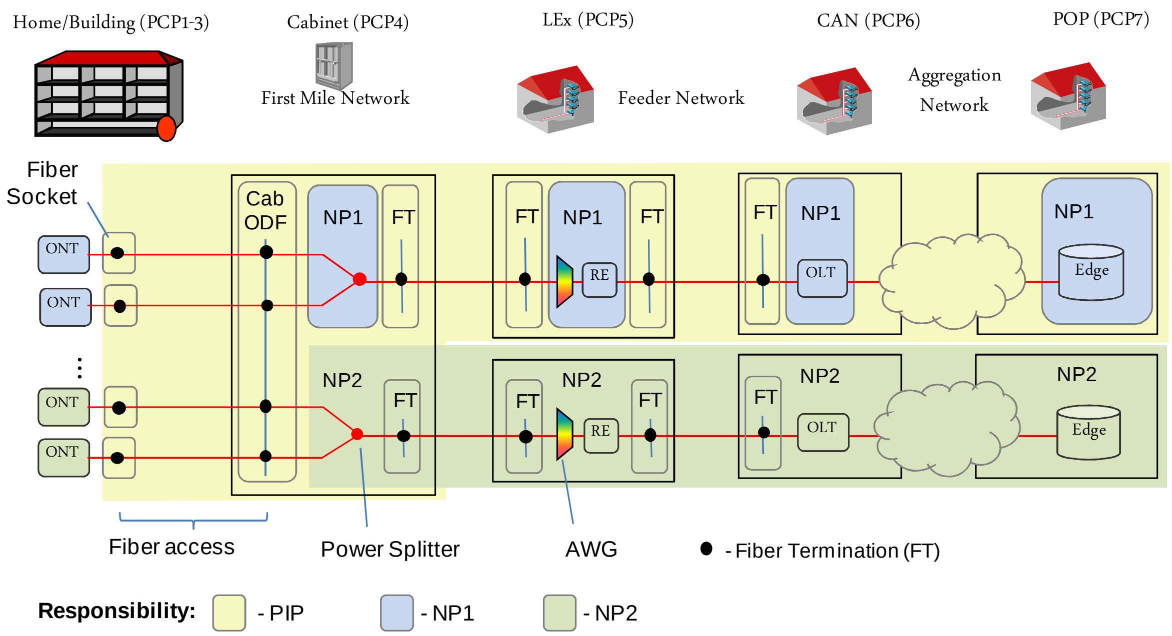


Figure 5-6: Hybrid WDM/TDM-PON fibre OA scenarios (examples)

- Maximum sharing scenario:
  - PIP provides co-location at PCP4, PCP5, PCP6 and PCP7
    - NP uses the co-location at PCP4 for installing power-splitters
    - NP uses the co-location at PCP5 for installing AWGs and optionally reach extenders
    - PCP6 co-location is used for installing the OLT
    - PCP7 co-location enables access to the aggregation network
  - PIP provides fibre open access between PCP2 and PCP4
  - NP1 rents dark fibres between PCP4 and PCP6 from PIP and transport capacity from aggregation network provider between PCP6 and PCP7 (dark fibres between PCP6 and PCP7 optionally)
- Minimum sharing scenario:
  - PIP only provides co-location at PCP4 in order to install power-splitters
  - PIP provides fibre open access between PCP2 and PCP4
  - NP2 utilizes own fibres and facilities (e.g. buildings) between PCP4 and PCP7

5.1.6 Fibre OA with Two-stage WDM-PON

Figure 5-7 shows an example of fibre open access with PCP4 (street cabinet) interface for Two-stage WDM-PON in the maximum and minimum sharing scenario.

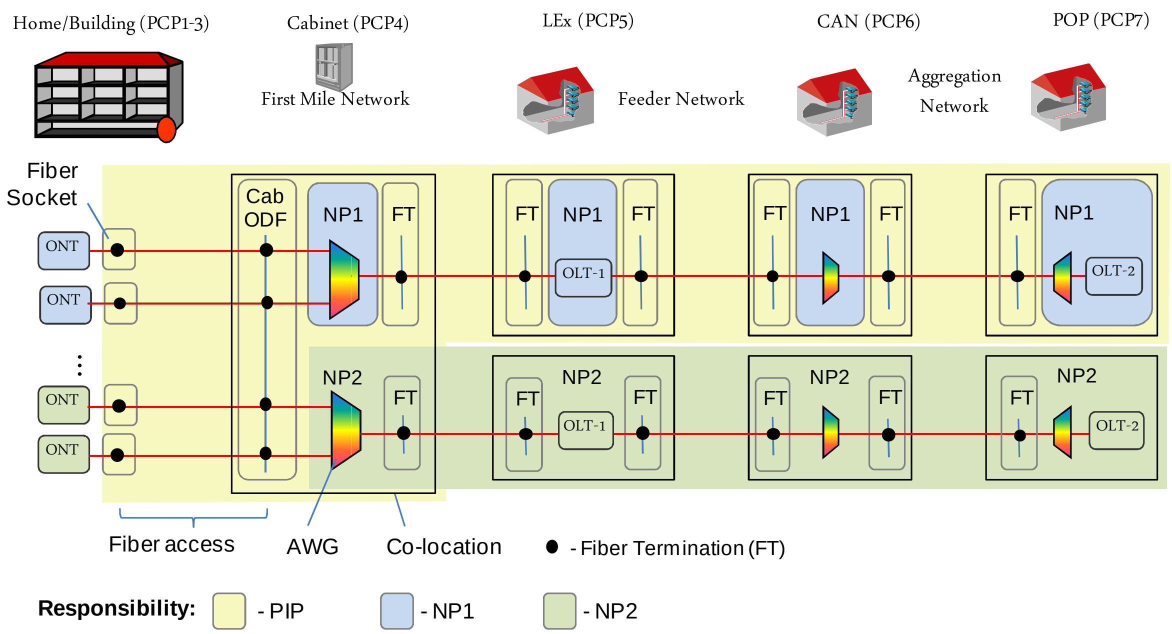


Figure 5-7: Two-stage WDM-PON fibre OA scenarios (examples)

- Maximum sharing scenario:
  - PIP provides co-location at PCP4, PCP5, PCP6 and PCP7
    - NP uses the co-location at PCP4 for installing power-splitters
    - NP uses the co-location at PCP5 for installing OLT-1
    - PCP6 co-location is used for feeder fibre distribution via AWG
    - PCP7 co-location is used for installing the OLT-2
  - PIP provides fibre open access between PCP2 and PCP4
  - NP1 rents dark fibres between PCP4 and PCP7 from PIP
- Minimum sharing scenario:
  - PIP only provides co-location at PCP4 in order to install AWGs
  - PIP provides fibre open access between PCP2 and PCP4
  - NP2 utilizes own fibres and facilities (e.g. buildings) between PCP4 and PCP7

5.1.7 Fibre OA with AON

Figure 5-8 shows an example of fibre open access with PCP5 (LEx) interface for AON home-run in the maximum and minimum sharing scenario.

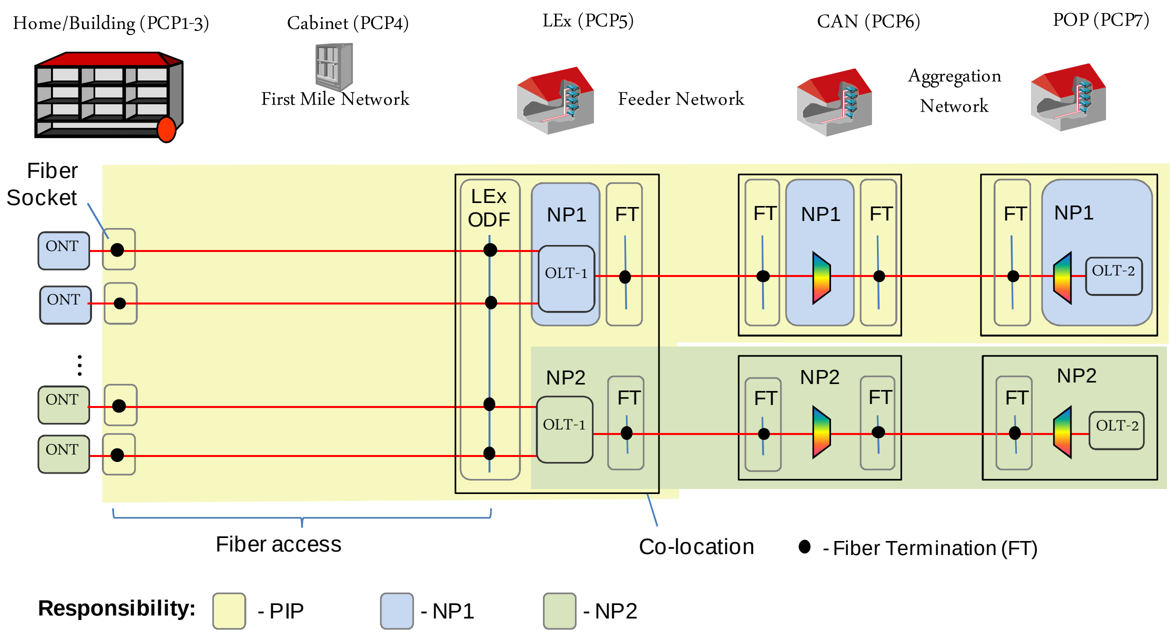


Figure 5-8: AON active star fibre OA scenarios (examples)

- Maximum sharing scenario:
  - PIP provides co-location at PCP5, PCP6 and PCP7
    - NP uses the co-location at PCP5 for installing OLT-1 (Ethernet switch)
    - PCP6 co-location is used for feeder fibre distribution via AWG
    - PCP7 co-location is used for installing the OLT-2
  - PIP provides fibre open access between PCP2 and PCP5
  - NP1 rents dark fibres between PCP5 and PCP7
- Minimum sharing scenario:
  - PIP only provides co-location at PCP5 in order to install OLT-1
  - PIP provides fibre open access between PCP2 and PCP5
  - NP2 utilizes own fibres and facilities (e.g. buildings) between PCP5 and PCP7

In the following sub-chapters the focus will be on how to utilise certain architectures in order to open up the infrastructure. The figures in these chapters will focus on OA aspects of the architecture and not infrastructural elements like ODFs unless it is a vital part of opening up the architecture. Please refer back to this chapter for a more detailed discussion on the passive infrastructure, e.g. ODF location at points of unbundling.

5.2 WDM-PON

5.2.1 Data plane architecture

This sections starts with an important note about highly integrated OLTs and afterwards different possibilities to open the wavelength layer (if dedicated wavelength transceivers are used, instead of highly integrated ones) are presented.

GENERAL CONSIDERATIONS

This section refers to Wavelength-Routed WDM-PON only, mainly for reasons of systems CapEx and reach. As a recap (from D3.1), Figure 5-9 shows several WR-WDM-PON options and their assignment to the reference architecture points PCP2-7. The options shown here (line protection to PCP4, optional RE, last filter stage in PCP4 vs. PCP3) do not influence the following discussion. If different configurations of WR-WDM-PON are chosen, e.g., one with an OLT located in PCP5 for whatever reason, the discussion results change accordingly.

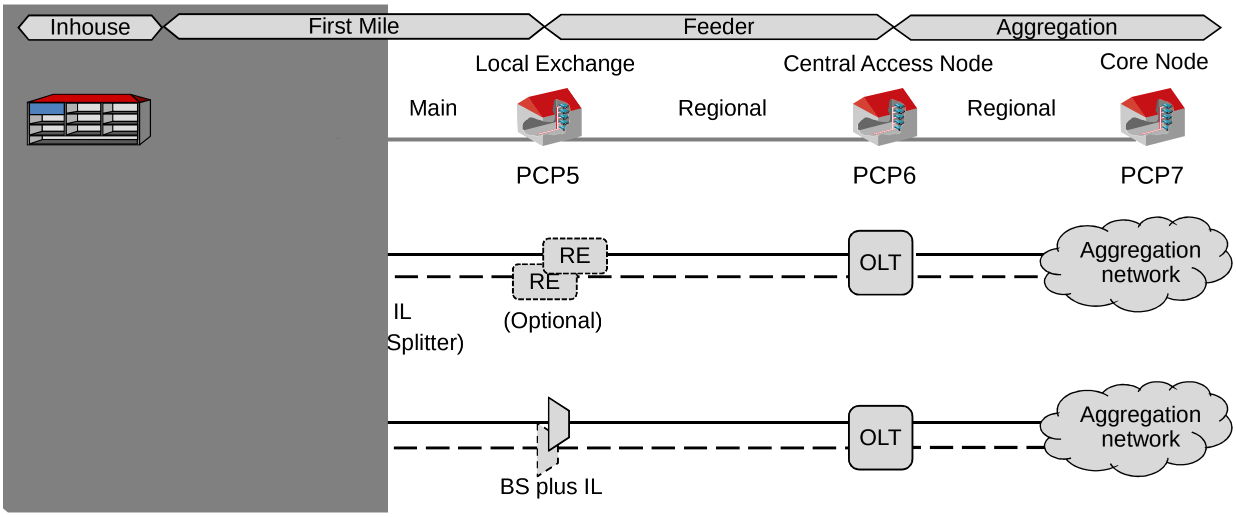


Figure 5-9: Recap: WR-WDM-PON architecture.

From Figure 5-9, one can derive where access is generally possible, and on what level. The important question for this system variant is if wavelength access is feasible and if so, where. Generally, wavelength access is possible in PCPs 1/2/3, 4, 5 (given there is a filter in PCP5, see lower part of Figure 5-9), and 6. However, it is our strong belief that such access will most probably not be implemented for reasons of CapEx and form factor. In order to minimise both of these, the WR-WDM-PON OLT (and the same applies for WS-WDM-PON and UDWDM-PON) has to be integrated to the highest possible degree, ideally in 64/80/96-channels (the final number is irrelevant) PICs (Photonic Integrated Circuits). These PICs will directly be connected, most likely via $N\times10$G backplanes in the OLT shelf, to aggregation switches. *It is important to note that the highly integrated PIC-based WDM-PON OLT is not open for wavelength access*. Individual wavelengths could be added/dropped in PCP6 outside the PIC, but this solution adds insertion loss and is not economically viable on a broader scale. In addition, technical problems associated with the ONU wavelength tuning or assignment make it highly difficult to provide wavelength access. This holds for seeded/reflective WDM-PON (this needs a *centralized* broadband seed), as well as for tuneable-laser-based WDM-PON (this needs *central* wavelength management). These aspects make it *de-facto impossible to open the PON at passive filters in PCP4 and PCP5*. Therefore, a highly integrated WDM-PON will allow open access only on bit-stream level on Layers 2 and/or 3. The resulting open-access scheme is shown in Figure 5-10.

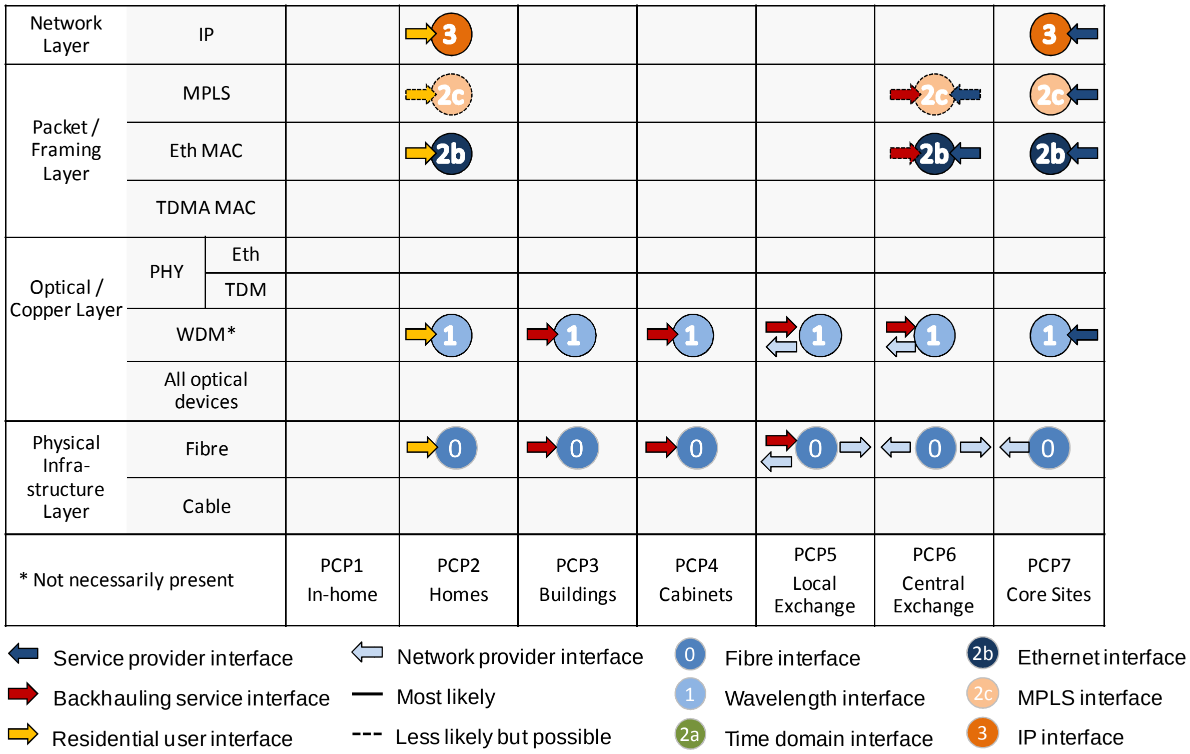


Figure 5-10: Open access on different layers and PCPs for WR-WDM-PON

It is relevant to note that wavelength access could be made possible. However, next to high CapEx, added insertion loss (due to the use of a power splitter in combining the tuneable lasers) and difficulties with the wavelength control/assignment, this will also increase the energy consumption of such an approach. This increase results from using dedicated wavelength transceivers instead of integrated multi-channel PICs in the OLT.

In the following sub-chapters the focus will be on how to utilise certain architectures in order to open up the infrastructure. The figures in these chapters will focus on OA aspects of the architecture and not infrastructural elements like ODFs unless it is a vital part of opening up the architecture. For a more detailed discussion on the passive infrastructure, e.g. ODF location at points of unbundling, please refer to chapter 5.1.

WAVELENGTH OA ARCHITECTURES (WR-WDM-PON)

We indicated six different options for offering wavelength open access in WR-WDM-PON, as discussed below.

Feeder Fibre based wavelength open access

General considerations: In this configuration, since each NP/SP has a separate feeder fibre, it is referred to as feeder fibre based Open Access, which WDM-PON easily. Figure 5-11 depicts a scenario for the feeder fibre based open access.

Architectural considerations: The OLT requires N+M wavelengths. If feeder fibres are combined, then NP/SP has to share spectrum leading to complexities.

Techno-economic & business aspects: For offering open access, additional feeder fibres (as # feeder fibres = # NPs) required. At PCP4, an M:N AWG is required instead of a 1:N AWG. At PCP2-3, tuneable ONUs are assumed, so that the customers can tune to the right wavelength to select the NP/SP. However, the additional cost and power consumption per user will be high due to the low fan out.

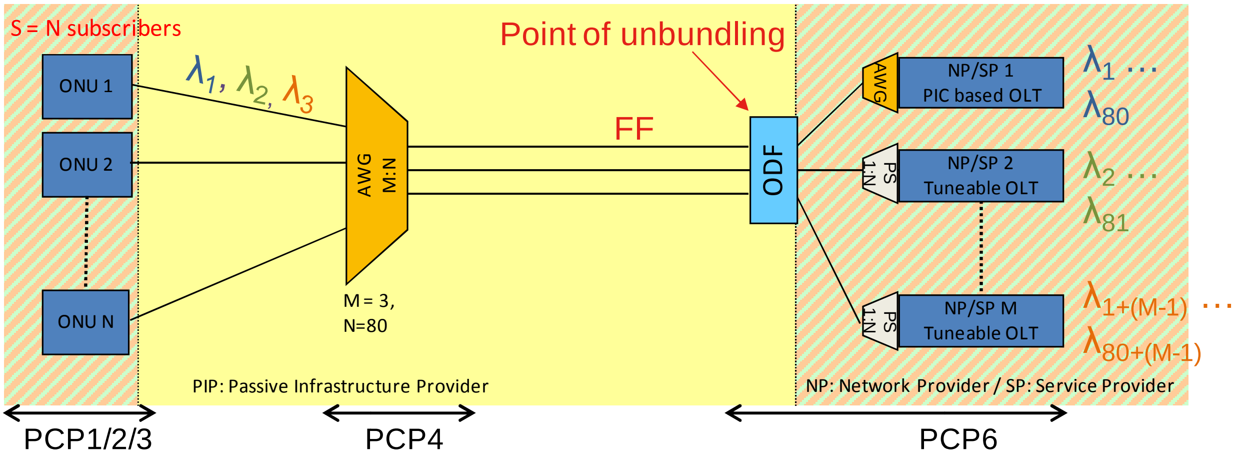


Figure 5-11: Feeder Fibre based wavelength open access in WR-WDM-PON

Manual wavelength open access

General considerations: In this configuration, a manual patch panel is used to provide Open Access. As an alternative, fibre robots could be used to minimise manual error in patching. Figure 5-12 depicts a scenario for a manual wavelength open access scenario.

Architectural considerations: All OLTs will share N wavelengths. The scheme assumes Manual fibre patching uses an AWG based demux inside. The fibres can be connected to each port but this will increase the number of fibres running from each OLT to the fibre patching point. The NP/SPs can be geographically located at different positions. The ONU is using fixed receiver.

Techno-economic & business aspects: This solution has high OpEx cost as every time a customer wants to migrate fibre re-patching is required.

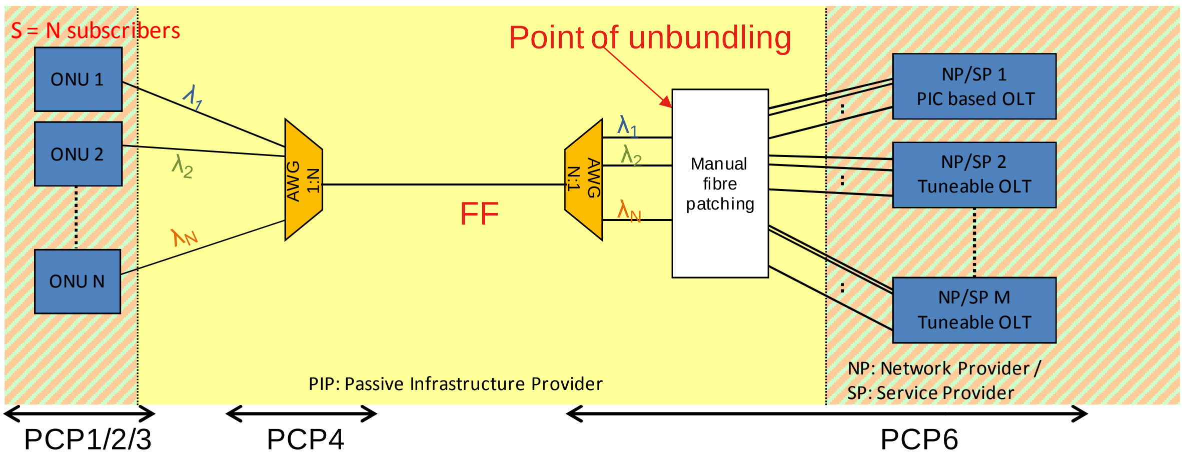


Figure 5-12: Manual wavelength open access in WR-WDM PON

Electrical wavelength open access

General considerations: In this configuration, a cross-point switch is used to provide Open Access. Figure 5-13 depicts a scenario for a electrical wavelength open access scenario.

Architectural considerations: the wavelength-switching is operated in the electrical domain. The OLT does not include any Ethernet switching element.
For any NP/SP, it is possible to collect clients from different PONs.
Subscriber management is handled in fully automated way operating on the electrical domain. The NP can be geographically located at different positions. This scenario requires a PIP provider, with an extended scope, that control passive infrastructure and low level switching.
No barriers for small NP/SP operators: they can serve customers geographically distributed on different PONs.

Techno-economic & business aspects: This solution has a low OpEx cost as every time a customer wants to migrate reconfiguration of the switch is enough (no manual intervention is needed) .

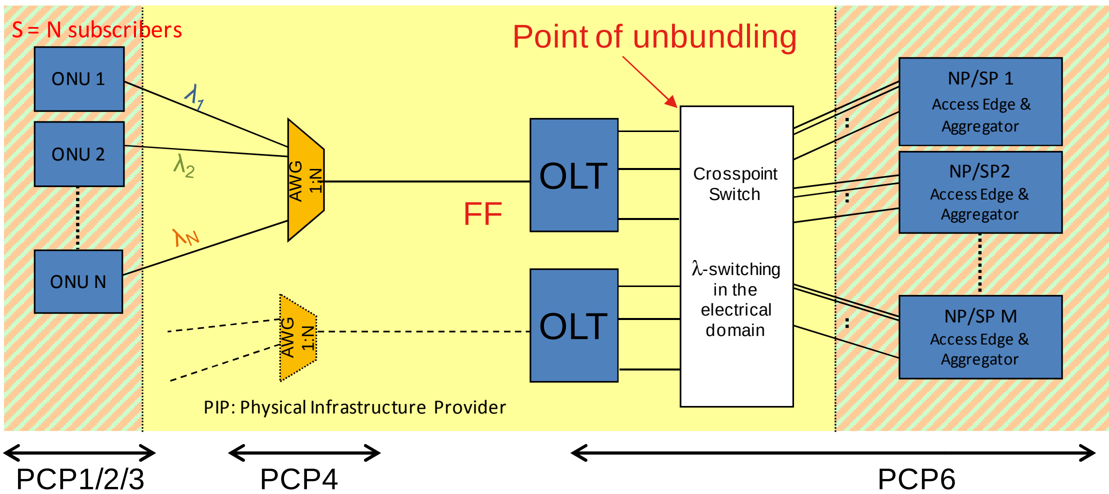


Figure 5-13: Electrical wavelength open access in WDM PON

Power Splitter based wavelength open access

General considerations: A power splitter is used to provide open access. Figure 5-14 depicts a scenario for the power splitter based open access.

Architecture & system aspects: The OLT requires N wavelengths. This scheme allows for dynamic spectrum sharing between NP/Ps, but it requires a control frame to co-ordinate between different NP/SPs.

Techno-economic & business aspects: This scenario is using a power splitter as point of unbundling. If the customer wants to change NP/SP, the NP/SP has to provide the right wavelength. Due to the use of a power splitter, it has a shorter reach (rural scenario) than the other considered open access scenarios for WR-WDM-PON.

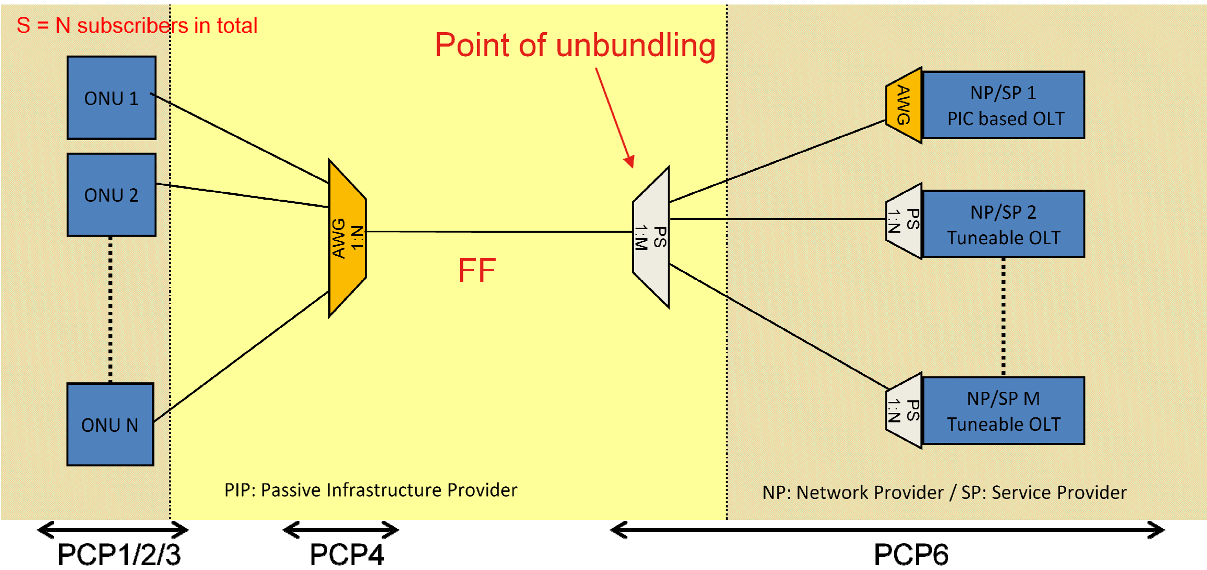


Figure 5-14: Power-splitter based wavelength open access in WR-WDM-PON

Waveband Splitter based wavelength open access

General considerations: A waveband splitter is used to provide open access. Figure 5-15 depicts a scenario for the waveband splitter based open access.

Architecture & system aspects: The OLT requires N wavelengths. The spectrum distribution between NP/SPs is static. AWGs with a subband cycle are used at PCP4, and a multiple of the free spectral range (FSR) of an AWG is used to feed multiple wavelengths to an ONU.

Techno-economic & business aspects: Tuneable ONUs are assumed, so that the customers can tune to the right wavelength to select the NP/SP. A waveband splitter is used to provide open access. At PCP4, a cyclic AWG is required, with an FSR equivalent to the band allocated to one NP/SP, i.e. supporting K wavelengths. It has fewer customers than most scenarios, with N/M (instead of N) subscribers, affecting the location of the AWG (at PCP4). The number of customers decreases as the number of NP/SP increases.

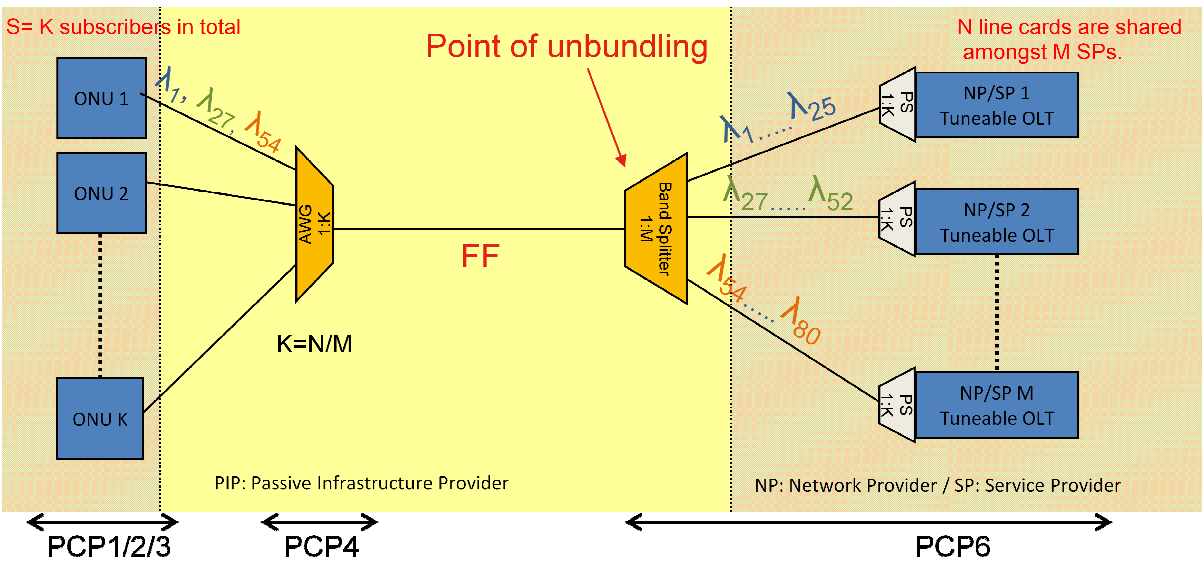


Figure 5-15: Waveband splitter based wavelength open access in WR-WDM-PON

WSS based wavelength open access

General considerations: A WSS is used to provide open access. Figure 5-16 depicts a scenario for WSS based open access.

Architecture & system aspects: The OLT requires N wavelengths. The spectrum distribution between NP/SPs is dynamic through the use of a WSS. The use of WSSs will avoid the need of co-ordination between different SPs.

Techno-economic & business aspects: Tuneable ONUs are assumed, so that the customers can tune to the right wavelength to select the NP/SP.

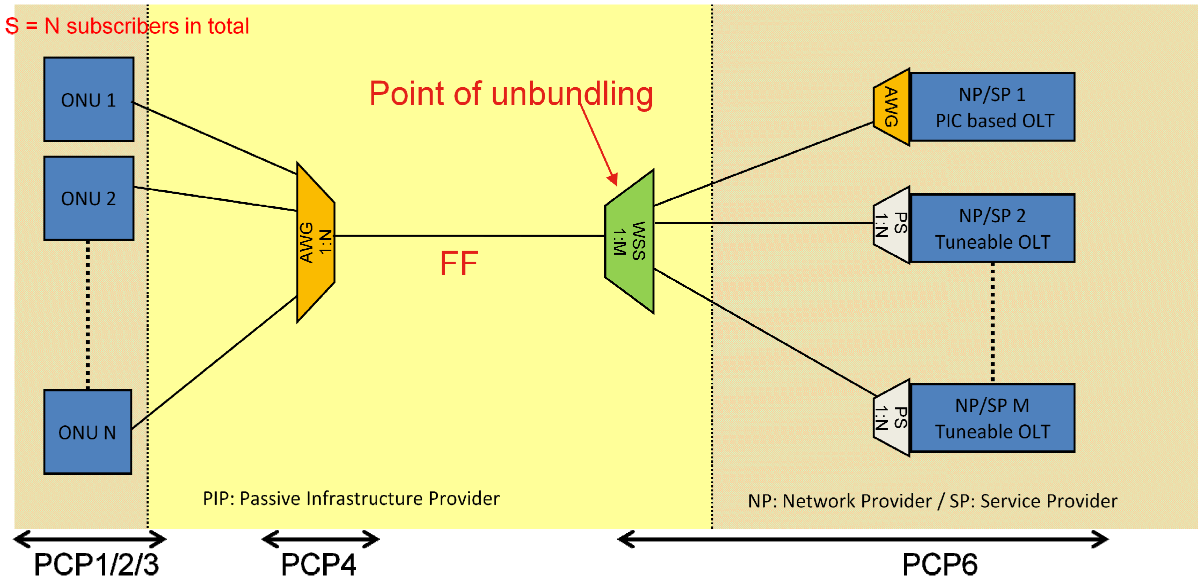


Figure 5-16: WSS based wavelength open access in WR-WDM-PON

WAVELENGTH OA ARCHITECTURES (WS-WDM-PON & ULTRA-DENSE WDM-PON)

For WS-WDM-PON and UDWDM-PON, only the power splitter based open access scheme is shown in this section. However, the manual, electrical, waveband splitter based and WSS based wavelength open access schemes are also valuable options, and will offer wavelength open access in a comparable way as for WR-WDM-PON. For architectures with a power splitter based ODN, we cannot use feeder fibre based wavelength open access as multiple feeder fibres cannot be connected to a power splitter at PCP4.

Power Splitter based wavelength open access

General considerations: A power splitter is used to provide open access. Figure 5-17 depicts a scenario for power splitter based open access.

Architecture & system aspects: The OLT requires N wavelengths. It allows for dynamic spectrum sharing between NP/SPs, but requires a control frame to co-ordinate between different NP/SPs. Note that for UDWDM-PON (with coherent transceivers), it is more problematic to offer dynamic wavelength sharing between different NP/SPs and the complexity of this solution is much higher than for DWDM-PON, like the considered WR-WDM-PON and WS-WDM-PON architectures.

Techno-economic & business aspects: At PCP6, a power splitter is added. If the customer wants to change NP/SP, the NP/SP has to provide the right wavelength. At PCP2-3, tuneable

ONUs are assumed, so that the customers can tune to the right wavelength to select the NP/SP.

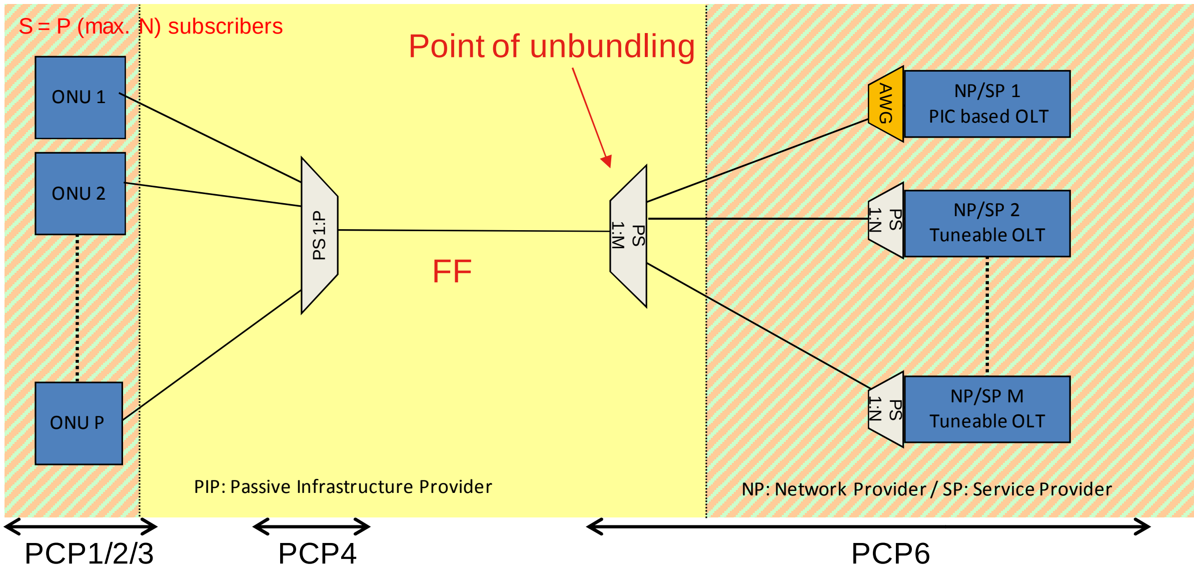


Figure 5-17: Power splitter based wavelength open access in WS-WDM-PON & UDWDM-PON

5.2.2 Control and management architecture

As mentioned in the first subsection of chapter 5.2.1, massive control challenges would be required for open wavelength access in the context of wavelength control or assignment. We regard this as technically and economically not viable. However, open access in WDM-PON does not pose additional effort with respect to control and management. The WDM-PON system is run entirely by one entity. It interfaces with different SPs in PCP6 on Layer2/3. This scenario does not differ from other multi-SP or even carriers'-carrier scenarios. Hence, standard means for control and management, including means for securing SLAs and QoS, can be applied. Since the related problems have been addressed to a high degree in the OTN (Optical Transport Network, especially with respect to TCM, Tandem Connection Monitoring), applying OTN framing to the WDM-PON access must be regarded an option for open-access scenarios. (Similar considerations are discussed in FSAN in the NG-PON2 context.) If OTN is added, it will also add to system cost. If it is not added, alternative means must be implemented. These means must include multiple levels of management, monitoring or communications channels, e.g., Layer-2 VLANs or, Provider-Backbone-Bridging (PBB, aka MAC-in-MAC) or similar tagging/labelling techniques. They must also include BER-monitoring means, e.g., FEC, for the NP who runs the WDM-PON system. (Otherwise, the NP will not be in the position to prove his SLA / QoS aspects.)

5.2.3 Evaluation

In low-cost implementations of WDM-PON, open access is limited to bit-stream open access on Layer-2 or above (Ethernet, MPLS, IP), see Figure 5-10. On Layer-2, access is possible without additional restrictions. Access to individual wavelengths (Layer-1) at the OLT is 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. On a large scale, this is regarded inefficient with regard to cost. Since uplink 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.

It must be noted that WDM-PON loses many of its advantages (reach, cost, form factor) in attempts to open the wavelength layer.

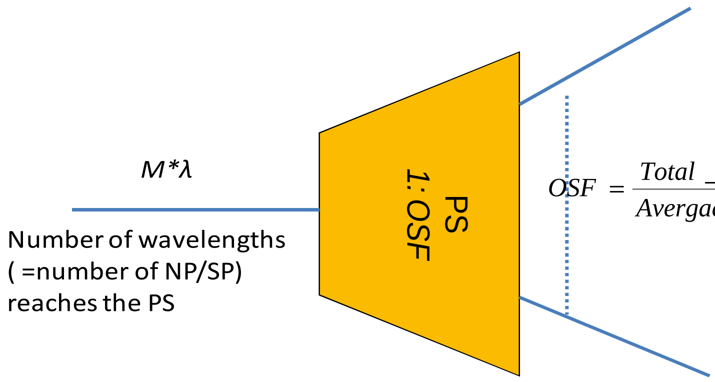
In an end-to-end context, it is worth noting that attempts to open the wavelength-layer in the OLT will also have a negative effect on the aggregation network. If wavelength access was implemented in the OLT, it would also require separation of aggregation switches. This again contradicts energy-efficient (integrated) implementations, and therefore would increase both CapEx and OpEx.

5.3 HYBRID WDM/TDM-PON

5.3.1 Data plane architecture

The hybrid WDM/TDM PON architecture supports open access on several levels: fibre, wavelength, and bitstream. For fibre and bitstream open access, the hybrid WDM/TDM PON will have no significant additional CapEx and OpEx cost. From the architectural perspective, the most challenging flavour of open access is wavelength open access. Hybrid WDM/TDM PON needs to overcome many challenges to facilitate open access at the wavelength level, where the main issues are the NP isolation and the number of customer optimisation. The hybrid WDM/TDM PON has a power splitter at remote node 2, and thus if different NPs serve the customers behind the same power splitter, it will lead to security issues. Thus, to provide NP isolation, special hybrid WDM/TDM PON architectures should be designed. The hybrid WDM/TDM PON architectures that allow NP isolation can be designed using an interleaved filter and an additional patch panel at the users' location. These architectures will be discussed in more detail in the next section.

Another issue is how to optimise the number of supported customers in the open access scenario. It is important to note that, in wavelength open access, there is a requirement that every wavelength should reach every customer, which in turn results in a high spectrum capacity reaching every PS. To utilise the high spectrum availability at each PS, the optimal split requirement at the PS is very high and that will limit the reach of the solution. The optimal split factor (OSF) required in case of three NP/SPs is 60 as shown in the calculation done in the figure below. If the OSF is equal to the split factor in the non-open access scenario is chosen, the number of customers will reduce in proportion to the number of NP/SPs. Thus, in the open access scenario, there is a trade-off between optimising reach and the number of customers.



$$OSF = \frac{Total\_Wavelength\_Capacity}{Avergae\_datarate\_per\_user} = \frac{3*10\,Gbps}{500\,Mbps} = 60.$$

Figure 5-18: The trade off between the optimal split factor and reach.

The OLTs necessary to offer open access can be designed in two ways: one utilising tunable transceivers and the other utilising PIC based transceivers. The tuneable transceivers can reduce the form factor at OLT. The PIC based OLTs use AWGs to combine all the wavelengths from all the transceivers, and the tuneable based transceivers are followed by a PS.

There can be many points of unbundling present in the architecture, like at a PS, a WSS and a BS. The BS allows only the static distribution of spectrum amongst NP/SPs. The PS provides for the dynamic spectrum sharing amongst the NP/SPs, however, it requires a complex coordination between NP/SPs, which has severe implications for business modelling. The use of WSSs increases the CapEx of the network but this may be offset by the fact that many customers will share it. The WSS will facilitate the dynamic spectrum sharing between the customers without the need of complex coordination between the NP/SPs.

In this, we consider two variants of hybrid WDM/TDM PON: passive hybrid WDM/TDM PON with AWG based remote node and semi-passive hybrid WDM/TDM PON with WSSs at the first remote node. Which will be further described in the next sub-chapter.

Normally, wavelength open access can be provided at all PCP location, cf. Figure 5-19. Wavelength open access may become practical in the unbundling scenario, where the PIP is not technology neutral and all NP/SPs may provide services using the same technology.

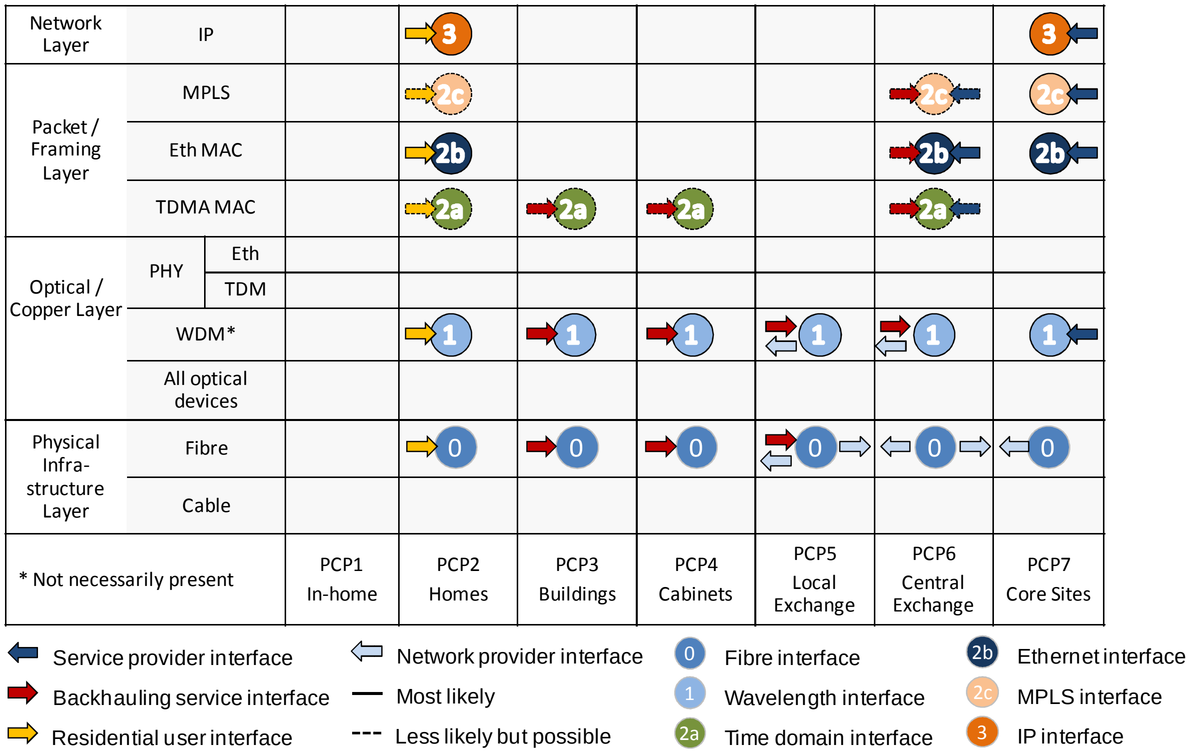


Figure 5-19: Open access on different layers and PCPs in a hybrid WDM/TDM-PON architecture

In the following sub-chapters the focus will be on how to utilise certain architectures in order to open up the infrastructure. The figures in these chapters will focus on OA aspects of the architecture and not infrastructural elements like ODFs unless it is a vital part of opening up the architecture. For a more detailed discussion on the passive infrastructure, e.g. ODF location at points of unbundling, please refer to chapter 5.1.

Wavelength OA architectures (Passive hybrid WDM/TDM-PON)

Three different options are shown for wavelength open access in a passive hybrid WDM/TDM-PON. The other three options, as presented for WR-WDM-PON in section 5.2.1, are also valuable solutions for a hybrid WDM/TDM-PON with an AWG at PCP5.

Feeder Fibre based wavelength open access

General considerations: Hybrid WDM/TDM-PON also supports Feeder Fibre Open Access (# feeder fibres = # NPs). Figure 5-20 depicts a scenario for the feeder fibre based open access.

Architecture & system aspects: The OLT requires N+M wavelengths.

Techno-economic & business aspects: For offering open access, additional feeder fibres (as # feeder fibres = # NPs) are required. At PCP5, an M:N AWG is required instead of a 1:N AWG. At PCP2-3, tuneable ONUs are assumed, so that the customers can tune to the right wavelength to select the NP/SP. However, the additional cost and power consumption per user will be low due to the high fan out.

Note about the problem of over-subscription: at the input of the power splitter, 3 wavelengths are fed and for a 500 Mbps bandwidth delivery per customer, the number of customers is 48. However, a split of 1:48 will reduce the reach and a split of 1:16 or 1:32 may be the only viable options, leading to fewer customers per NP/SP. As the number of NPs/SPs increases, the trade-off becomes more severe and thus for the same reach, a NP/SP may serve less customers than it possibly could serve in a non-competitive scenario, leading to CapEx issues.

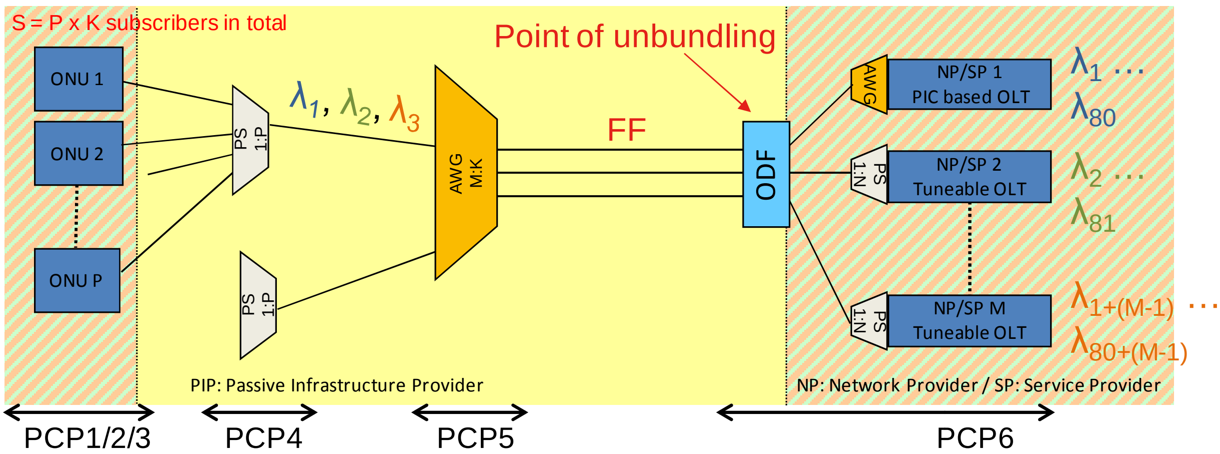


Figure 5-20: Feeder Fibre based wavelength based open access in passive hybrid WDM/TDM-PON

Manual wavelength open access

General considerations: In this configuration, also a manual patch panel/fibre robot can be used to provide open access. Figure 5-21 depicts a scenario for manual wavelength open access.

Architectural considerations: All OLTs will share N wavelengths. The scheme assumes Manual fibre patching uses an AWG based demux inside. The fibres can be connected to each port but this will increase the number of fibres running from each OLT to fibre patching point. The NP/SPs can be geographically located at different positions. Note that, besides AWGs, PSs are also used in the patch panel, which makes the patch panel more complex than for WDM-PON. The ONU will use a tuneable receiver.

Techno-economic & business aspects: This solution has high OpEx cost as every time a customer wants to migrate fibre re-patching is required.

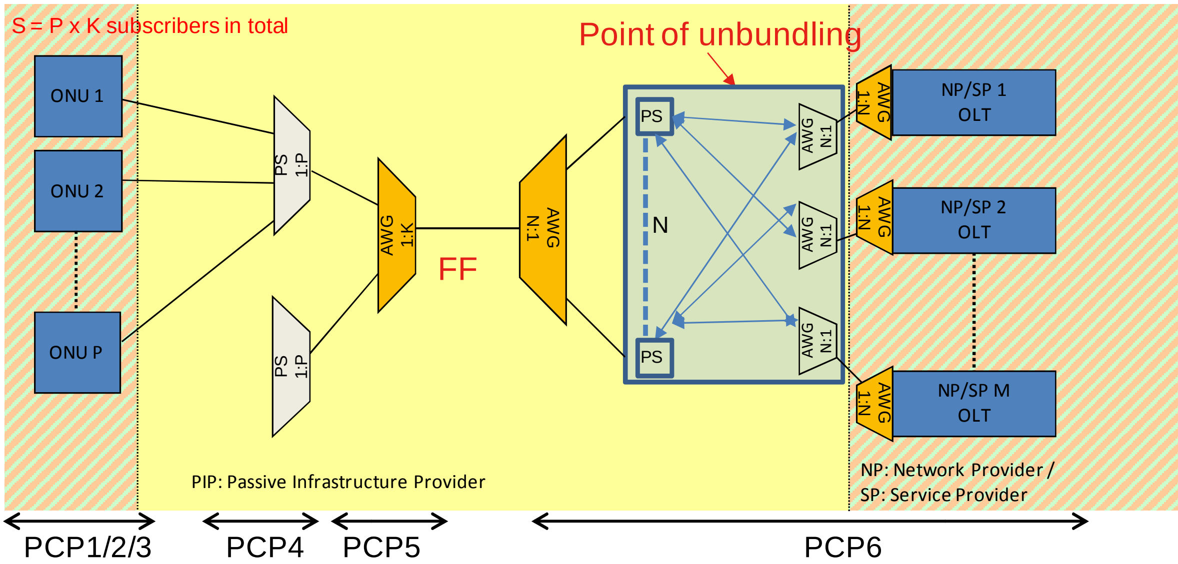


Figure 5-21: Manual wavelength open access in passive hybrid WDM/TDM-PON

Power Splitter based wavelength open access

General considerations: Hybrid WDM/TDM-PON also supports power splitter based wavelength open access. Figure 5-22 depicts a scenario for the power splitter based open access. The architectural and techno-economic aspects are same as in WR WDM-PON.

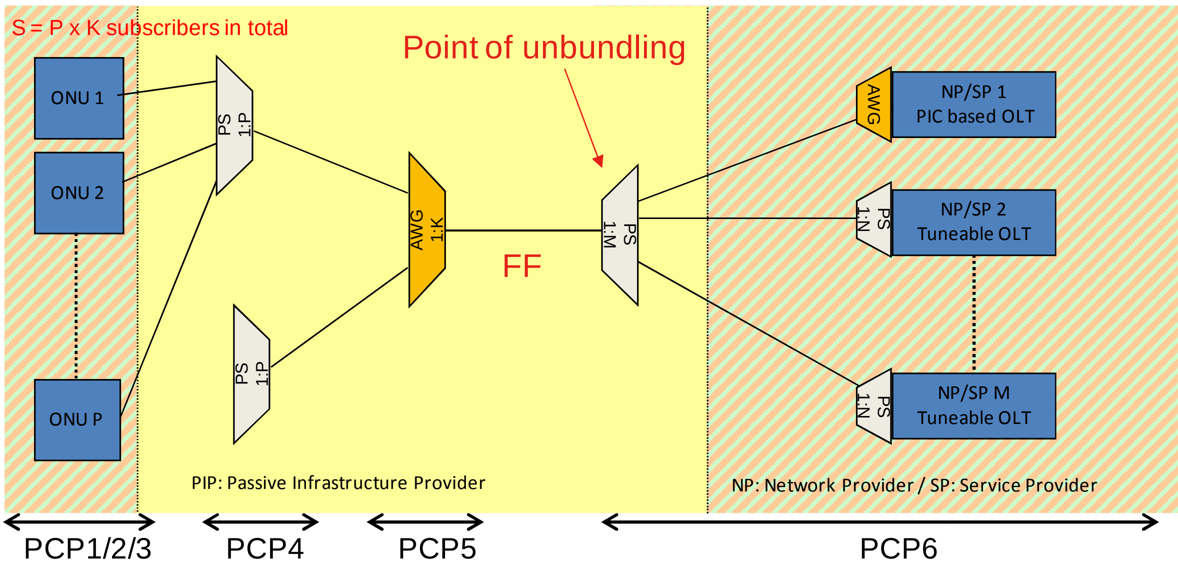


Figure 5-22: Power splitter based wavelength open access in passive hybrid WDM/TDM-PON

WAVELENGTH OA ARCHITECTURES (SEMI-PASSIVE HYBRID WDM/TDM-PON)

The most likely wavelength OA option for semi-passive hybrid WDM/TDM-PON is the waveband splitter based scenario, as shown below.

Waveband Splitter based wavelength open access

General considerations: Figure 5-23 depicts a scenario for the waveband splitter based wavelength open access for semi-passive hybrid WDM/TDM-PON. The architectural and techno-economic aspects are same as in the waveband based open access in WR WDM-PON.

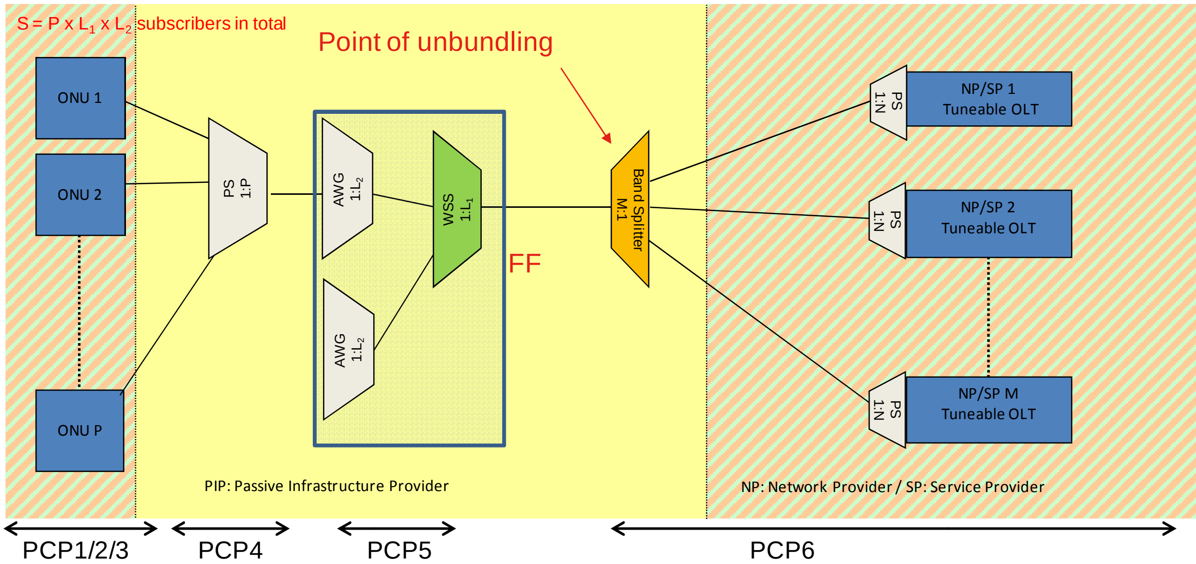


Figure 5-23: Waveband splitter based wavelength open access in semi-passive hybrid WDM/TDM-PON

SECURE WAVELENGTH OA ARCHITECTURES FOR HYBRID WDM/TDM-PON

In Figure 5-24, we show the secure OA architecture implementation in a passive hybrid WDM/TDM PON. For the illustration of this scheme, we use feeder fibre based OA scenario as discussed before. However, the technique of providing network isolation is implemented between PCP4 and PCP1/2/3, and can be used over all open access flavours. At PCP4, we use an interleaver filter in combination of a PS. The inter-leaver filter will create separate NP space. The users can access different NPs using a patch panel at PCP3, which is typically at the location of a building basement. This approach will indeed safeguard against a rogue user and provides higher security against malicious users. Moreover, using a patch panel will not increase the OpEx cost if a user himself is allowed to slot in his fibre. A malicious user can still theoretically affect the services of other NPs, but it can be easily monitored by CCTV cameras or by other approaches. However, if customers cannot be considered to do fibre patching themselves, this scheme will incur high operational expenditures and hybrid WDM/TDM PON will not be able to provide a pure (fulfilling all the criteria) wavelength open access solution. A use case for this scenario could be an MDU with a patch panel in the basement and where the porter is allowed to patch the different users. Without such a central entity (like a porter), it will be very difficult to implement this scheme.

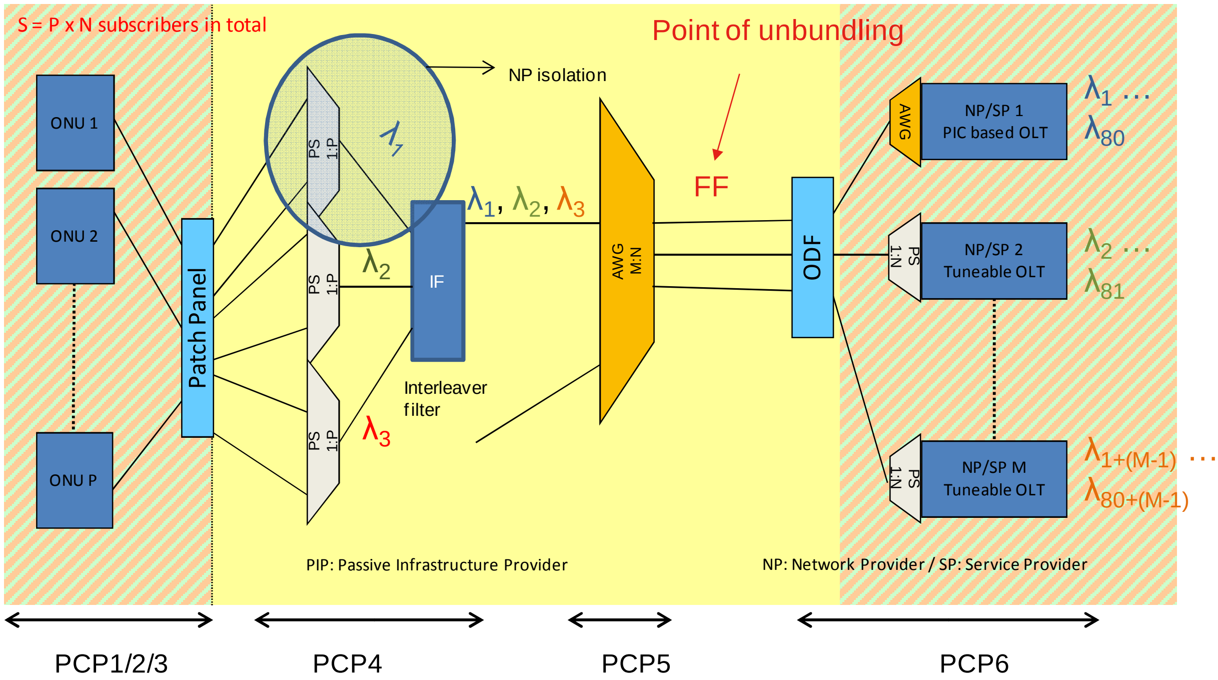


Figure 5-24: Inter-leaver filter used to provide NP isolation over a multiple feeder fibre.

5.3.2 Control and management architecture

The control and management challenges in the open access scenario are many and are discussed in section 3.2. At fibre open access, the challenges in hybrid WDM/TDM PON are same as in non-open access scenario and are discussed in D3.1. At wavelength open access, as in WDM-PON, the techniques of OTN framing can be employed in hybrid WDM/TDM PON. Furthermore, the NP/SP isolation can be provided using VLAN tagging or MPLS based VPN connections. Hybrid WDM/TDM PON suffers from location and identification issues due to nomadic access discussed in section 3.2.

5.3.3 Evaluation

As shown in Figure 5-19 hybrid WDM/TDM-PON offers a large number of open access possibilities. In general, it can support multiple network providers and/or service providers. Both, bit-stream and wavelength open access are possible. In fibre rich scenarios, the SPs may directly connect to an AWG. Due to the passive splitters each subscriber can be reached by multiple service providers and a user can automatically connect to one of them.

Wavelength open access will pose penalties of cost, power consumption and reach. Thus, in the end, it may not be a viable solution. Bit stream open access can be provided using VLAN or MPLS techniques as discussed before. Besides bit-stream open access at the Ethernet, MPLS and IP layer, it should also be possible to open the network at the TDMA MAC layer by assigning different time slots to different SPs. However, bit-stream open access at the TDMA layer has some important constraints, as it has to be controlled by one entity, which will be the NP in this case. Note that opening/open access the network at the TDMA layer for multiple NPs will not be possible. In Figure 5-19, open access at the TDMA MAC layer is indicated as possible, but less likely. Thus, hybrid WDM/TDM-PON allows better flexibility. However, since now each SP is present until the end user, it will also bring isolation issues.

5.4 Two-stage WDM PON

5.4.1 *Data plane architecture*

As a recap (from D3.1), Figure 5-25 shows the Two-Stage WDM-PON architecture and its assignment to the network reference model and the PCPs. Other configurations are possible (e.g., OLT2 in PCP6), but they do not change the results of the open-access analysis. In addition, the configuration shown in Figure 5-25 clearly is the most meaningful configuration, especially in site-consolidation scenarios.

For the open-access analysis of Two-Stage WDM-PON it is relevant to consider two aspects:

- Two WR-WDM-PONs are cascaded
- The two WDM-PONs can be implemented differently

These two aspects have severe impact on the open-access analysis.

Next, it is relevant to note that the *secondary* WDM-PON (the one with OLT1 in PCP5) is a WR-WDM-PON as discussed already in chapter 5.2. The two-stage set-up discussed here has no influence on the outcome from this chapter. Therefore, we can conclude that the secondary WDM-PON will not be configured in a way to allow wavelength access. The secondary WDM-PON will allow open access on Layer 2/3 only.

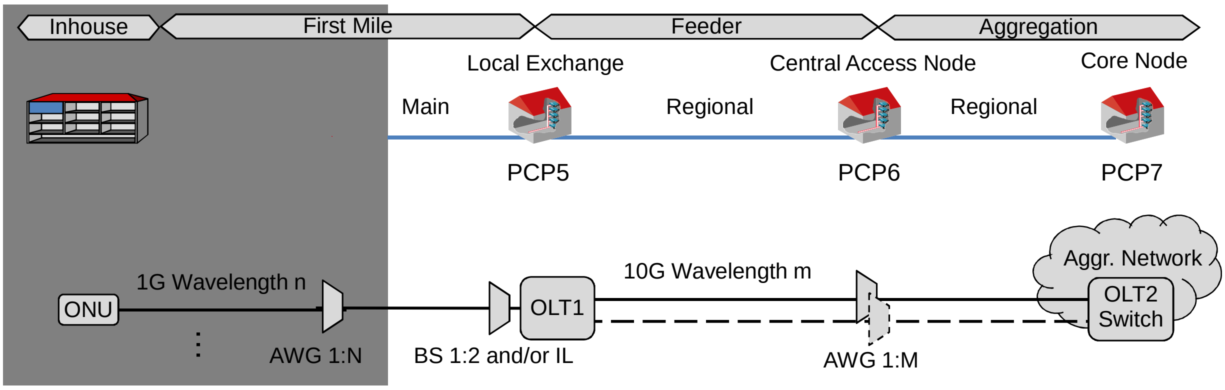


Figure 5-25: Recap: Two-stage WDM-PON architecture.

For the backhauling WDM-PON (the one with OLT2 in PCP7 in Figure 5-25), the situation differs. The reason is that this PON can be implemented in a different way. One possibility is to implement the OLT (OLT2) similarly to OLT1, i.e., in a highly-integrated multi-channel PIC. This transceiver array has to support 10 Gbps per channel since lower bit rates are meaningless in (near-) future backhaul. In this case, the backhauling WDM-PON performs similarly to the access WDM-PON. Open access would only be possible on Layers 2/3.

However, it is likely, and has been considered for the general (cost, performance) analysis throughout this project, that the backhauling WDM-PON will be based on dedicated10-Gbps pluggables, i.e., on tuneable SFP+ transceivers, even in the OLT. There are several technical reasons for using these transceivers:

- Form factor. With fully integrated arrays of 40…80 WDM channels, the total capacity may exceed what can be expected for the near future in terms of per-slot shelf backplane capacity. In other words: for backhaul at 10 Gbps per channel, best form factor is not required.
- Flexibility. The backhaul WDM-PON has to support a variety of architectures anyway. This includes all sorts of wireline and wireless backhauling scenarios. As

such, termination multiplexers with a broader range of channel counts will be required. These may have to support different topologies, e.g., physical point-to-multipoint (star, tree), bus, dually-parented bus, and also rings and partial meshes.

For these reasons, it is likely that backhauling WDM-PON will be based on tuneable SFP+. (It will also *always* be implemented as WR-WDM-PON. There is no reason in the backhaul for considering power-split architectures.)

WDM-PON based on dedicated pluggables can offer better flexibility w.r.t. wavelength access. Wavelength open access in the OLT is relatively straightforward, compared to a fully integrated OLT. 10 Gbps services do not necessarily have to be routed via a backplane. In Wavelength-Routed WDM-PON, wavelength assignment is done via the respective AWG port. Tuning means are either integrated into the SFP+, or can be implemented externally, based on the wavelength-selective AWGs (in the OLT and the RN). Miss-tuning does not have impact on other channels due to the crosstalk-suppression capability of the AWGs. Consequently, there is only one aspect to be considered: in PCP7, a single (physical and logical) WDM multiplexer/de-multiplexer is required. This filter can be split into multiple stages (cascaded filters), but it cannot be parallelized. Hence, there still has to be an owner of the WDM filter (or, at least, the first filter stage which combines several secondary filter stages). In addition, open access in PCP7 is possible on Layers 2 and 3. Figure 5-26 shows the resulting open access reference diagram.

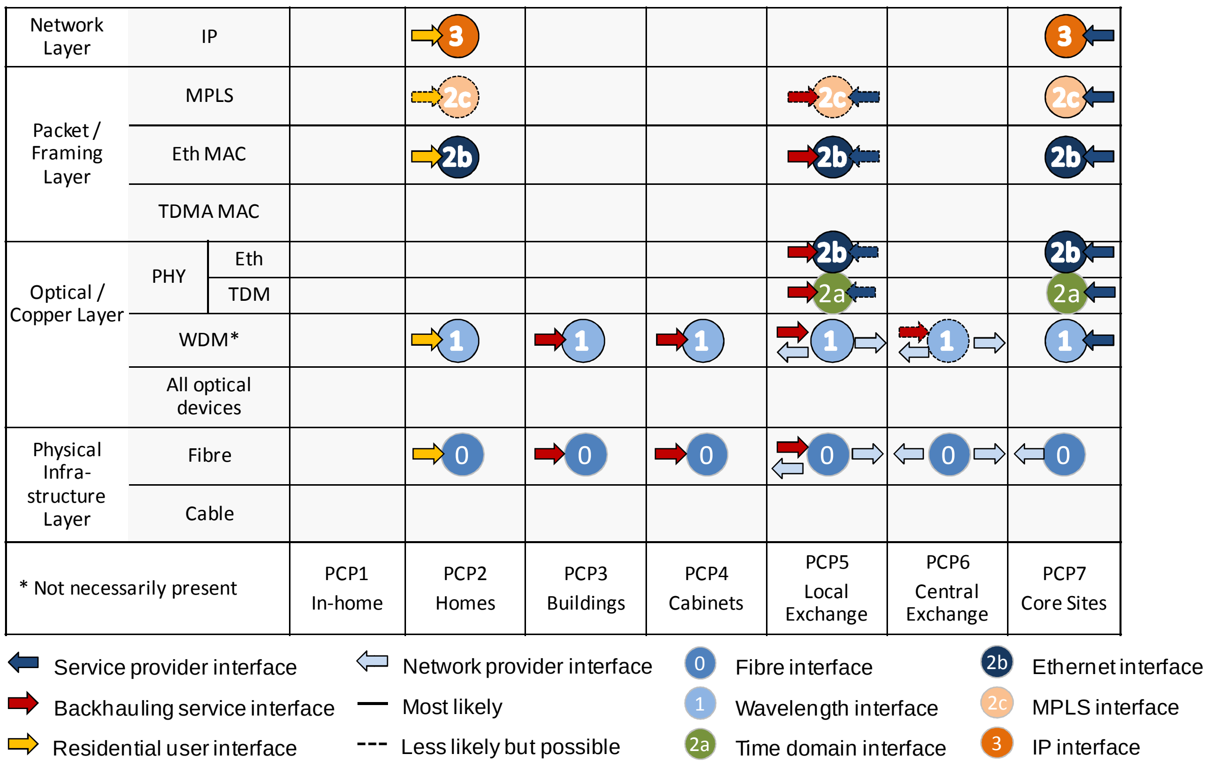


Figure 5-26: Open access on different layers and PCPs for Two-stage WDM-PON

The backhauling WDM-PON can be combined with optical transport network framing. Then, carriers'-carrier-type services can easily be provided. In this case, it is also possible to open individual wavelengths on a sub-wavelength granularity. For 10 Gbps wavelengths with OTU2 optical channels (Optical Transport Unit), payload content can be any out of ODU2 (Optical Data Unit), ODU1, ODU0 or ODUflex. No matter if the respective backhauling wavelength is opened on the optical-channel (OCh) or ODU layer, the secondary WDM-PON which is backhauled by the respective transport capacity is run by the related SP.

It is worth noting that the total open-access solutions space results from the WR-WDM-PON as described in chapter 5.2, combined with the well-known open-access capabilities of standard WDM transport (applied to the backhaul part).

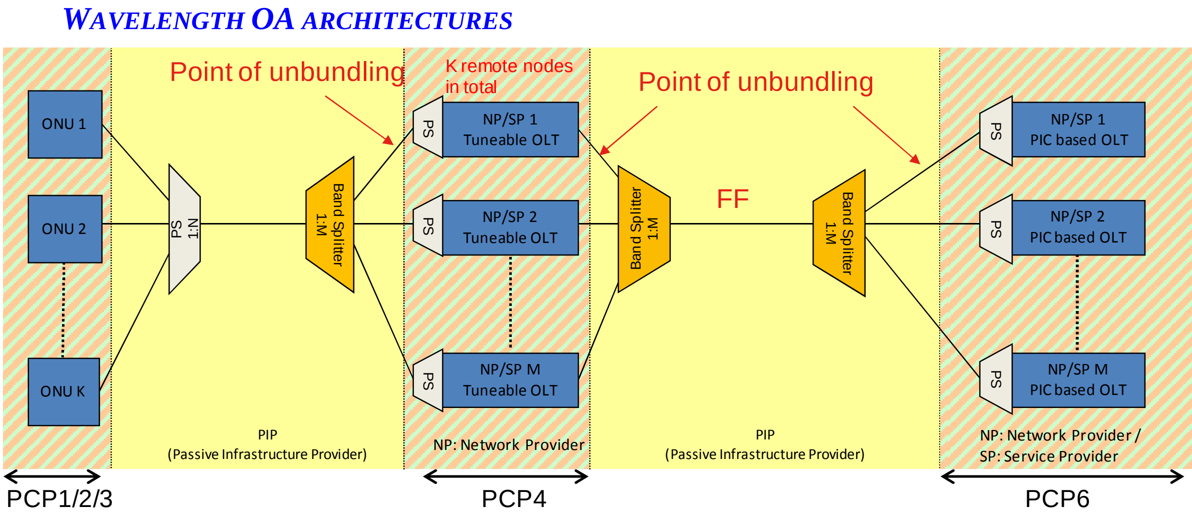


Figure 5-27: Open access on wavelength layer in Two-stage WDM-PON

The band splitter before PCP4 (Figure 5-27) gives a 1:1 mapping between NPs in the two stages. A flexible mapping between NPs in the two stages is possible if band splitter is replaced by a PS, this would make it possible to have two points of open access. For a more detailed discussion on the passive infrastructure, e.g. ODF location at points of unbundling, please refer to chapter 5.1.

5.4.2 Control and management architecture

With regard to the secondary WDM-PON (OLT1 in PCP5), chapter 5.2.2 applies. For the backhauling WDM-PON, open-access-related control and management issues are best solved if OTN framing and monitoring is applied. Then, standard carriers'-carrier OAM functions can be used.

Isolation between NPs or SPs slightly differs for the open-access possibilities. If two NP/SP run separated wavelengths in the backhaul part, it is possible to fully isolate them (despite the fact that both have to traverse common filters, as explained above). If multiple SPs share a common backhaul wavelength, they must be isolated in the electronic domain, preferably via OTN time slots. This is regarded standard OTN functionality.

5.4.3 Evaluation

The Two-Stage WDM-PON has decentralized OLT1's in PCP5 sites. On the one hand, this contradicts fully passive the PCP5 sites. On the other hand, it allows to locally switching certain traffic. The two-stage approach can thus support locality-of-traffic aspects and potentially relieve the backhaul and consequently the core network from certain traffic amounts. The approach further allows high capacity × reach.

In addition to the local-switching aspects, Two-stage WDM-PON offers a comparatively large number of open-access possibilities due to the cascaded approach (see Figure 5-26). In general, Two-Stage WDM-PON can support multiple Network Providers (NP) and/or Service Providers (SP). Both, bit stream OA and wavelength OA (backhaul part) are possible. The access-PON part has OA functionality identical to WR-WDM-PON as discussed in chapter 5.2. The backhaul part adds OA to a TDM layer (given OTN is used) and/or to the Ethernet layer (backhaul based on 10GbE).

5.5 NG AON

5.5.1 Data plane architecture

Open-access for NG-AON can be accomplished on the bit-stream level and is easy to open up on the fibre level. Several commercial deployment of bit-stream access exits today, with a wide variety of solutions. It can also be accomplished on top of all the previous architectures.

For a more detailed discussion on the passive infrastructure, e.g. ODF location at points of unbundling, please refer to chapter 5.1.

BIT-STREAM OA ARCHITECTURE

Bit-stream OA can be accomplished over virtually all layers (e.g. TDMA, WDMA, or hybrid architectures), and in turn several methods exist for each layer. Figure 5-28 indicates the strong point of AON and NG AON, i.e. the flexibility of placement of active equipment. Figure 5-29 shows the preferred hybrid with WR WDM PON, since both of the can fulfil isolation/security requirements by point-to-point data plane allocations, i.e. not shared medium architectures (the latter is optional, as indicated in the figure). In OASE the focus has been on consolidation and comparative studies so the RN/OLT is place in PCP4/5 and the second aggregation step in PCP6 (see D3.1). Current OA operators usually operate their network either on L2 (Ethernet) or L3 (IPv4), where management system exists for configuring there OA network.

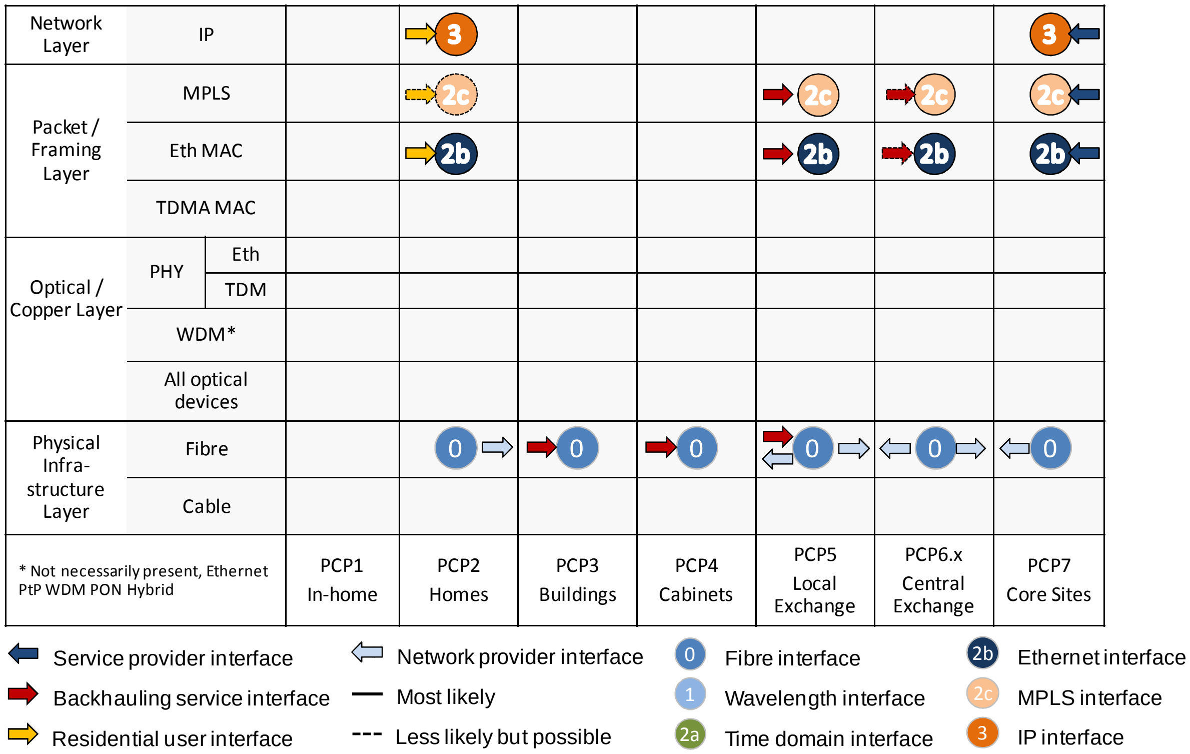


Figure 5-28: Open access on different layers and PCPs in a NG-AON based bit-stream architecture.

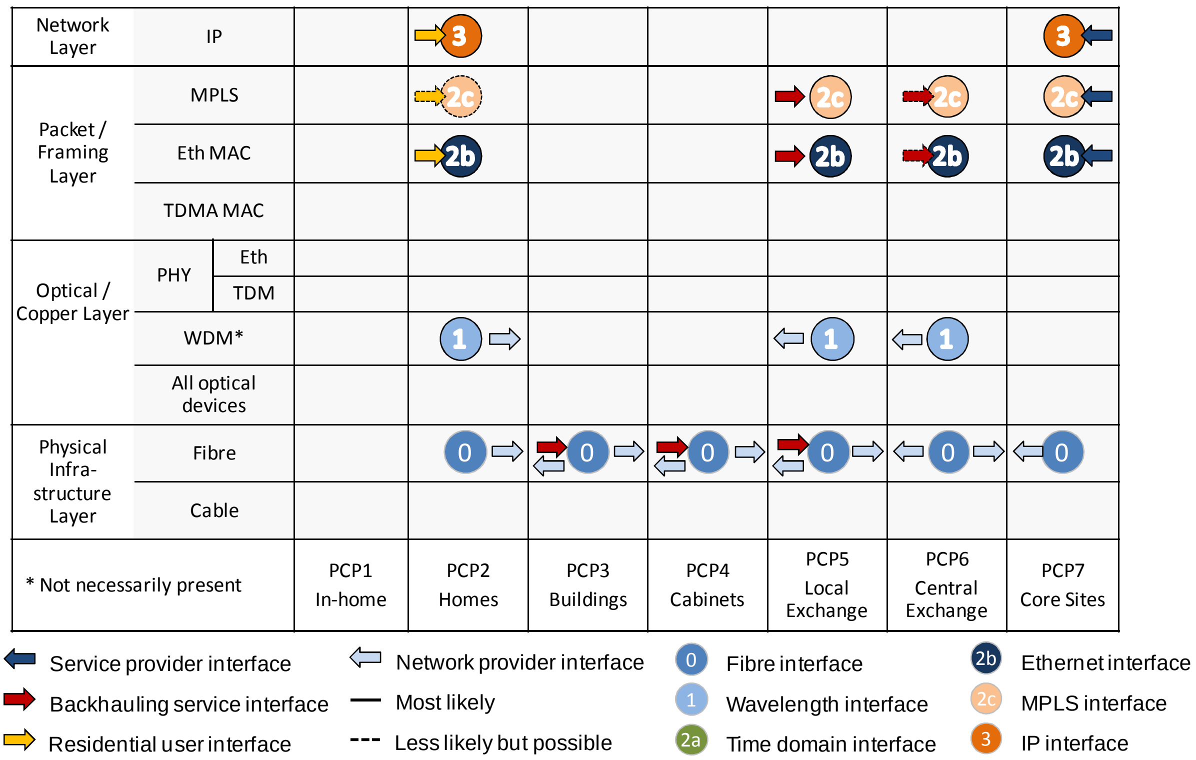


Figure 5-29: Open access on different layers and PCPs in WR WDM PON based bit-stream architecture

Two issues need to be addressed when considering OA between the home and the first active device (RN/OLT), separation of SP and how control of these should be handled. The choice of either affects how the end-to-end management is handled and this section will therefore deal with the different options of separation (electrical link based mux/demux) of the data plane, while the aggregation chapter will deal with the end-to-end aspects.

802.1Q Ethernet based forwarding in the access (Figure 5-30 - current)

The most common way to separate SPs today is to use IEEE 802.1Q VLAN tags (C-VLANs), where different VLAN values are used to identify service and SP. Several variations of this technique are possible depending on where the tagging of the VLAN ID is performed. The technically simplest solution is where the VLAN tagging is performed on an in-home facing port by the home gateway, where the gateway has preset in-home port to indicate which service is accessible through that port. Which VLAN ID to use on which in-home facing port is already decided in the production process. This VLAN ID is then translated by the first access switch to an ID that reflects both SP and service.

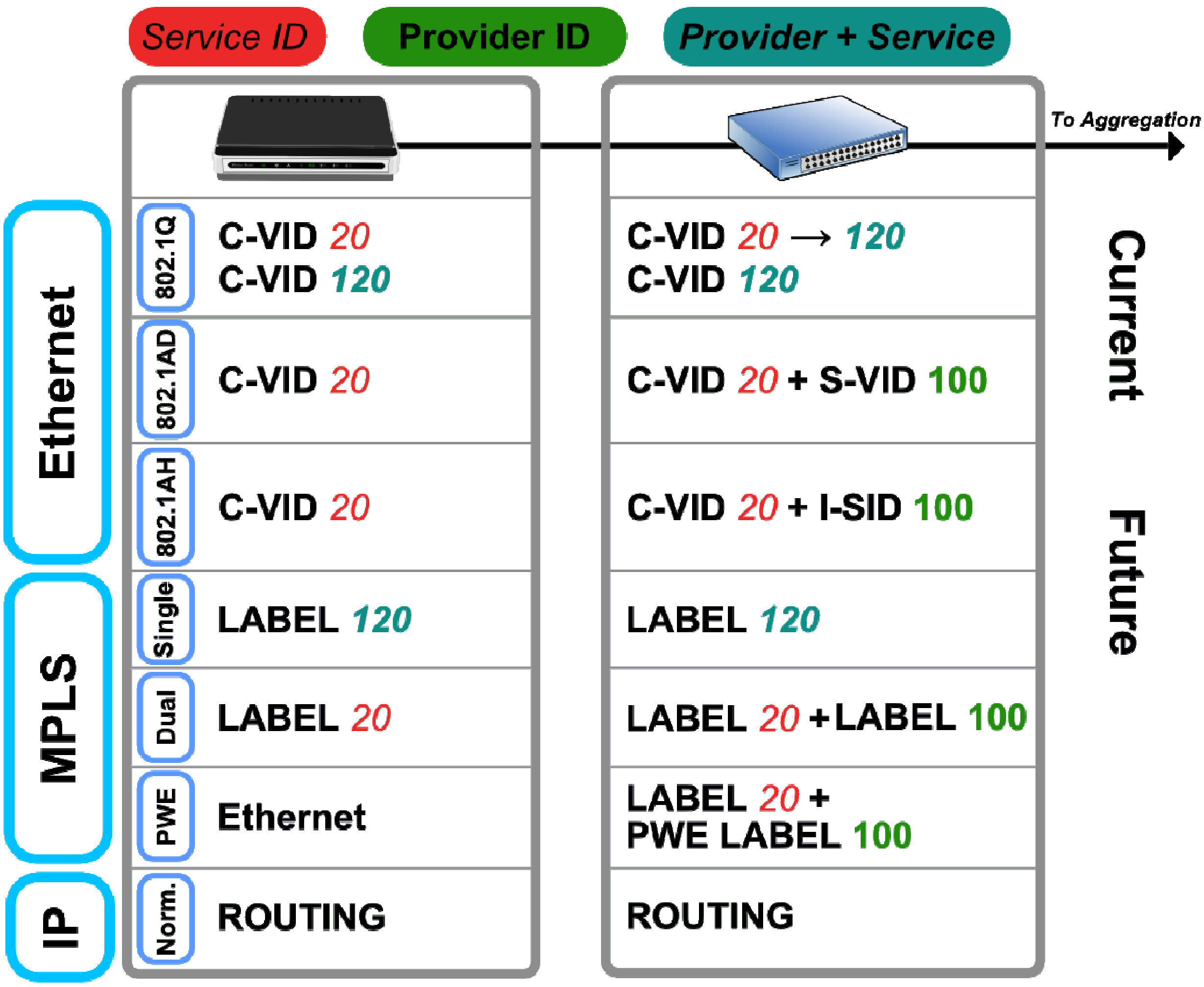


Figure 5-30: Overview of different data plane possibilities, with color coding for future approaches and currently deployed solutions. The ID values of VLAN and labels are indicative.

A slightly more advanced solution is having a home gateway which can reconfigured by the network (e.g. configuration server address can be supplied via DHCP), in this a VLAN ID that reflects both SP and service is already assigned on the gateway, and a translation of the VLAN ID is therefore not necessary in the access switch. These two variations could further modified by adding a monitoring capability of the gateway. This approach is simple and is supported by virtually all hardware sold today, but may lack in scalability (the maximum amount of C-VLAN IDs are 4096), and requires high amount of configuration because of the large amount of VLAN IDs which needs to be configured on all switches leading to the customer.

A similar approach with less configuration and better scalability can be accomplished by using IEEE 802.AD (S-VLAN) tags as well as normal VLANs. In this approach the gateway would first tag the traffic, based on port, with a service specific C-VLAN. This traffic is then tagged with a S-VLAN on the first access switch which corresponds to an SP. The traffic is from that point tagged with both an S-VLAN and a C-VLAN, but only the S-VLAN used for forwarding the traffic. This reduces the configuration need, since access switches only need to configure with the S-VLAN, as well as improves the scalability of network.

Utilizing VLAN IDs for SP, service, and customer identification (i.e. not only SP and service) would potentially lead to extreme scalability issues. The extreme scalability issues could be eased but maybe not handled by S-VLAN domain segmentation that is terminated on the IP level, i.e. the possibility of reusing C-VLAN space in separate and IP terminated S-VLAN domains. These issues can be overcome for services that use DHCP by using the option 82 extension. This extension adds identifiers for port and switch to the DHCP request, which the SP can then use to map the assigned IP address to the switch-port, which in turn can be mapped to a customer. In chapter 3.2.4 this and a solution for current usage of PPPoE is discussed.

A last possibility on L2 is to use IEEE 802.1AH, also known as PBB (see D3.1), where the first access switch would encapsulate the C-VLAN tagged service traffic with an I-tag at the first access switch. The I-SID in the I-tag would then be specific to the SP and customer, and switched to the SP based on that value. This method would require PBB support of the first access switch that has great flexibility and scalability (which is not common in today's hardware and mainly geared towards core applications). This solution also provides a way for the SP to identify the customer based on the I-SID values, assuming that the PBB network is terminated at the SP border rather than on the NPs side of the border.

IP based forwarding in the access (Figure 5-30 - current)

When using IP the first access router (and potentially the gateway) will route the traffic based on the IP range of the packet. For IPv4 this present a problem when bootstrapping as this requires DHCP, which operates on L2, which least to the need of a central DHCP server which handles address assignments for all SPs. This is also important for populating the routing tables as well as making sure that IPv4 address spaces does not overlap. For IPv6 this could be by passed by not using DHCP as well as only using globally routable addresses.

MPLS based forwarding in the access (Figure 5-30 - future)

The possibility to terminate MPLS on the first access switch, or even on the gateway, is a possible and realistic future since MPLS capable hardware is coming down in price and enables a seamless data plane from the access, via the aggregation, to the core [13]. The reason is increased demand by operators of a higher degree of end-to-end traffic engineering. A MPLS based access architecture could be configured in several different ways, but perhaps the simplest is to tag a service with a label which identifies both the service and the service provider.

This is still provides an acceptable level of scaling as the MPLS label space is rather large (1048576 possible labels), which means that it could handle around 350k users with three services each, even without using label stacking. Such a single layer MPLS solution could work but creates a large amount of forwarding tables entries and a better solution is there for to use label stacking. In this case the gateway would add a MPLS label for the service, for example based on port, and then the first access switch would add additional label which identifies the service provider. This enables less forwarding entries and improves the scaling of both the access and aggregation/metro (see chapter 6.2).

The most interesting solution is to use MPLS pseudo-wires, where an Ethernet is encapsulated by MPLS using two labels, where pseudo-wires are used to e.g. emulate an Ethernet connection over MPLS. The NP could then supply an emulated and traffic engineered Ethernet connection over an MPLS. Using this solution the traffic would be encapsulated with an MPLS frame using a service identifying label and the tagged with a service/customer label. This could be performed either on the first access switch or on the gateway, where the gateway option would simplify the handling of the resulting Ethernet payload. This enables the SP to send any type of Ethernet traffic to the customer, with the result of easier management for the NP.

All the MPLS solution can enable the SP to identify the customer based on the MPLS label. And in the case of pseudo-wires it enables the SP to communicate with the customer as if there where point-to-point connection to it, creating a simple interface for SP as well as giving the SP the possibility to send arbitrary Ethernet traffic to the customer.

Gateway ports

An issue not to overlook is how different services are separate on the gateway as this affects how the customer practically uses the network. The common approach is to have service specific ports on the home gateway, e.g. a colored in-home facing port labeled *"IPTV"*, which requires the customer to connect its TV setup box to that specific port. The upside of this approach solves the separation issue and is easy to implement but leads to support issues when the customer fails to connect the right equipment to the right port. It is therefore desirable to have all ports of the gateway be equal and let the system differentiate in a different way.

Perhaps the simplest solution is to have the equipment which uses the gateway indicate the type of service. For example the set-top box could add a VLAN tag to identify the service, instead of having the gateway adding a VLAN tag identifying IPTV based on port. This solution could be implemented in virtual all hardware but requires coordination between the SP and NP when selecting VLAN IDs to use. Traffic which does not have a VLAN tag would be assumed to be internet traffic.

A more advanced solution is for the gateway to detect the type of service based on a property of the traffic. An obvious choice for this is to use the Ethernet MAC address to detect if the connected device is for example a set-top box and then tag it with the appropriate value. This could also be done based on the Organizationally Unique Identifier (OUI), which is the first three bytes in the MAC address and identifies a manufacturer, which reduces the amount of MAC address patterns to match against. This approach has the downside of requiring information about the connected device from the SP.

The best long term solution for problem is to run all services over IP as they were normal internet based services. This removes problems of having different service port and makes boot strapping of the services easier. This would also allow the customer to connect it's devices through a customer bough router as the remote destination would be accessible through the router, and the device could simply use the IP address provided by the router.

FIBRE OA ARCHITECTURE

Open-access on the fibre level is a possible solution for AON, even if bit-stream open-access might be the obvious solution (see Figure 5-31). With fibre open-access the remote node in PCP4 (or PCP5) is opened up to allow several NPs to install equipment and access customer via dedicated fibres to the customers. Several NP could connect to customers if multiple fibres are installed to the customer. This means that an additional patch panel in needed in this location to allow the connection of the fibres to be changed, and possibly more space for accommodating the extra network equipment.

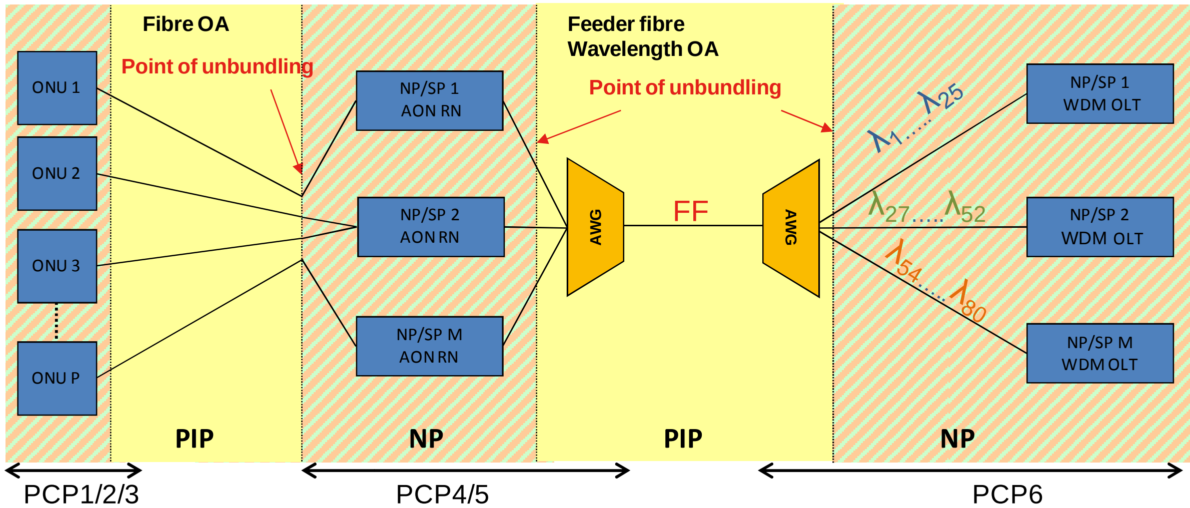


Figure 5-31: An active architecture which supplies a multiple NP scenario over an transparent PIP between PCP2 and PCP4/5, and an opaque PIP between PCP4/5 and PCP6.

It is also possible for the NP to share the uplink between PCP4/5 to PCP6 by multiplexing the different NP wavelengths in to the WDM-based link. This requires a limited amount of coordination as the wavelength separation is enforced by the configuration of the AWGs.

5.5.2 Control and management architecture

A major benefit of NG-AON is that the same C&M solution can be used end-to-end, through the access to the aggregation/metro. Since this chapter is focusing on the OASE OA architectures, and not the aggregation/metro, so here we will not address end-to-end aspects of the C&M; this will instead be covered in chapter 6. In NG AON the RN/OLT is the same type of equipment as in the aggregation/metro so the section below will focus on the gateway. One of the main focuses in the below is to alleviate the “black box” problem discussed previously. This can be done via the use of virtualization and the goal is to simplify the NP operations by having the NP focusing on physical network nodes and to manage virtual slices of these nodes and the NP’s network infrastructure. The responsibility of more advanced C&M functions and operations can then be shifted to the SP (which would be good in the case where the SP is a national or global network and service provider). Of course in the case of less advanced SPs the NP can take a greater responsibility of the C&M operations (and has the possibility to charge for it).

GATEWAY VIRTUALIZATION

In an open access environment where one customer may get services from several providers it quickly becomes costly and problematic for each service provider to have their own gateway at the customer premises. One combined gateway could replace these multiple boxes, which could reduce both operational and capital cost, and provide a better service to the customer.

To accomplish this each service provider need to be able to run their software on the box, and for that software to have access the appropriate physical resources, such as port for network and telephony. It is also vital that these multiple service provider do not affect each other and therefore strong isolation (see chapter 3.2.1) between each service provider instants is required.

Virtualization (see chapter 3.2.2) for enterprise computing needs are well studied and several proven solution exists today, even if these solutions where developed for use on servers and workstations the development in hardware performance has made it possible to use the same technologies in current and especially future gateways. One virtualization technique that could be implemented in current hardware is the lightweight Linux based LXC, short for Linux Containers, which provides virtualization between instances in a way that is light in resource use and therefore suitable for devices with low performance.

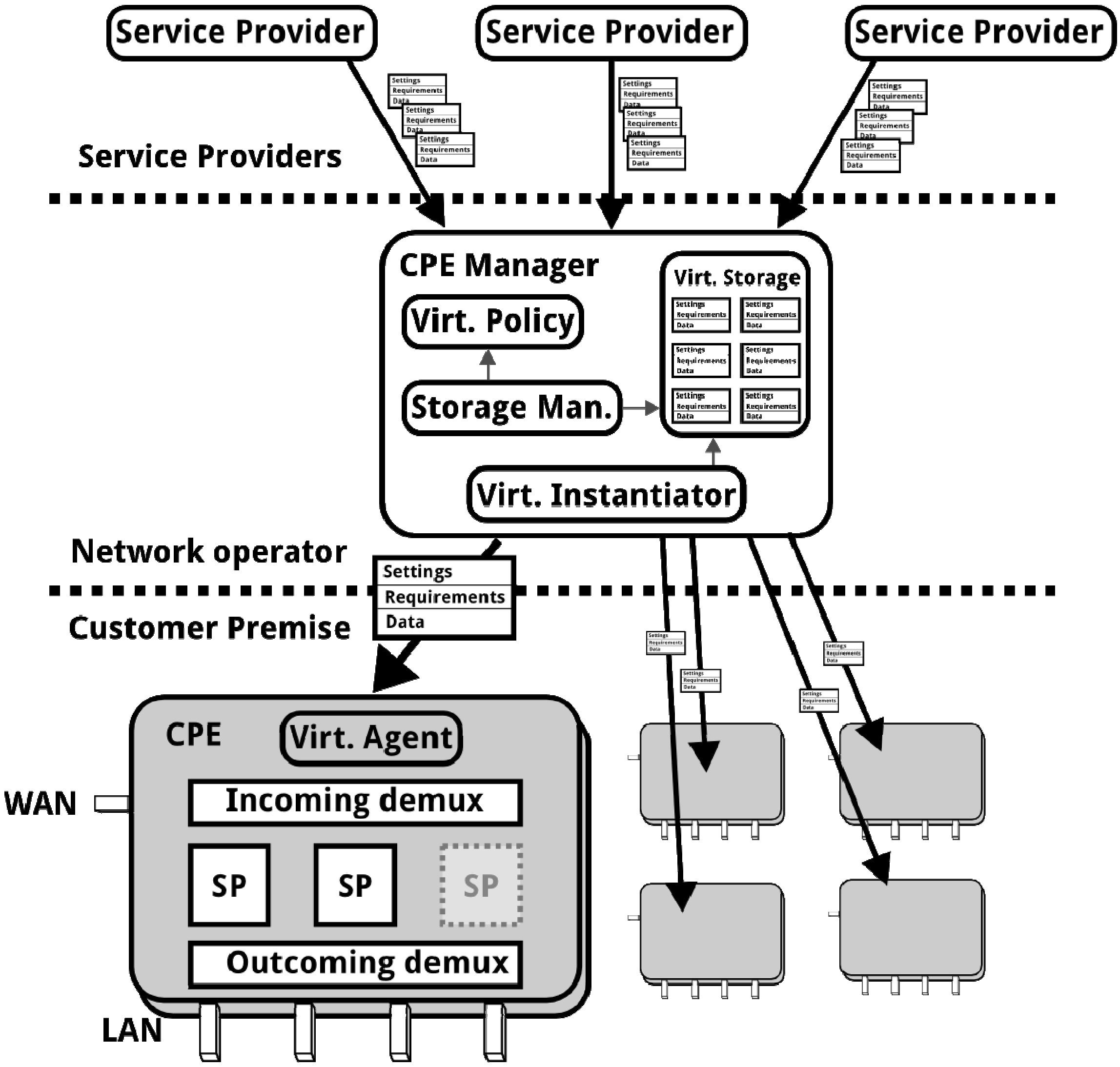


Figure 5-32: architecture for virtualization of home gateways

A prototype architecture for such a virtualization approach can be seen in Figure 5-32, where several Customer Premise Equipment receives software from a CPE Manager who in turn gets this software from the service provides. The SP could provide the software directly to the gateway, but this would require the SP to run a software distribution software server. This would also require the gateway to manage validation of the SP requirement as well as handle the resource distribution between SPs. Furthermore it would be possible for the NP to provide common gateway software, for example a simple Ethernet switch, in case the does not want advanced software on the gateway. More specifically the components in this architecture are:

CPE

Each customer device is capable of running several instances of service provider software, using for example Linux LXC. The instantiation of these service provider instances are controlled by a virtualization agent, who is responsible for the correct setup based on the setting, requirements and data received by the CPE Manager.

There is also a need to isolate the incoming data from the network and route this traffic to the correct instance, which can be solved with any number of encapsulation technique, for example VLANs or MPLS tunnels. The same is true for the home side of the network ports; here one can separate the virtualization stances on port, meaning each instance gets exclusive control over a network interface. It is also possible for several instances to share an interface facing the home side but presents more complications, but handling the de-multiplexing on the packet level between the SPs is none trivial.

For other types of ports, such as VoIP port, these ports needs to be allocated exclusively to one service provide instance as sharing such a resource is hard or in some cases impossible or impractical, as they are not packet based ports or even analogue.

CPE Manager

The network operator runs a node in its network that is in charge of instantiating and managing the gateways in the network. Each service provider sends the settings, requirements and the software to this node, where it is stored. Using this information the manager knows when to instantiate and what resources go give to an instance provided by the service provider.

Each gateway in the network keeps in contact with the manager and receives instruction and data for creating instances of the service provider's software. For example when a customer select a new service provider for a VoIP service the manager pushes an instance of the service providers software down to the gateway, who in turns start the software and there for enables the customer to start using the service.

Service Provides

Each service provides send a set of requirements, specifies the need of the software, the required settings and finally the actual C&M plane software data.

This solution could be built today with current hardware and software but more research to the details are needed. Especially the isolation between service provider instances needs to be explored in further detail.

5.5.3 Evaluation

In NG-AON (active star and home run) the main focus is on a single NP over a fibre open access, i.e. not unbundling on the wavelength level. This does not exclude fibre unbundling and therefore allows for multiple NPs on parallel fibre strands and sharing on the site level. A NG-AON open access platform can be accessed on multiple layers and multiple geographical locations from PCP2 to PCP5 or PCP6 (pure open access) or up to PCP7 (open access and aggregation/metro), see Figure 5-28. A point-to-point (home run) scenario on Layer-2 Ethernet can also be created utilizing PtP wavelengths through a WDM-PON system (for open access implications in this scenario see chapter 5.2). In order to meet WP2 requirements it is assumed that an active remote node is utilizing the WDM dimension when connecting to the main access node (in fibre rich scenarios this WDM link could be changed to multiple fibres). This can be realized via PtP WDM links, WDM-PON, or a WDM ring. Each option can realize different resilience scenarios.

Since the focus is mainly on bit-stream open access at the logical layers (Ethernet, MPLS, IP), the goal is to create a working end-to-end architecture. The main challenge is to meet the isolation needs of the logical layers, and creating and end-to-end bit-stream open access architecture based on more evolutionary virtualization techniques (should be compared to more revolutionary / clean slate approaches in e.g. EU FP7 SPARC).

6. Open access in aggregation/metro networks

As discussed in chapter 4 it is possible to have a variety of different NP/SP scenarios. One scenario is where the SP connects to the open access infrastructure in PCP7 and the open access network provider opens up its infrastructure also in PCP7. As with the access network the aggregation/metro network can be opened up on different layers e.g. fibre, wavelength or bit stream. The main focus in OASE has been on opening the aggregation/metro network up on the bit stream layer. All of the open access architectures discussed in the previous chapter is assumed to be handled by the open aggregation/metro network described in the following text.

Below we start with a short section on current open aggregation/metro architectures and then move on how to mitigate certain issues (e.g. see D3.1 NG AON section for a more in depth discussion of these) of these in the next generation architectures.

6.1 Current Architectures

Current open access aggregation/metro networks are closely related to the current aggregation/metro solutions already covered in D3.1. These architectures include multi-layer Ethernet and MPLS as higher layer architectures, and passive WDM and OTN as lower layer architectures. Complementary to these, and used in open access applications, is an IP based, i.e. routed architecture, which utilizes IP routers in all topological positions (PCP4 to PCP7). Current open access in aggregation/metro architectures is mainly realized on the higher layers, i.e. an end-to-end OASE scoped open infrastructure including an aggregation/metro network that utilizes a multi-layer Ethernet (e.g. [5]) or an IP based forwarding architecture. Multi-layered VLAN hierarchy and filter based IP forwarding creates a fairly isolated resource allocations per SP.

D3.2 also covers the aggregation/metro network and it shows both a physical tree and ring topology (where the ring allows for higher level mesh topologies). As indicated in chapter 3.3.2 there are some implications of these when applied to an open access infrastructure scenario. One implication is that the access architectures lead to two main cases; 1) multiple NP, and 2) a single NP in PCP5/6 (Figure 6-1). In the aggregation/metro part this leads to, in case 1), the need of having separate and parallel transport between PCP5/6 and PCP7. In case 2) as single shared transport is utilized. The main difference between the two cases is capacity dimensioning of the aggregation/metro system/systems and the floor space and fibres used.

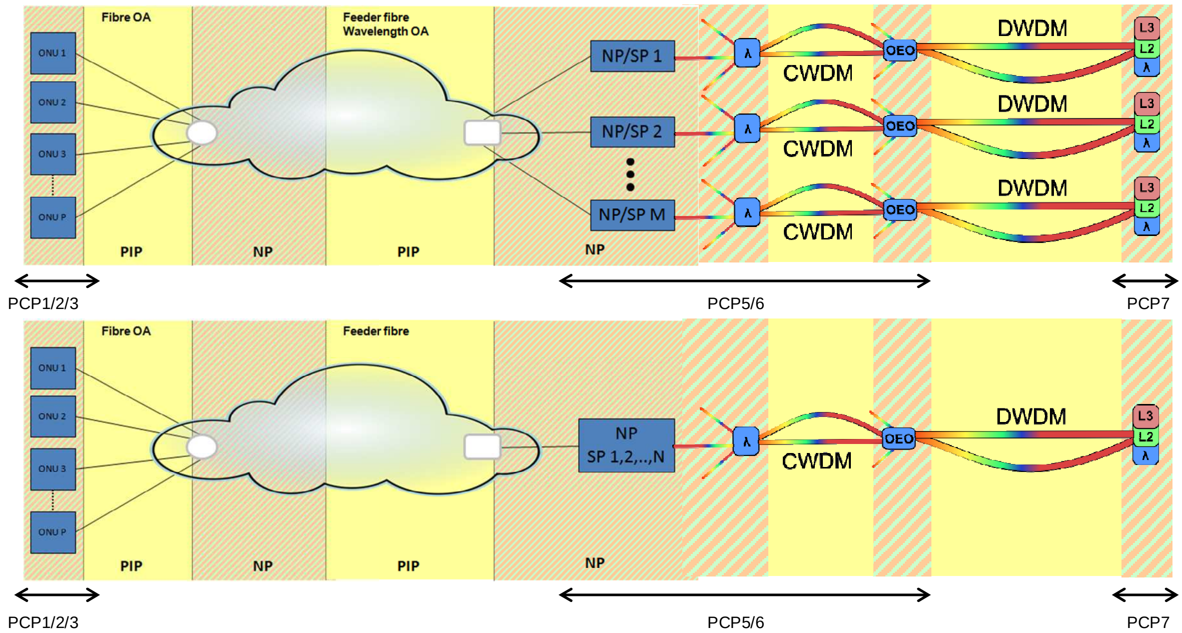


Figure 6-1: The top figure shows an architecture that is open in the access (wavelength OA) while the aggregation/metro part is not shared. The bottom figure shows a E2E type open infrastructure which covers the full OASE scope. The equipment located in PCP5/6 depends on consolidation scenario.

In reality the open aggregation/metro architectures of today quite commonly are a mix of Ethernet and IP, where the forwarding element located in PCP7 is, usually, Ethernet terminating, i.e. it forwards on the IP level. Traffic forwarding to different SPs are usually IP filter based, which puts a requirement of SP coordination of the IP address, both uni-cast and multi-cast, ranges used by the SPs. The positive side of these hybrid architectures is that it less of an issue with of VLAN ID scalability than a pure end-to-end Ethernet solution can have (employing a full multi-layer 802.1Q hierarchical Ethernet solutions does not have these scalability issues). A hybrid solution also add some added functionality of filtering of traffic since IP based network element usually have a more advanced set of tools for these functions. On the other hand does a pure Ethernet solution have an added benefit in migrating to an IPv6 based world since such a migration would be more or less transparent from a forwarding point of view (IP based switch management would require a migratory step). For a discussion on how the external interfaces to an open infrastructure relates to this please see chapter 3.3.1.

However, in the OASE context the goal of next evolutionary development of open aggregation/metro network is to lower the need of coordination between SPs (e.g. VLAN or IP address coordination), to allow for the SP to have more or less full control over its segmented piece of the shared access and aggregation/metro infrastructure. The reason for the first one is that coordination increases the threshold of delivering services over a shared infrastructure since coordination would lead to higher costs. The second goal, we call the black box problem since in current solutions the SP has none or little insight of the shared infrastructure, which leads to high support cost when troubleshooting. Another side of this benefit is that the NP of the shared infrastructure gives away responsibility of operations to the SP which in turn lowers requirement on the technical staff of the open infrastructure network provider.

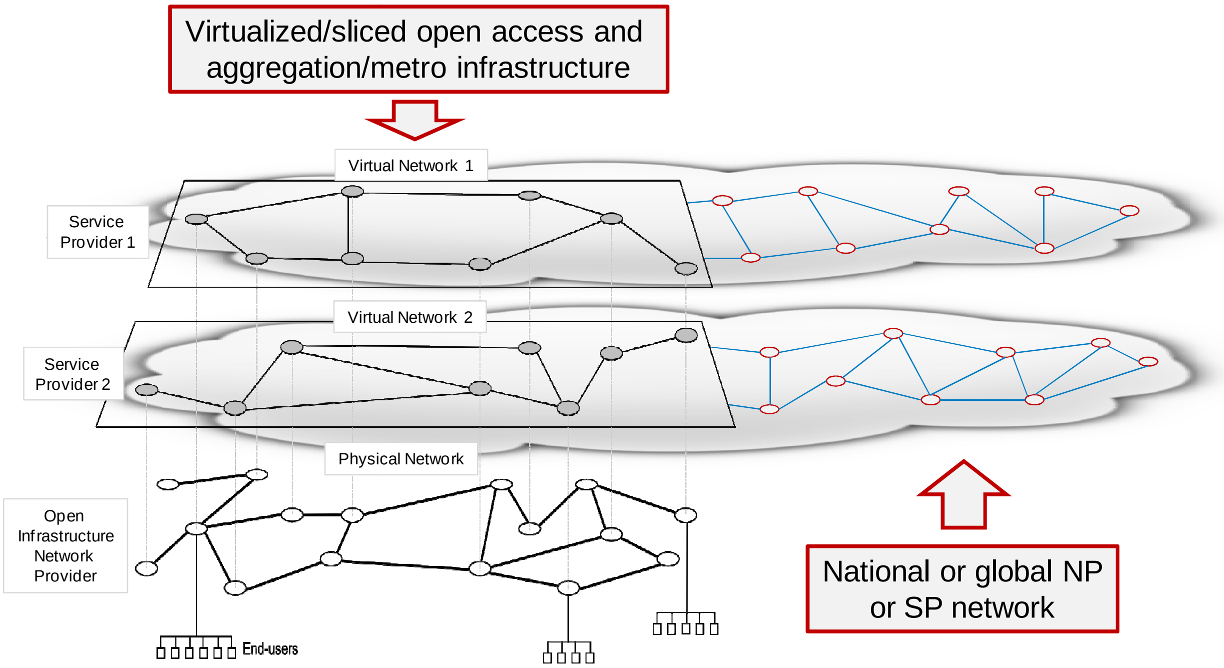


Figure 6-2: Shows an open access and aggregation/metro network that is an extension of the SP's or national/global NP network.

Isolation and virtualization techniques of data/forwarding and control/management planes are a way forward in working towards these goals (see chapters 3.2.1 and 3.2.2). In software defined networks e.g. OpenFlow based architectures (see OASE D3.1 and FP7 project SPARC) a more clean slate approach is employed while in OASE we try a more evolutionally approach which tries to utilize already existing techniques. An OASE architecture that employs such techniques is shown in the below section on next generation aggregation/metro architectural configurations.

6.2 Next generation configurations

This section describes potential future configuration options for handling open-access network with an end-to-end scope.

6.2.1 Virtualization based on VRF/VSF

One virtualization solution that could be deployed today is one based on L3 forwarding (either IPv4 or IPv6), where each router is separated by the today available VRF (Virtual Routing and Forwarding) solutions. In this solution each SP gets its own virtual instance of the IP router, where each instances is separated on the layers below. Wavelengths could be used for separation, where enough are available. For other links VLAN tagging could be used, where the VLAN ID on each packet is used to switch the packet into the correct VRF instance. Please refer to chapters 3.2.1 and 3.2.2 for an initial discussion on isolation and QoS, and virtualization between virtual slices.

A similar variation of this is VSF (Virtual Switching and Forwarding), which work on the same principal but on L3 and uses different packet-level separation when physical separation (port/wavelength) is not possible. This would be similar to what is the realization of MPLS based L2VPNs, which uses a smaller scale version called Virtual Switch Instance when emulating Ethernet functions at the egress of pseudo-wire tunnels. There are several possible approaches for packet-level separation, but perhaps the most realistic is to use S-VLAN based separation, which means each VSF instance can use all of the C-VLAN name space.

This enables the NP to easily perform the initial creation and separation of the VRF/VSF instances (see Figure 6-3), a process that easily could be performed automatically by a NMS. The NP would then provide connectivity from each VRF/VSF instance to the SP, where the SP then configures the instance, which then can use control and management plane protocols that fits with its own infrastructure in order to create an end-to-end SP infrastructure (see Figure 6-2).

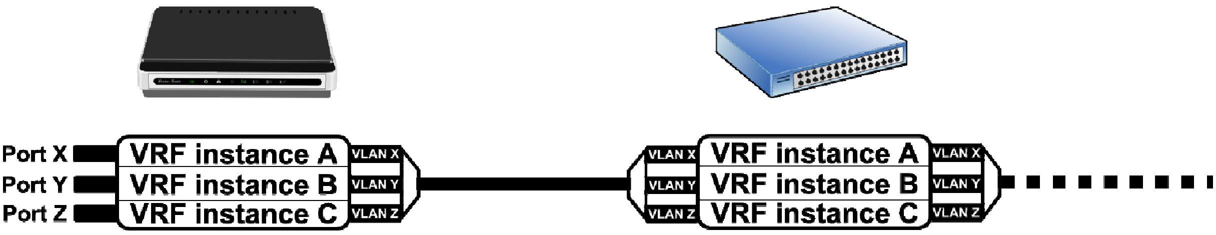


Figure 6-3: Example of VRF configuration with a configurable home gateway, with VLAN tags for packet-level separation.

This approach could be utilized from the NP/SP border all the way to the gateway, giving the SP full control of its slice of the network on L2/3. Where the separations of VRF/VSF instances on the gateway could be done based on port. This means that traffic entering port X would be handled by SP X. The combination of VRF and VSF in a network would also fit well with NP that uses L3 equipment in access and used L3 equipment in aggregation. The downside if the approach is that it lacks the possibility for the SP to affect the optical routing of the network, if such would exist.

6.2.2 Virtualization based on OpenFlow

Software defined networking is today a popular research topic, where OpenFlow is popular variation of this. OpenFlow offers many interesting possibilities for virtualization, many which can be applied to open-access networks. This research topic is researched in many projects, include FP7 project SPARC, and will therefore not be discussed here (a short introduction can be found in D3.1).

6.2.3 Virtualization based on GMPLS

Optical elements must be a part of the access/aggregation network to handle the long term OASE objective of 300-500 Mbps sustainable bandwidths per customers, and it is therefore desirable to have a virtualization solution which provides the NP/SP with the possibility to slice and control the routing of wavelengths. This could for example be used to bypass active equipment or to change the bandwidth allocation to network nodes based on changes in the network (see D4.4 for a none open aggregation/metro solution that incorporates parts of this). The technology closes to achieving a standard protocol suit to control optical network is generalized multi-protocol label switching (GMPLS) (see D3.1), which is a suit of protocols standardized by IETF. It consists at its core of two mandatory protocols, OSPF-TE and RSVP-TE, augmented with extensions to support more generic resources. Topology distribution is handled by OSPF-TE and RSVP-TE handles the actual resource allocation.

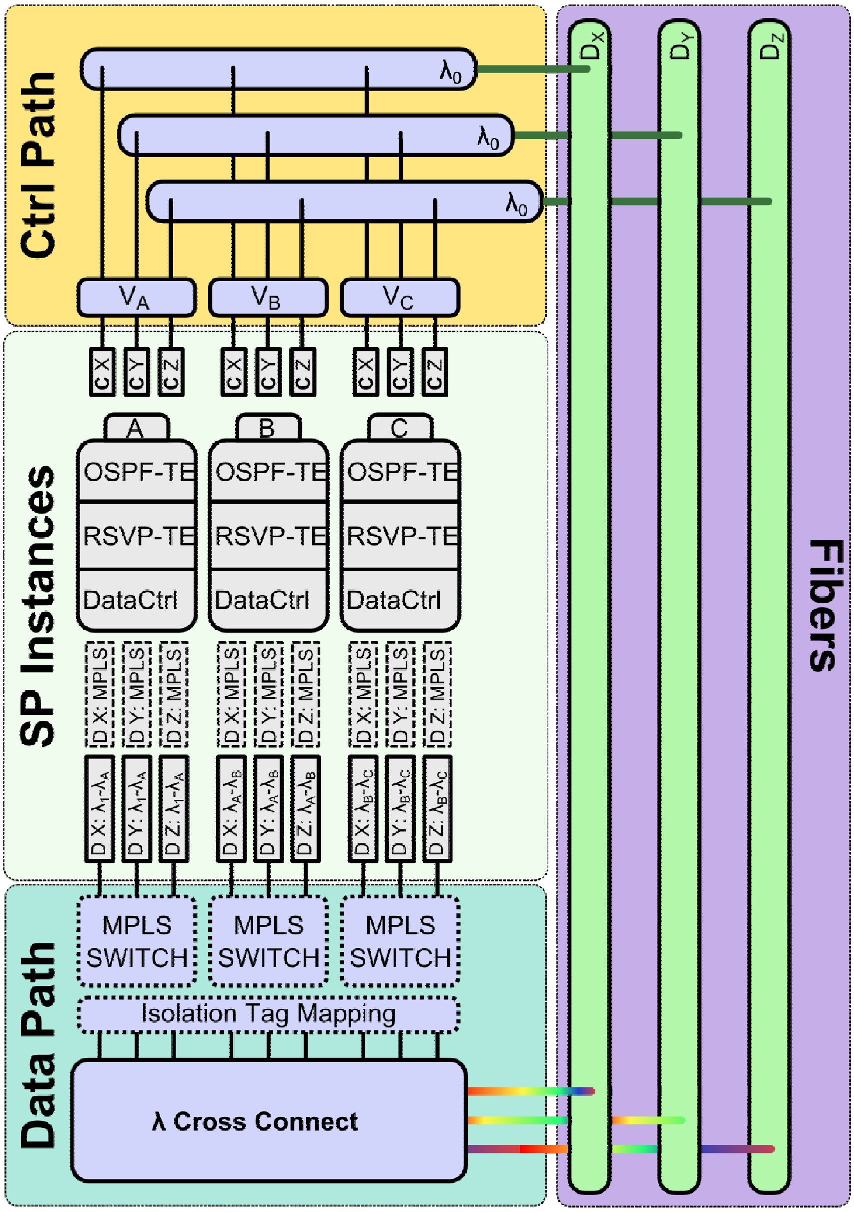


Figure 6-4: Virtualization of a GMPLS node, which supports both electrical and optical switching, based on creating multiple instances of the GMPLS control plane.

This protocols suit could be separated to support virtualization, so each SP could control its part of the network, including both optical and electrical forwarding. One approach to this, visualized in Figure 6-4, is to have several instances of the GMPLS control software running on each node. With this approach one wavelength would be used for in-band signalling, proving connectivity to each node (Ctrl Path). This channel would be separated using VLANs to provide one VLAN per SP, and isolating SPs control traffic from each other. The same channel is used by the NP to control and configure the instances. The VLAN tagging of the control traffic need to be enforced by the node, and should therefore be transparent to the SPs. Each instance, which is control by a SP, would then have control of a subset of the wavelengths offered by the node. In this case the traffic for each SP is separated using wavelengths and each SP has therefore unrestricted use of all electrical forwarding.

The network traffic needs to be slices for electrical nodes without WDM based interfaces as well, for example in case of a NG-AON RN. In such a node the uplink is WDM based, but the interfaces facing the customers are not. In this case 802.1AD S-tags could be used to separate the traffic, and still provide each SP unrestricted usage of 802.1Q tags as well as MPLS labels. The gateway at the customer would tag the traffic with S-tags based on the received port, which value would correspond to a SP, and the get forwarded to the RN where it is sent to the corresponding SPs forwarding table. For the MPLS layer this could also be done by pushing an extra MPLS tag on the outgoing MPLS frames, this tag would identify the service provider. When a MPLS frame is received the reverse would be performed, the tag is removed and based on this value the frame is give to the correct service provider instance.

The limiting factor for the implementation of this method is the amount of control plane resources on the node, most critically the amount of memory. Resource limits must be set between control plane instances to prevent one SP to affect the control plane of other SPs. The same kind of limits needs to be enforced on the forwarding plane of the node, so that the forwarding engine table space is not all used by one SP instance (see the discussion of hierarchical QoS in chapter 3.2.1).

A way to reduce power use is to shutdown unused devices or parts of devices, like interfaces, for example as described in D4.4. This kind of approaches requires interworking between SP in a virtualized network as the operation of shutting down a component may affect several SP and can therefore not be performed by a simple SP. One method for circumventing this issues to have a central path computation element for all SPs in the network, which has knowledge about both each SP slice of the network as well as the complete view of the network. This element can therefore make allocation recommendations which take the full state of the network into consideration. By using this approach the some network element could still be shutdown even in a virtualized network.

6.2.4 Pure IP network

The long term evolution of services points to future scenarios where all services are delivered as internet based services, even if they could still be terminated inside the SP network. Examples of such services today include NetFlix, Spotify and Youtube. These services are delivered purely via publically routable IPv4 addresses and do not require any special configuration of the network.

This leads to a future where a customer’s primary choice is its internet service provider and there is therefore no need configure the network for specific services, like for example IPTV. A SP can still provide several services, but they are deployed as normal internet based services, and require that a customer has an internet service.

The common argument against such a future is the problem of live TV broadcasts, where many customers want access to the same live contents. This could for example be the world cup in football. Today these scenarios are resolved by using multicast, where the access/aggregation network is configured to handle these streams and set-top boxes configured to receive it. But the use of multicast is problematic for internet based streams and can practically not be implemented over the internet. Instead the contents could be unicasted to the customers, which is technically simple to implement. But this requires extra bandwidth as the content need to be sent to each customer individually. The scalability of this method depends on where content source is located, if placed near the customer the extra bandwidth is reduced. This method of distribution of live content is actively used by Google, who’s record at the time of writing is six million concurrent views [33] by using unicast streams from a CDN. It is therefore possible to resolve live streaming of video content by using a CDN network with nodes near the customer but requires a network with high available bandwidth, such as the architectures considered in OASE (see chapter 4 for additional aspects of locality based traffic).

The approach to solving live streaming could be further improved by using peer-to-peer offloading, in addition to using a CDN network (e.g. see chapter 4.3). In this case the devices at the customer would send data to other devices in the access/aggregation network, and thereby reducing the need for traffic higher up in the network. A practical example of this could for example be that the live content is first streamed to a customer A, which retransmits the data to customer B who join the live stream later. To what degree this is acceptable for the customer depends on how important the liveliness of the stream is, and if what happened earlier in the stream matters. For example the opening ceremony of the Olympics is an event which a customer might wants to see from the start, and a delay could be acceptable. The timeliness sporting events are more important and in this case only small delays may be acceptable.

Running such a network on IPv6 also resolves the need to use private address spaces since IPv6 has a large address space. This means that routing in the NPs network becomes easy, and can be handled with normal routing protocols. Address assignments could be performed either by using static IPv6 address methods or via Neighbour Discovery Protocol (NDP) if dynamic address assignments are needed.

7. Open access summary

In this chapter we will summarise all open access architectural aspects. We begin with a summary in table form which describes OA aspects of the access architectures from chapter 5. Following that is the short list of open access, which is a list which tries to represent the more probable of the above solutions. This short list is the fruit of collaboration with WP5 and WP6, and is very much influenced by a set of business model requirement. The chapter ends with a general summary which summarises the full deliverable.

7.1 SUMMARY TABLE

The following tables compare all the different next generation optical access architectures which have been geared towards use in open access networking scenarios. The goal of these tables is to give the possibility of a high level comparison and see the strengths and weaknesses of the architectures.

The information of the tables is mainly based on the OA architectures in chapter 5, but some are a qualitative assessment of the architecture. Examples of such a qualitative assessment are; "complexity of solution" in Table 6 and Table 7, or "amount of co-ordination needed between NPs" in Table 7, or "Maturity of OA solutions" and "Maturity of OA virtualization solutions" in Table 8. These qualitative assessments represent a highly important indication of the architectures by the gathered expertise in OASE.

Table 6: Fibre Open Access

Architecture	WR-WDM-PON	WS-WDM-PON	UDWDM-PON	Hybrid WDM/TDM PON	Hybrid WDM/TDM PON with WSS	Two-stage WDM-PON	AON (PtP)	AON (Active Star)
Fibre Open Access	YES	YES	YES	YES	YES	YES	YES	YES
Can be opened up in remote node?	YES	YES	YES	YES	YES	YES	NO	YES
Fibre OA interface (typical options)	PCP4	PCP4	PCP4	PCP4	PCP4	PCP4	PCP5	PCP4
Complexity of solution?	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Simple	Simple
Co-location needed (best case/ worst case)	BC: PCP4 WC: PCP4,6,7 (PCP5 optionally)	BC: PCP4 WC: PCP4,6,7 (PCP5 optionally	BC: PCP4 WC: PCP4,5,6,7	BC: PCP4 WC: PCP4,5,6,7	BC: PCP4 WC: PCP4,5 ,6,7	BC: PCP4 WC: PCP4,5,6,7	BC: PCP5 WC: PCP5,6,7	BC: PCP3 or PCP4 WC: PCP3 or PCP4 and PCP5,6,7

Table 7: Wavelength Open access

Architecture	WR-WDM-PON						WS-WDM-PON	UD-WDM-PON	Hybrid WDM/TDM-PON					Two-stage WDM-PON	NG-AON
Variant	**Feeder Fibre**	**Manual**	**Electrical**	**Power Splitter**	**Wave-band Splitter**	**WSS**	**Power Splitter**	**Power Splitter**	**Feeder Fibre**	**Power Splitter**	**Wave-band Splitter**	**WSS**	**Secure with Feeder Fibre**	**Wave-band Splitter**	**Generic**
Wavelength Open access	YES	YES	YES	YES	YES	YES	YES	YES but problematic	YES	YES	YES	YES	YES	YES	NO
Amount of coordination needed between NPs?	Minimal	Minimal	Minimal	High	Medium	Medium	High	High	Minimal	High	Medium	Medium	Minimal	Medium	N/A
Amount of concurrent NPs?	Limited to amount of FF	Limited to amount of FF	Limited to cross-point switch	High	Pre-con-figured	High	High	High	Limited to amount of FF	High	Pre-con-figured	High	Limited to amount of FF	Pre-con-figured	N/A
Security layer needed?	NO	NO	NO	YES	NO	NO	YES	YES	YES	YES	YES	YES	NO	NO	N/A
Can all NPs reach all ONUs?	YES	YES (manually)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	N/A
Can a NP OLT interfere with OLTs from other NPs?	NO	NO	NO	YES	NO	NO	YES	YES	NO	YES	NO	NO	NO	NO	N/A
Can an ONU interfere with ONUs of the same NP?	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	N/A
Can an ONU interfere with ONUs from different NPs?	NO	NO	NO	NO	NO	NO	YES	YES`	YES	YES	YES	YES	NO	NO	N/A
Wavelength OA type	PtP	PtP	PtP	PtP	PtP	PtP	PtMP	PtMP	PtMP	PtMP	PtMP	PtMP	PtMP	PtP	N/A

Support of Broadcast overlay wavelength (e.g. Video broadcast)	NO	NO	NO	NO	NO	NO	YES	YES	YES (between PCP2 and PCP5)	YES (between PCP2 and PCP5)	YES (between PCP2 and PCP5)	YES (between PCP2 and PCP5)	YES (between PCP2 and PCP5)	NO	NO
Complexity of solution?	Low	Low	Medium	Medium	Low	High	Medium	High	Low	Medium	Low	High	High	Medium	Medium
Passive equipment is WDM/PHY layer technology agnostic (Transparent or Opaque)	Opaque PIP						Opaque PIP	Opaque PIP	Opaque PIP					Opaque PIP	Trans-parent PIP

Table 8: Bit-stream Open access

Architecture	WR-WDM-PON	WS-WDM-PON	UDWDM-PON	Hybrid WDM/TDM-PON	Hybrid WDM/TDM-PON with WSS	Two-stage WDM-PON	AON (PtP)	AON (Active Star)
Bit-stream Open access	YES	YES	YES	YES	YES	YES	YES	YES
Maturity of OA solutions?	No commercial systems	No commercial systems	No commercial systems	No commercial systems	No commercial systems	No commercial systems	Commercial systems available	Commercial systems available
Maturity of OA virtualization solutions	Research topic	Research topic	Research topic	Research topic	Research topic	Research topic	Research topic	Research topic
First location of NP-SP interface	PCP6 + PCP7	PCP6 + PCP7	PCP6 + PCP7	PCP6 + PCP7	PCP6 + PCP7	PCP4 + PCP7	PCP5+ PCP6+PCP7	PCP3+PCP6+PCP7 or PCP4+PCP6+PCP7
Identification (Line-ID) added by	OLT	OLT	OLT	OLT	OLT	OLT-1	PCP5 Switch	First Switch at PCP3 or PCP4
Customers physical location fixed, no nomadic access (refer to 3.2.4)	YES	NO	NO	NO	NO	YES	YES	YES

(1) Assuming layer-2 aware NGOA system technology

7.2 OPEN ACCESS SHORT LIST

This section describes a short list of all the open access architecture variations which has been transferred to WP5 and WP6 for evaluation. The short list has been created in collaboration with WP5 and WP6 in order to zero in on the most relevant and likely versions of all that has been researched.

In order to narrow down the full list of OA architectures WP6 supplied the following business model related requirements (in no particular order):

- Concurrent NPs
    - An end-user can have multiple NPs in a slowly varying serial manner or in a parallel manner (thought less likely), and in preferably in a non manual way
    - Mainly applicable to wavelength open access, since in fibre and bit-stream open access a change of NP would mainly be done in a manual way
- Inter NP isolation
    - A rogue ONU (a misbehaving ONU – deliberate or not) should not be able to effect the service of another NP, e.g. hybrid ONUs that effect other ONUs in the same NP domain is ok, but not between NPs
- Coordination
    - No master NP, i.e. if there is a need for coordination of resources (e.g. wavelength span etc) this function should not lie with one of several NPs offering service in the same area
    - It should, if needed, be coordinated by the PIP since it is considered the most neutral party

The last two requirements are the most stringent since this introduces the need of high isolation on the OA architectures. This is especially hard those architectures that targets a wavelength open access scenario. The end result was that in order to open up on the wavelength level, a cost hit was needed in replacing optical splitters (which have low degree of isolation) with reconfigurable optical filters (e.g. WSS) and AWGs. However the cost hit per end-user is not great. But it shows that the open and vertical business models are not easily combined since in this case there would be a need of exchanging all splitters installed if the NP wants to go from a vertical to an open architecture. And being able to utilize existing power splitters in migration scenarios is one of the more stringent requirements in PON based accesses.

The resulting short list of open access architectures are:

- Fibre open access
    - Transparent PIP
        - Usually fibre rich
            - Green field infrastructures which maximises on fibre count
        - Normally point-to-point on fibre and optical level
- Wavelength open access
    - Opaque PIP
        - Usually fibre poor
            - Brown field infrastructures that optimizes on fibre count
        - Includes optical devices
            - Optical devices – e.g. optical splitters, AWGs, WSSs

            - Legacy installations are normally point-to-multi-point on optical level (i.e. splitter based), while new installations can be point-to-point (i.e. purely AWG or WSS based)
    - WDM-PON
        - Wavelength routed (WR) WDM-PON
            - AWG and multi feeder fibre based
    - Hybrid WDM PON
        - Passive hybrid WDM PON
            - Multiple feeder fibre with NP isolation
- Bit-stream open access
    - WR WDM PON
        - A “pure” optical ptp WDM PON
            - No optical splitters for shared medium applications
    - NG-AON
        - Active remote node with WDM backhauling

Including these short listed architectures into the full scope of WP3, i.e. including the aggregation/metro network, show that there are basically two scenarios where focus is 1) on wavelength open access in the pure access, and 2) on bit-stream open access in the full OASE architectural scope. In Figure 7-1 on can see what these different focuses lead to. 1) pushes the SP to the access and to the need of having and operating an aggregation/metro network, while 2) allows for sharing of the network infrastructure in the aggregation/metro network. The first one is comparable to the current situation of when unbundling has occurred in the copper access, while the latter is also referred to the E2E type of open access infrastructures (see Figure 2-1).

Applying these to the open access reference model in order to see on which level and at which point in the network an infrastructure is opened up yields what is shown in Figure 7-1. It shows the open access interface occurs on all studied levels in PCP2, and on all PCPs on the fibre level. PCP5 and PCP6 are used for wavelength open access but also for backhauling purposes. PCP7 is mainly used for bit-stream based E2E type open access infrastructures.

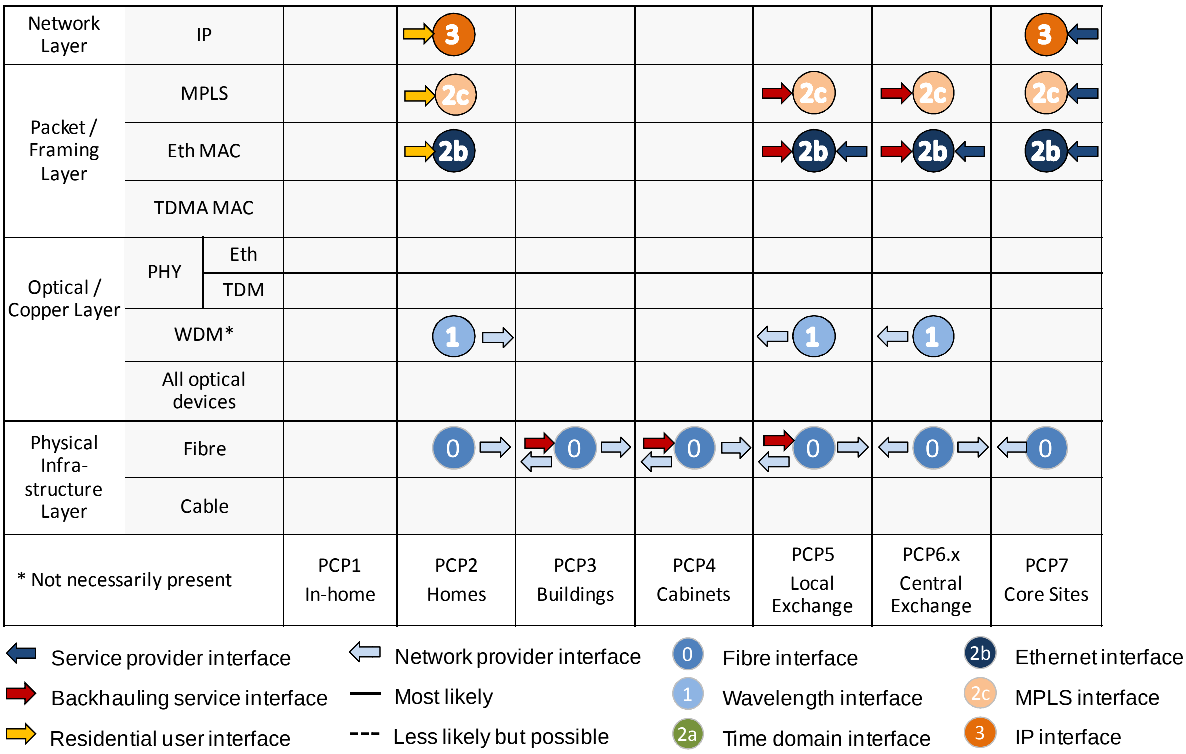


Figure 7-1: The resulting open access reference model figure based on the short list of OA architectures delivered to WP5 and WP6

7.3 General Summary

In this deliverable we have evaluated and developed access and aggregation/metro network architectures for open access type scenarios, and analysed traffic patterns and its implications on next generation optical access and aggregation/metro networks with a qualitative analysis of the impact on open access. The deliverable has had the full OASE scope defined in D3.3, i.e. from a gateway at the customer premises to the core network edge.

An initial background to the open access networking business model was given, where the aim is to share infrastructure in order to lower the costs borne by the entities utilizing the open access infrastructure. The business model has implications on the network architecture at mainly three levels; 1) fibre, 2) wavelength, and 3) bit-stream.

In order to visualize where and on which level open access is made possible by the architectures under study, an open access reference model has been developed and used when describing the different variations of open access architectures. It was used in order to describe all variants of the open access architectures and as well when creating the short list of open access architectures to be used by WP5 and WP6.

It has been identified that the main impact on the physical infrastructure provider (PIP) is due to opening of the wavelength level. This lead to the need to modelling the PIP in two different ways, i.e. an opaque PIP and an transparent PIP, where an opaque PIP is a PIP that needs to manage optical devices (e.g. optical splitters, arrayed waveguide gratings (AWGs), and wavelength selective switches (WSSs)). The reason for this is that wavelength open access leads to the need of having an entity that manages and coordinates the optical spectrum (wavelength) access between the entities that utilise it, i.e. the network providers. It is possible that the PIP or NP, or even a totally separate entity could coordinate this. However, based on discussion with e.g. WP6 it was decided that the most likely and neutral entity would be the PIP.

A transparent PIP is more of a traditional role. Otherwise it is mainly the scope of OASE that leads to an extended scope of open access, i.e. OASE fibre open access is not only opening of the FTTH but also the dark fibre infrastructure in and between sites leading up to the core. Also the dimensioning of the sites (co-location) needs to take into account the possibility of multiple network and service providers' equipment at these locations.

When it comes to bit-stream open access the main focus has been to increase the isolation between network providers and service providers utilizing the shared infrastructure on an electrical forwarding level, and on the control and management level. The latter alleviates the current "black box" problem in open access networking where the operator of the shared infrastructure has full control over the network while the service provider usually has little insight in the state of the shared infrastructure. This can lead to very high support costs when customers are reporting problems while the service provider does not have the tools to trouble shoot or locate the cause of the reported problems. In this deliverable a more evolutionary approach based on virtualization has been suggested, where more disruptive approaches are studied in e.g. FP7 projects like SPARC.

In the end the evaluation and development of open access architectures lead to six different versions of WDM PON, five different versions of Hybrid PONs, and a single of each of the two stage PON and NG AON, and this does not include the fact that you can run bit-stream open access over any of the different architectural versions. However, based on the discussions with WP5 and WP6 we ended up with a short list of architectures that included four different WDM/Hybrid PONs and AON based architectures that fulfilled the requirements.

Also included in the work are studies related to traffic flows which have a focus on video content distribution and the locality and caching of such traffic flows. If there is such a locality aspect in the nature of the traffic flows then this would counteract some of the expected benefit of extreme consolidations. The reason would be that it would not be optimal to send traffic into the core when it could have been kept more locally in the access. The locality study show that even though not utilizing an highly distributed caching infrastructure there were at least 18% simultaneous users of the same video content. With caches this figure would go up and architectures that allows for such traffic flows would then off load the core network to a fairly high degree.

In summary the main contributions of the deliverable is the work on; different open access models, open access reference model, optical monitoring in multi network provider scenarios, traffic studies, the large variety of wavelength open access architectures, evolutionary virtualization based open access architectures, and the short list of open access architectures based on discussions with WP6 which will be vital to the further analysis of the architectures within other work packages.

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