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BEREC Report on the New Forms of Sharing Passive Optical Networks Based on Wavelength Division Multiplexing

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1 Introduction and objective

New forms of sharing passive optical networks (PON) have become possible, in particular with the adoption of the new PON standard NG-PON2 (G.989.2), which was approved by the ITU in December 2014. NG-PON2 uses several wavelengths per direction over the same PON fibre infrastructure to serve multiple end-users. This raises the opportunity that several network operators share the same PON fibre infrastructure and each deploys its own NG-PON2 equipment and uses different wavelengths. Examples of how this new form of sharing PON might be used are: (i) Two or more operators co-invest in PON fibre infrastructure and each deploys its own NG-PON2 equipment and uses different wavelengths to serve customers. (ii) SMP operator invests in and deploys NG-PON2 and is obliged by regulation to offer wavelengths, i.e. wavelength unbundling (WU) (iii) Single (potentially, but not necessarily SMP) operator invests in PON fibre infrastructure and deploys NG-PON2 and offers access to wavelengths on a commercial wholesale basis. In principle, WU is also possible without deployment of NG-PON2, however, the possibilities are reduced compared to those in case of NG-PON2. In 24 (80%) of 30 European countries examined in this report, the SMP operator has a FTTH network based on PON and therefore NRAs may consider whether or not to impose WU on the SMP operator.

In order to get a deeper insight in this new form of sharing PON based on wavelength division multiplexing (WDM) and to foster the knowledge transfer between NRAs, this report has the following three objectives:

- to provide an overview of the current and expected future deployment of NG-PON2 based on information from 50 European network operators and three major vendors;
- to analyse whether WU was imposed in any of the 14 EU countries[1] in which NRAs took a decision on Market 3a since the standardisation of NG-PON2 and to discuss aspects which may be useful to take into account when an NRA considers whether or not to impose on the SMP operator WU;
- to explore whether WU based on NG-PON2 might increase the interest of network operators to co-invest in PON also based on information of 50 European network operators.

The analysis is descriptive and does not aim to be normative or to recommend best practice.

The information from European network operators and major vendors was collected based on questionnaires. Table 1 provides an overview of how many network operators, which have a FTTH network based on PON, completed the questionnaire per European country. 16 (32%) of these 50 network operators are incumbents, the other (68%) alternative network operators (ANOs).

[1] Bulgaria, Croatia, Cyprus, Denmark, Germany, Greece, Italy, Lithuania, The Netherlands, Portugal, Romania, Slovak Republic, Spain and Sweden

The questionnaire for vendors was sent to five major vendors who offer NG-PON2 systems (ADTRAN, Calix, Huawei, Nokia, ZTE) and participated in the standardization of PON. Three of them (ADTRAN, Nokia and ZTE) completed the questionnaire.

Table 1: European network operators which have a FTTH network based on PON and completed the questionnaire

Country	Number of operators	Country	Number of operators	Country	Number of operators
Austria	1	France	2	Norway	1
Bulgaria	12[2]	Germany	4	Portugal	2
Croatia	4	Italy	3	Slovakia	2
Czech Republic	3	Latvia	1	Slovenia	4
Denmark	1	Luxemburg	1	Spain	3
Estonia	1	Montenegro	3	United Kingdom	2

Source: BEREC

The document begins with an overview of PON technologies and the possibilities to unbundle wavelengths of PONs (section 2) and then provides an overview of current and expected future deployment of NG-PON2 (section 3). In the next step regulatory decisions on Market 3a are considered (section 4). This examination begins with an overview of the current status of market analysis procedures on Market 3a in Europe (section 4.1), followed by an analyses whether WU was imposed on the SMP operator in regulatory decisions on Market 3a since the standardisation of NG-PON2 (section 4.2) and, finally, a discussion of WU specific aspects which may be useful for an NRA to take into account when it considers whether or not to impose WU on the SMP operator (section 4.3). In a further step, the document explores whether WU based on NG-PON2 might increase the interest of network operators to co-invest in FTTH networks (section 5). Finally, conclusions are drawn (section 6). The document has two annexes which provide further information on PON technologies and examples of WU.

2 Overview of PON technologies and of WU

This section provides an overview of PON technologies and the possibilities to unbundle wavelengths of PONs. A more detailed description of PON technologies is provided in Annex 1 and examples of WU are discussed in Annex 2.

2.1 Overview of PON technologies

Table 2 gives an overview of PON technologies and shows the number of wavelength per direction and the data rates. All PON technologies except NG-PON2 use only one wavelength per direction. The data rates of G-PON is 2.5/1.25 Gbps (down/up) or lower (see footnote 5),

[2] Although Bulgaria is stronger represented than the other countries, the analysis of the completed questionnaires shows that the results only slightly differ when the 12 network operators of Bulgaria are not taken into account. Section 3.1 provides also the three results with the biggest difference (see footnotes 11, 12 and 13).

of XG-PON 10/2.5 Gbps, of XGS-PON 10/10 Gbps and of 10G-EPON 10/10 Gbps or 10/1 Gbps. The data rate of NG-PON2 as foreseen in the standard is per wavelength 10/10 Gbps, 10/2.5 Gbps or 2.5/2.5 Gbps and the maximum total data rate is in case of 4 (8) wavelength 40/40 Gbps (80/80 Gbps). The three vendors of NG-PON2 which provided data currently offer NG-PON2 systems with 4 wavelengths and a data rate per wavelength of 10 /10 Gbps, two also with 10 /2.5 Gbps (see section 5 of Annex 1).

These PON technologies have a point-to-multipoint topology and the wavelength is shared between different end-users (based on Time Division Multiplexing (TDM)). In contrast to the other PON technologies, NG-PON2 uses more than one wavelength per direction, however, each wavelength is also shared between the end-users (based on TDM). Therefore, another term used for NG-PON2 is "TWDM PON" (a combination of TDM and WDM).

Table 2: Data rates of PON technologies[3]

	PON technology				
	G-PON	**XG-PON[4]**	**XGS-PON**	**NG-PON2**	**10G-EPON**
Standard	ITU-T G.984	ITU-T G.987	ITU-T G.9807	ITU-T G.989	IEEE 802.3av-2009
Number of wavelengths per direction	1	1	1	4-8	1
Data rates per wavelength (down/up in Gbps)	2.5/1.25[5]	10/2.5	10/10	10/10, 10/2.5, 2.5/2.5	10/10, 10/1
Total data rate (down/up in Gbps)	2.5/1.25	10/2.5	10/10	Up to 40/40 (80/80)	10/10, 10/1

Source: Standards mentioned in the table

NG-PON2 optionally can also support a point-to-point (PtP) topology and provide a dedicated wavelength (per direction) for each customer. For this type of NG-PON2 the term "PtP WDM PON" is used. However, this type of NG-PON2 seems to be significant more challenging than the other type (TWDM PON)[6].

Currently new PON technologies are also in the process of standardisation. The ITU-T standardises the new PON technology G.metro which is a PtP WDM PON with up to 80 wavelengths (per direction) and a data rate per direction of up to 10 Gbps. IEEE works on the new standard 100G-EPON with symmetric and/or asymmetric data rates of 25 Gbps, 50 Gbps and 100 Gbps. This PON technology, however, is not suited for WU (see section 7 of Annex1).

[3] PON technologies with a downstream data rate of solely 1.25 Gbps or lower (e.g. B-PON, 1G-EPON) are not shown in the table.

[4] Another term used is XG-PON1 because the XG-PON standard (G.987) defines two types of XG-PONs, XG-PON1 and XG-PON2, but only standardises XG-PON1 (not XG-PON2). XG-PON2 was standardised later, however, in a separate recommendation (G.9807) which uses the term XGS-PON (instead of XG-PON2).

[5] Maximum data rate. The standard also foresees several options with lower data rates.

[6] E.g. currently ADTRAN and Nokia do not offer NG-PON2 based on PtP WDM PON and ZTE provided no data on that.

For the introduction of new PON technologies, it is important whether a smooth upgrade from the currently deployed (legacy) PON technology to the new PON technology is possible.[7] The NG-PON2 standard foresees a co-existence of legacy PON technologies (G-PON, XG-PON) with NG-PON2 (see section 4 of Annex 1), however, the customer premises equipment of the legacy PON (ONU) has to fulfil specific requirements defined in standards in order to work properly in the presence of NG-PON2 wavelengths. Therefore, whether a smooth upgrade to NG-PON2 is actually possible depends on whether or not the installed customer premises equipment (ONUs) fulfil these requirements (see also the operators' view in section 3.1 Figure 2).[8]

2.2 Possibilities to unbundle wavelengths of PONs

NG-PON2 uses several wavelengths per direction (see section 2.1) which raises the opportunity that. different wavelengths are used by different network operators (see section 6 of Annex 1). This form of WU enables two or more network operators to deploy their own NG-PON2 equipment (OLT, ONU) and build their own NG-PON2 based on the same PON fibre infrastructure. However, in order to enable this, some prerequisites need to be fulfilled and solutions to fulfil them are still under development (see section 6 of Annex 1).

In case of other PON technologies which only use one wavelength per direction (e.g. G-PON, XG-PON; see section 2.1, Table 2), in principle WU is also technically possible since they are based on different wavelengths.[9] Therefore, altogether several possibilities to unbundle wavelengths of PONs exist. Some examples are discussed in Annex 2. However, NG-PON2 is a more future-proof technical solution which allows two or more operators to use the same PON technology on the same PON fibre infrastructure which is not the case with the other PON technologies which only uses one wavelength per direction.

From a regulatory point of view, it is of interest whether WU is possible per end-user which would be rather similar to physical unbundling.[10] In order to enable this, the number of subscribers of each network operator connected to the same PON would need to be identified reliably. According to vendors, methods which enable this may be possible at the level of the Operation Support System (OSS) or network management but not at the NG-PON2 layer (physical layer or MAC layer) and currently such methods are not (yet) available (see section 3 of Annex 1).

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[7] In the context of this report, 'smooth' means that legacy and new systems can co-exist over the same infrastructure, allowing some customers to upgrade before others. However, upgrades are likely to involve customer disconnection to introduce the 'CE' module (see section 4 of Annex 1), and hence will invariably involve an interruption of service.

[8] The co-existence reduces the reach of the PON and therefore after the introduction of NGPON2 some end-users may no longer be within the reach of the PON (see section 4.3 point (x)).

[9] An exception is XGS-PON which uses the same wavelength (range) as XG-PON (or alternatively as G-PON) (see ITU-T 2016, p. 1, 33).

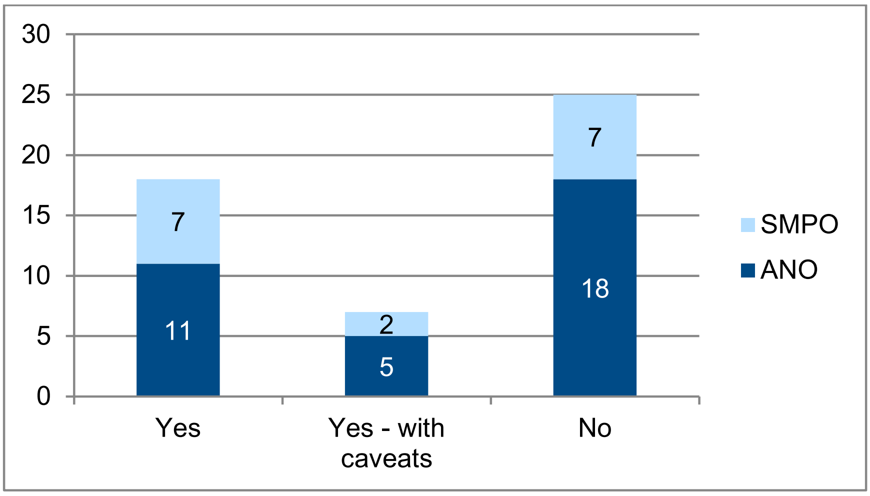
[10] With regard to colocation and ancillary services there are no differences between WU and physical unbundling since they are also necessary in case of WU.

3 Current and expected future deployment of NG-PON2

This section provides an overview of the current and expected future deployment of NG-PON2 based on information from 50 European network operators and three major vendors (see section 1, Table 1).

3.1 Perspective of 50 European network operators

All of the 50 European network operators considered have a FTTH network based on PON and to date NG-PON2 is not yet deployed in any of these networks. However as shown in Figure 1, the question whether it is likely that the company will deploy NG-PON2 in its FTTH network was answered by 25 operators (50%) with “Yes”, seven of them mentioned some caveats (e.g. with regard to time frame, certainty). Nine of these operators are SMP operators (57% of the SMP operators) and 16 ANOs (47% of the ANOs).[11]



Source: BEREC questionnaire completed by 50 European network operators

Figure 1: Is it likely that your company will deploy NG-PON2 in its FTTH network?

Table 3 provides an overview of the main reasons of the 25 network operators why it is likely that they will deploy NG-PON2 in their networks. For 16 operators, the main reason is that NG-PON2 enables higher bandwidths (in both upstream and downstream direction) and to respond to the increase of the traffic demand in their markets (residential/business market, mobile networks). Four operators mentioned, as the main reason to upgrade the network, that NG-PON2 enables wholesale wavelength unbundled services and that NG-PON2 enables the reuse of the passive network infrastructure (fibres and splitters) as well as co-existence of legacy PON and NG-PON2. For three operators, the main reason is that NG-PON2 is a future

[11] The 50 network operators considered are of 18 EU countries and one country (BG) is stronger represented than the others (see Table 1, footnote 2). Without the network operators of this country, the results are as follows. 22 (58%) of 38 network operators will likely deploy NG-PON2 and 16 (42%) not.

proof technology and four operators mentioned other main reasons (e.g. leased fibre is sparse and NG-PON2 enables to use several wavelengths).

Table 3: Main reasons why it is likely that the network operators will deploy NG-PON2

Main reason	Number of operators
Enables higher bandwidths (upstream and downstream) and to respond to the increase of traffic demand (residential/business markets, mobile networks)	16
To upgrade current network	4
Enables wholesale wavelength unbundled services	4
Enables reuse of the passive network infrastructure and co-existence of legacy PON and NG-PON2	4
NG-PON2 is a future proof technology	3
Other reasons	4

Source: BEREC questionnaire completed by 50 European network operators

Table 4 gives an overview of the current state of activity of the 25 network operators which likely will deploy NG-PON2. Three are rather close to the deployment of NG-PON2 in the FTTH network. One plans to employ NG-PON2 in the short term, another already carries out field tests and the third lab tests. Further five operators evaluate (2) or plan tests (3) of NG-PON2. 14 operators have interest in NG-PON2, three of them are tracking the development of NG-PON2 and following the market, the other 11 have not yet taken further steps so far.

Table 4: Current state of activity of the network operator with regard to NG-PON2

Current state of activity	Number of operators
Planning to deploy NG-PON2 technology in the short term	1
Small field trials	1
Several lab tests	1
Next step is testing in lab	2
Tests planned when existing supplier offers NG-PON2	1
Evaluate NG-PON2	2
Tracking the development of NG-PON2 and following the market	3
Have interest in NG-PON2 but has not yet taken further steps	11
No information	3

Source: BEREC questionnaire completed by 50 European network operators

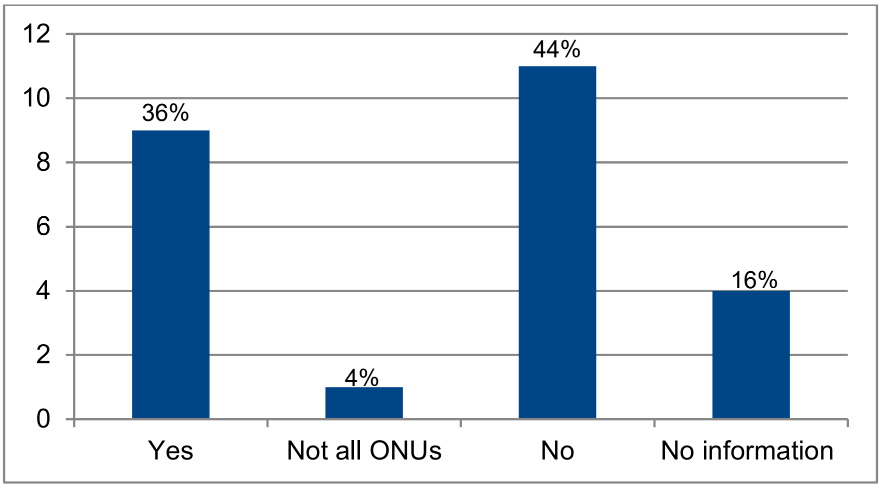
Table 5 lists the main reasons why it is not likely that the other 25 network operators will deploy NG-PON2. The main reasons are for 13 operators that capacity of existing PON technology (G-PON) is sufficient, for 11 operators the high price of NG-PON2 equipment, for four operators NG-PON2 is not fully mature and three operators each have a further main reason (e.g. operator just recently started to deploy G-PON).

Table 5: Main reasons why it is not likely that the network operators will deploy NG-PON2

Main reason	Number of operators
Capacity of existing PON technology (G-PON) is sufficient	13
NG-PON2 equipment is expensive	11
NG-PON2 is not fully mature	4
Other	3
No information	3

Source: BEREC questionnaire completed by 50 European network operators

For the 25 operators which not likely will deploy NG-PON2, a further reason could be that a smooth upgrade of the PON technology used in the existing FTTH network to NG-PON2 is not possible. Figure 2 shows that for nine of these operators (36%) such a smooth upgrade is possible, for 11 operators (44%) not. In case of one operator, a smooth upgrade is possible for approximately 70% of the customer premises equipment (ONUs).

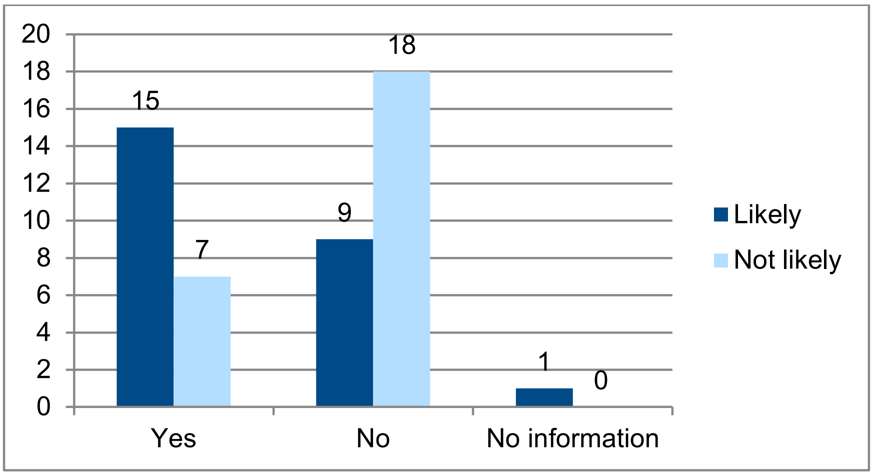


Source: BEREC questionnaire completed by 50 European network operators

Figure 2: Smooth upgrade of the current PON technology to NG-PON2 possible?[12]

Some of the 50 European network operators considered are also interested in alternative PON technologies to NG-PON2. Figure 3 shows that 15 operators which likely will deploy NG-PON2 and seven operators which will not likely deploy NG-PON2 have also interest in alternative PON technologies to NG-PON2.

[12] Without the one country (BG) which is stronger represented than the others (see Table 1, footnote 2) the results are as follows: “Yes” 44%, “Not all ONUs” 6%, “No” 44% and “No information” 6%.



Source: BEREC questionnaire completed by 50 European network operators

Figure 3: Interest in alternative PON technologies to NG-PON2?[13]

Table 6 provides an overview of the PON technologies in which the network operators are interested in. 14 operators in XGS-PON, ten operators in XG-PON, two operators in 10G-PON (this could be either XGS-PON or XG-PON or 10G-EPON) and three operators in other PON technologies (e.g. 100G-EPON in the long term, WDM PON).

Table 6: Alternative PON technologies to NG-PON2 in which network operators are interested in

Alternative PON technology	Number of operators
XGS-PON	14
XG-PON	10
10G-EPON	2
Other	3

Source: BEREC questionnaire completed by 50 European network operators

3.2 Perspective of three vendors

According to ADTRAN, Nokia and ZTE, in Europe NG-PON2 is currently in a state of lab tests and field trials and not in a state of first deployments or beginning of mass market deployment which is consistent with the information of the 50 European network operators considered (see section 3.1). Mass deployments of NG-PON2 (TWDM PON) are expected to begin between 2019 and 2020. All three vendors expect that the installed legacy PON (G-PON ONUs) will allow a smooth upgrade to NG-PON2 which is, however, not confirmed by the 50 European network operators considered, since in case of 11 (44%) of 25 of them such a smooth upgrade is not possible (see section 3.1). In detail, the perspective of these three vendors on the current and expected future deployment of NG-PON2 is as follows.

[13] Without the one country (BG) which is stronger represented than the others (see Table 1, footnote 2) the results are as follows: “Yes” 14/7, “No” 8/9 and “No information” 0/0 (each “likely”/”not likely”).

With regard NG-PON2 (TWDM PON), all three vendors conduct lab tests, Nokia is also engaged in field trials and ADTRAN and ZTE plan to start such field trials in Q4/2017.[14] Nokia already has a first commercial deployment.[15] Mass deployments are expected to begin in 2019 by ADTRAN, around 2019/2020 by Nokia and in 2020+ by ZTE.

With regard the other type of NG-PON2, PtP WDM PON (see section 2.1), ZTE conduct lab tests and plans to start field trials in 2018. Mass deployments are expected to begin in 2020+ (but after TWDM PON) by ZTE. In the view of Nokia, PtP WDM PON are not suitable for mass deployments (much higher costs than TWDM PON) and will be limited to specific applications. For ADTRAN, the future of PtP WDM PON is less clear and ADTRAN anticipates that PtP WDM PON will lag in time, if it develops at all.

NG-PON2 brings new capabilities which require the development of new technological building blocks (hardware and software). The ONUs need to be equipped with tunable lasers and filters and has to support multiple and close WDM channels. OLTs also have challenging technical specifications to comply with, although they do not need tunable lasers.[16] As is commonplace for new technologies, NG-PON2 equipment costs will be reduced as these technologies mature and the effects of scale take hold.

ADTRAN and Nokia anticipate that first use cases of NG-PON2 systems will be symmetrical 10/10 Gbps for demanding applications such as mobile x-haul (front-/backhaul) and (premium) business services. Residential deployments will follow later.

Nokia and ZTE expect that, in Europe, the installed G-PON ONUs typically comply with G.984.5 (ITU-T 2014a), and therefore would enable a smooth upgrade of existing GPONs to NG-PON2. ADTRAN points out that much of the high volume G-PON deployments in countries like Spain, France and Portugal are very recent and therefore based on very current ONU equipment which would enable a smooth upgrade to NG-PON2.

4 Regulatory decisions on Market 3a

This section

- provides an overview of the current status of market analysis procedures on Market 3a in Europe based on information from 31 European countries;
- analyses whether WU was imposed in the 14 EU countries in which NRAs took a decision on Market 3a since the standardisation of NG-PON2 and
- discusses WU specific aspects which may be useful for an NRA to take into account when it considers whether or not to impose WU on the SMP operator.

[14] Nokia has 24 completed trials world-wide, of which 8 in EMEA.
[15] In Chattanooga in the United States of America.
[16] E.g. high-speed burst mode for receiver, high power and constrained spectrum for the laser.

4.1 Current status of market analysis procedures on Market 3a

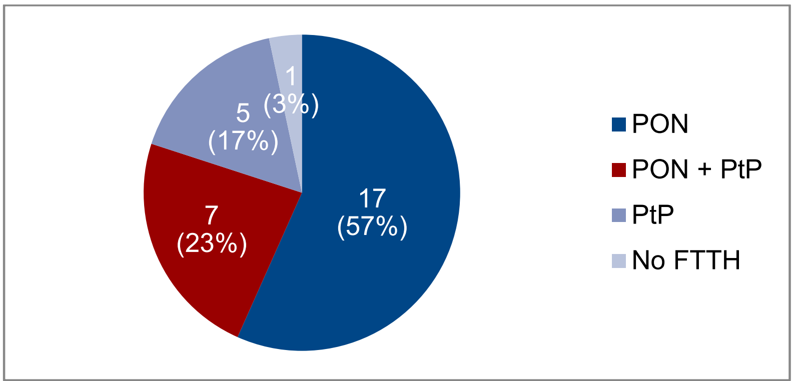
Table 7 provides an overview of the current status of market analysis procedure on Market 3a in the 31 European countries considered. In 14 countries, a regulatory decision was taken on Market 3a since the standardisation of NG-PON2 at the end of 2014 and in 14 countries Market 3a is currently under review. In four countries, neither a regulatory decision was taken on Market 3a since the beginning of 2015 nor is Market 3a currently under review.

Table 7: Current status of Market analysis procedures on Market 3a

Current status of Market 3a analysis	Number of countries	Country
Regulatory decision taken since beginning of 2015	14	BG, CY, DE, DK, ES, GR, HR, IT, LT, NL, PT, RO, SE, SK
Under review	14	AT, BE, CZ, EE, FI, FR, IE, IT, LU, LV, MT, NO, SI, UK
Other	4	CH, ME, PL, RS

Source: BEREC

Figure 4 and Table 8 give an overview of the FTTH architecture in the network of the SMP operator on Market 3a in 30 of the 31 countries considered.[17] The SMP operator has a FTTH network based on PON in 17 countries (57%), based on PtP fibre in five countries (17%), based on both architectures in seven countries (23%) and in one country it does not have a FTTH network. Therefore, in total in 24 countries (80%) in the FTTH network of the SMP operator PON are used.



Source: BEREC

Figure 4: SMP operators' FTTH architecture

[17] In one country (RO), no operator has SMP on Market 3a and this market is no longer regulated.

Table 8: SMP operators' FTTH architecture

FTTH architecture	Number of Countries	Percentage	Country
PON	17	57%	AT, BE, BG, CY, CZ, DE, EE, ES, IT, LV, ME, MT, NO, PL, PT, RS, UK
PtP	5	17%	CH, IE, LT, NL, SE
PON and PtP	7	23%	DK, FI[18], FR, HR, LU, SK, SI
No FTTH	1	3%	GR

Source: BEREC

In all 24 countries in which the SMP operator has a FTTH network based on PON, either exclusively or in addition to PtP fibre, the PON technology used is G-PON. According to the three major vendors which completed the BEREC questionnaire, G-PON is the most commonly used PON technology in Europe.

4.2 Regulatory decisions taken on Market 3a since standardisation of NG-PON2

A regulatory decision was taken on Market 3a since the standardisation of NG-PON2 at the end of 2014 in 14 of the 31 countries considered (see section 4.1, Table 7). In six of these 14 countries, WU is not relevant since the SMP operator does not deploy a FTTH network based on PON (five countries) or Market 3a is no longer regulated (RO). In one (DE) of the remaining eight countries, WU was imposed on the SMP operator in the others not.

In Germany, a general unbundling obligation was imposed on the SMP operator and the definition of fibre unbundling includes access which does not require any active products on the part of the SMP operator and therefore also WU. The SMP operator does not have the obligation to publish a WU reference offer. ANOs have the possibility to request access to the network of the SMP operator based on WU on a case-by-case basis. If they do not reach an agreement with the SMP operator, the NRA has to take a decision. However, this was not the case so far. Reasons why the unbundling obligation was not further specified with regard to WU are that there was neither relevant demand by the market nor feasible and actually marketed technical solutions at the time the decision was taken as well as that the SMP operator has also the obligation to offer a Layer 2 wholesale access product (L2 WAP).

Table 9 shows the reasons why in the other seven countries the regulatory decision taken on Market 3a did not impose WU on the SMP operator. The reasons are that the SMP operator has the obligation to offer a L2 WAP (six countries), ANOs did not demand WU (four countries), the SMP operator has the obligation to offer duct access (three countries) and/or fibre access (two countries). Reasons with regard the technology NG-PON2 are the SMP operator does not deploy this technology (four countries), this technology was not considered to be sufficient

[18] In Finland, over 20 operators have SMP on Market 3a. Some of them have FTTH networks based on PtP fibre and others based on PON. Typically the small operators are the ones who have PON networks.

mature at the time of the decision (two countries) and information of WU practices in EU countries were not available (one country).

Table 9: Reasons why WU was not imposed on the SMP operator on Market 3a

Reason why WU was not imposed	Number of countries	Country
SMP operator has the obligation to offer		
• duct access	3	BG, IT, PT
• fibre unbundling	2	DK, IT
• a L2 WAP	6	CY, DK, ES, HR, IT[19], SK
ANOs did not demand WU	4	DK, ES, HR, IT
SMP operator does not deploy NG-PON2	4	BG, CY, DK[20], HR
The NG-PON2 technology was not considered to be sufficient mature at the time of the regulatory decision	2	ES, IT
No information of WU practice in any EU country	1	HR

Source: BEREC

4.3 Aspects which may be useful to consider with regard to WU

When an NRA considers whether or not it is appropriate to impose on the SMP operator WU, then it may be useful to take the following aspects into account.[21]

(i) Duct access and fibre unbundling

In case effective competition at the retail level can be achieved with duct access and/or fibre unbundling, WU may not be relevant.

(ii) L2 WAP

A main difference between WU and L2 WAP (e.g. VULA) is that WU is not based on any active equipment of the SMP operator, therefore, an ANO can use its own NG-PON2 OLT and its own NG-PON2 ONU and can operate all network layers (although some prerequisites need to be fulfilled, see section 6 of Annex 1). This means it can choose, independently from the SMP operator, e.g. the VLAN concept used, number of VLANs per subscriber used, speed (down/up) per subscriber, customer premises equipment (ONU), traffic prioritisation, customer identification method, security measures at all OSI layers etc. ANOs may also be allowed to use a different NG-PON2 vendor than the SMP operator (see section 6 of Annex 1), which would enable them to also differentiate the technical capabilities (e.g. maximum Ethernet frame size) of the NG-PON2 equipment from the SMP operator.

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[19] In Italy, fibre unbundling is imposed as general obligation, if technically feasible (FTTH PON unbundling not considered feasible at the moment)

[20] In DK, the SMP is obliged to give access to fibre regardless of technology and topology.

[21] As with all remedies also the imposition of WU is subject to the requirement in Article 8 of the Access Directive (2002/19/EC) that obligations imposed shall be based on the nature of the problem identified, proportionate, and justified.

WU therefore allows the ANO higher value added and more differentiation from the incumbent and is in this respect preferable to L2 WAP. However, there might be other technical or commercial reasons (see the other points discussed here) not to impose WU and to rely on a L2 WAP instead. The decision to impose WU on the SMP operator depends on advantages/disadvantages of WU compared to a L2 WAP in the specific case.

(iii) Demand of ANOs

The acceptance of WU depends on the interest of ANOs in WU. Therefore, if ANOs do not demand WU, NRAs may not consider imposing WU. This might be the case, for example, if other existing wholesale access products, like L2/L3 active or passive access, are considered sufficient by ANOs e.g. in case the PON-coverage of the incumbent is still small.

(iv) Methods to identify the number of subscribers connected to a PON

In order to be able to implement a similar pricing regime as for physical unbundling of the copper or fibre loop (price per access line or customer per month), it is necessary to identify the number of customers of the ANO. Also with regard to enforcement of SLAs (mainly repair), it is necessary to know the number and location of end users. Since in the case of WU each ANO operates its own wavelength, the question arises whether it would be technically possible for the SMP operator to (automatically) identify the number of subscribers of the ANO. According to vendors, it may be possible at the level of the OSS or network management level of both networks but not at the NG-PON2 layer (physical layer or MAC layer). Currently such methods are not (yet) available (see section 3 of Annex 1). Another possibility would be contractual obligations which oblige the ANO to report the number (and location) of end users.

(v) Wavelength and PON technology ANOs can use

In principle, it is possible to unbundle different wavelengths of different PON technologies (see section 2.2 and Annex 2). Therefore, if an NRA decides whether or not to impose WU on the SMP operator, it may be relevant which wavelength is considered to be unbundled. Several possibilities for WU exist, examples are discussed in Annex 2.

(vi) Number of ANOs which can use WU and available bandwidth for the SMP operator

When considering WU, the number of ANOs which can use WU and the bandwidth available for the SMP operator may be of relevance, since the number of wavelengths used by PON technologies is limited. For example, if the SMP operator deploys a NG-PON2 system with a capacity of up to four wavelengths, each 10 Gbps symmetric (see section 5 of Annex 1), then the NG-PON2 wavelengths could be used for example as follows:

- one ANO uses one NG-PON2 wavelength and the SMP operator (up to) three;
- two ANOs use each one wavelength and the SMP operator two wavelengths.

This shows that the higher the number of ANOs which can use a NG-PON2 wavelength the lower the number of wavelengths available for the SMP operator. The number of ANOs which can use an unbundled NG-PON2 wavelength therefore depends on the maximum number of wavelengths of the installed NG-PON2 technology (currently 4, in future maybe 8, see section 5 of Annex 1) and the wavelength demand of the ANOs and the SMP operator.

In conclusion, wavelength unbundling means that the capacity or bandwidth of the PON is shared. This leads to lower maximum data rates for each provider (compared to a situation where one operator can use all wavelengths) and in particular also for the incumbent operator. (Regulated) Access could therefore counter the reasons for the investment in NG-PON2, namely higher bandwidths. When considering an access remedy, therefore it may be necessary to analyse whether the retail demand for bandwidth can be fulfilled, if the capacity is shared among several operators.

(vii) Whether NG-PON2 technology is deployed in the network of the SMP operator

The possibilities to unbundle wavelengths depend on the PON technology deployed in the network of the SMP operator (see examples in Annex 2). NG-PON2 enables that both, the SMP operator and an (or more) ANO(s) can deploy this technology on the same PON fibre infrastructure. In case of other PON technologies, which only uses one wavelength per direction, only one operator, the SMP operator or an ANO, can deploy this PON technology. Therefore, it is of relevance whether or not the SMP operator deploys NG-PON2.

(viii) Maturity of the NG-PON2 technology

If the NG-PON2 technology is not sufficient mature, neither SMP operators nor ANOs may have an interest to deploy this technology. If this is the case, unbundling of NG-PON2 wavelengths may not be appropriate. Operators may have a different view on whether or not the NG-PON2 technology is already sufficient mature and the NRA has to take into account the maturity of the NG-PON2 technology at the time when it takes a decision. Currently solutions for some prerequisites which need to be fulfilled to enable ANOs in case of WU to use their own NG-PON2 equipment (OLT, ONU) are still under development and in standardisation (see section 6 of Annex 1).

(ix) Co-existence of PON technologies in the network of the SMP operator

In principle, several PON technologies can co-exist on the same PON fibre infrastructure (see section 4 of annex 1). The interest of the SMP operator to deploy NG-PON2 on existing PON fibre infrastructure may depend on whether a co-existence of the already installed PON technology (e.g. G-PON) and NG-PON2 is possible. This depends on the technical capabilities of the customer premises equipment (ONU) of the legacy PON technology (see section 4 of Annex 1, section 3.1 Figure 2, section 3.2). It must be able to operate correctly although it not only receives the wavelength of the legacy PON technology but is also exposed to the NG-PON2 wavelengths. Co-existence of different PON technologies is also relevant in case other wavelengths than NG-PON2 wavelengths are unbundled (see examples 2 and 3 in Annex 2).

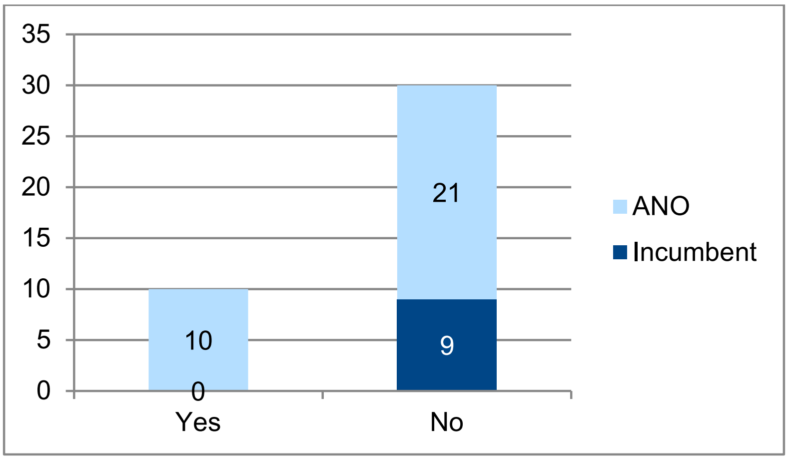
(x) Reduced reach of legacy PONs due to co-existence element

In order to enable co-existence of different PON technologies on the same PON fibre infrastructure, a so-called co-existence element needs to be deployed. The co-existence element is a passive network element and inevitably introduces optical power loss which will slightly decrease the reach of the installed PON.[22] Therefore, at least potentially, some of the end-users connected to the legacy PON may be out of reach. Therefore, for new PON deployments, it would be useful to take this additional loss into account.[23]

5 Co-investment

This section explores whether WU based on NG-PON2 might increase the interest of network operators to co-invest in FTTH networks based on information from 50 European network operators (see section 1, Table 1).

As shown in Figure 5, NG-PON2 increases the interest of ten (25%) of 40 operators to co-invest in FTTH networks based on PON.[24] All ten operators are ANOs (32% of the ANOs), six (60%) of them did not co-invest in FTTH networks based on PON with other network operators so far, the other four (40%) ANOs did.



Source: BEREC questionnaire completed by 50 European network operators

Figure 5: Does NG-PON2 increase the interest to co-invest in FTTH networks based on PON?

[22] This was also pointed out by one of the 50 European network operators considered in section 3.1.
[23] Also the optical power loss introduced by further passive elements which are included in addition to the co-existence element, e.g. a splitter at the CO.
[24] The information provided by ten operators (e.g. needs to be evaluated, it is not likely that NG-PON2 will be deployed, no answer) did not clearly answer the question and therefore could not be taken into account.

NG-PON2 does not increase the interest to co-invest in FTTH networks based on PON of the considered incumbent operators (nine) and 21 ANOs (68% of the ANOs).

In case only the network operators which likely will deploy NG-PON2 are considered, the share of operators which have an increased interest to co-invest in FTTH networks based on PON due to NG-PON2 increases slightly from 25% (ten of 40 operators) to 30% (seven of 23 operators).

NG-PON2 increases the interest to co-invest in FTTH networks based on PON of four (40%) of ten operators which already did co-invest in such networks with other operators and of six (20%) of 30 operators which did not co-invest in such networks so far.

6 Conclusions

In conclusion, it can be said that there are several possible forms to unbundle wavelengths of PONs. NG-PON2 is not a necessary condition for WU, however, it is a more future-proof technical solution which allows two or more operators to use the same PON technology on the same PON fibre infrastructure.

The current and expected future deployment of NG-PON2 is as follows. All of the 50 European network operators considered in the report have a FTTH network based on PON and to date NG-PON2 is not yet deployed in any of these networks. However, the question whether it is likely that the company will deploy NG-PON2 in its FTTH network was answered by 25 operators (50%) with “Yes”, seven of them mentioned some caveats (e.g. with regard time frame, certainty). Nine of these operators are SMP operators (57% of the SMP operators) and 16 ANOs (47% of the ANOs). According to all three vendors, in Europe NG-PON2 is currently in a state of lab tests and field trials and not in a state of first deployments or beginning of mass market deployment. Mass deployments of NG-PON2 (TWDM PON) are expected to begin in 2019 by ADTRAN, around 2019/2020 by Nokia and in 2020+ by ZTE.

To date the most commonly used PON technology in Europe is G-PON. In principle, a smooth upgrade from G-PON to NG-PON2 is possible, however, the customer premises equipment (ONUs) has to fulfil specific requirements (defined in G.984.5). The three vendors expect that, in Europe, the installed G-PON ONUs typically fulfil these requirements, however, for 11 (44%) of the 25 network operators which will not likely deploy NG-PON2 a smooth upgrade from G-PON to NG-PON2 is not possible.

In 14 of the 31 European countries considered, the NRA took a regulatory decision on Market 3a since the standardisation of NG-PON2 at the end of 2014 and in eight of them, the SMP operator has a FTTH network based on PON. In one (DE) of these eight countries, WU was imposed on the SMP operator in the others not. However, in this country “only” a general unbundling obligation was imposed on the SMP operator but the definition of fibre unbundling includes also WU. ANOs have the possibility to request WU on a case-by-case basis and if they do not reach an agreement with the SMP operator, the NRA has to take a decision which, however, was not the case so far.

When an NRA considers whether or not it is appropriate to impose on the SMP operator WU, then it may be useful to take into account the following aspects:[21]

- Duct access and fibre unbundling: In case effective competition at the retail level can be achieved with duct access and/or fibre unbundling, WU may not be relevant.
- L2 WAP: WU allows the ANO higher value added (see section 4.3 point (ii)) and more differentiation from the incumbent compared to a L2 WAP. However, due to other aspects (see section 4.3) WU may not be imposed on the SMP operator.
- Demand of ANOs: If ANOs do not demand WU, NRAs may consider not to impose WU.
- Methods to identify the number of subscribers connected to a PON: According to vendors, such methods may be possible (details see section 2.2 and section 3 of Annex 1). Another possibility would be contractual obligations which oblige the ANO to report the number of end users.
- Wavelength and PON technology ANO can use: Which wavelength is considered to be unbundled? Several possibilities for WU exist (examples are described in Annex 2).
- Number of ANOs which can use WU and available bandwidth for the SMP operator: WU means that the wavelengths of the PON are shared between ANOs and SMP operator. Therefore, WU may counter the reasons for the investment in NG-PON2.
- Whether NG-PON2 technology is deployed in the network of the SMP operator: The possibilities to unbundle wavelengths depend on that.
- Maturity of the NG-PON2 technology: The interest of both, the SMP operator and the ANOs to deploy NG-PON2 on the PON fibre infrastructure of the SMP operator depend on that (details with regard WU see section 6 of Annex 1).
- Co-existence of PON technologies in the network of the SMP operator: Whether or not this is the case has an impact on the possibilities to unbundle wavelengths and the interest of SMP operators to invest in NG-PON2.
- Reduced reach of legacy PONs due to co-existence element: Co-existence may result in a situation in which some end-users connected to the legacy PON are no longer within the reach of the PON due to the co-existence element.

NG-PON2 increases the interest of ten (25%) of the 40 operators considered (ten did not clearly answered this question) to co-invest in FTTH networks based on PON. All ten operators are ANOs (32% of the ANOs), six (60%) of them did not co-invest in FTTH networks based on PON with other network operators so far, the other four (40%) ANOs did.

It can be concluded that from an overall perspective NG-PON2 technology although currently still in a state of lab test and field trials will likely be deployed in networks of several SMP operators in the coming years. For NRAs considering whether or not to impose WU on the SMP operator, it may be useful to take the aspects discussed in this report into account. Altogether, WU in principle has advantages compared to a L2 WAP (e.g. VULA), however, the use of WU as an access remedy currently also faces significant obstacles.

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8 Abbreviations for countries

Abbreviation	Country
AT	Austria
BE	Belgium
BG	Bulgaria
CH	Switzerland
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain

Abbreviation	Country
FI	Finland
FR	France
GR	Greece
HR	Croatia
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
ME	Montenegro
MT	Malta

Abbreviation	Country
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

9 Further abbreviations

ANO Alternative Network Operator

BBF Broadband Forum

BEREC Body of European Regulators for Electronic Communications

CE Co-existence Element

CO Central Office

EMEA Europe, the Middle East and Africa

EPON Ethernet Passive Optical Networks

EU European Union

FTTB Fibre To The Building

FTTC Fibre To The Curb

FTTH Fibre To The Home

G-PON Gigabit-capable Passive Optical Network

HE Head End

ICTP Inter-Channel-Termination Protocol

IEEE Institute of Electrical and Electronics Engineers

ITU International Telecommuncation Union

ITU-T ITU’s Telecommunication Standardization Sector

L2 WAP	Layer 2 Wholesale Access Product
LLU	Local Loop Unbundling
MDF	Main Distribution Frame
NGA	Next Generation Access
NGN	Next Generation Network
NG-PON	Next Generation-PON
NRA	National Regulatory Authority
ODN	Optical Distribution Network
OLT	Optical Line Termination
ONU	Optical Network Unit
OTDR	Optical Time Domain Reflector
OSS	Operation Support System
PON	Passive Optical Network
PtP	Point-to-Point
RF	Radio Frequency
SMP	Significant Market Power
SMPO	SMP Operator
TDM	Time Division Multiplexing
VULA	Virtual Unbundled Local Access
WDM	Wavelength Division Multiplexing
WM	Wavelength Multiplexer
WU	Wavelength Unbundling
XG-PON	10-Gigabit-capable passive optical networks
XGS-PON	10-Gigabit-capable symmetric passive optical network

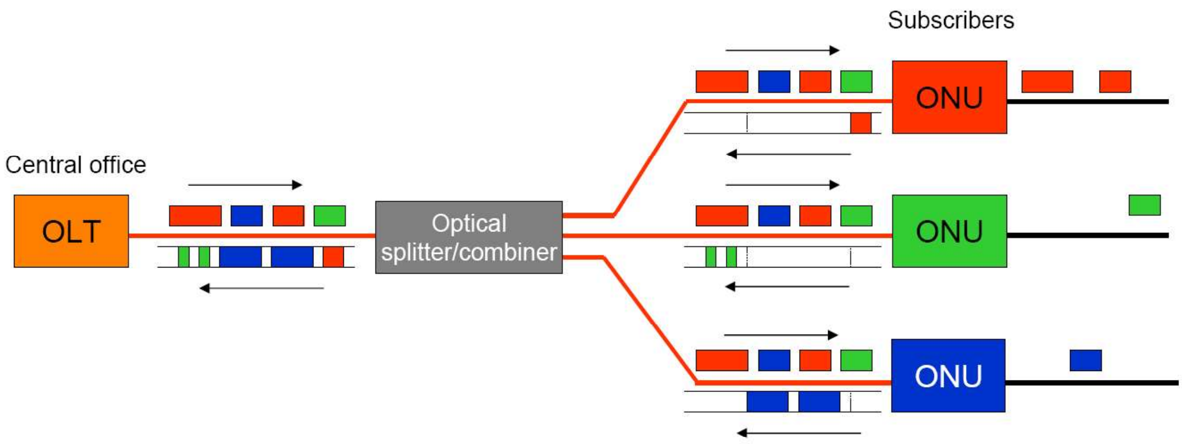
Annex 1: Further information on PONs

This section describes the following aspects of PONs:

- network topology and signal transmission;
- split ratio;
- number of subscribers connected to a PON;
- migration from legacy PON to NG-PON2;
- NG-PON2 systems available on the market;
- freedom to choose NG-PON2 equipment in case of WU; and
- future PON technologies which are currently standardised.

1. Network topology and signal transmission

The PON technologies described in section 2.1 (e.g. G-PON, X-GPON, NG-PON2) have a point-to-multipoint topology and the wavelength is shared between different end-users based on Time Division Multiplexing (TDM). Figure 6 shows the principle of the signal transmission in PON based on TDM in both downstream and upstream direction. In downstream direction the equipment at the central office (CO), the Optical Line Termination (OLT), transmits the signal with a certain wavelength and the information for the different end-users (in Figure 6 red, green and blue) is sent at different times. At the splitter location this signal is divided into several signals and each signal has the same wavelength and contains the same information as the signal transmitted between CO and splitter location but has a lower power since in PON no active components are used at the splitter location. The equipment at the customer premises, the Optical Network Unit (ONU), filters the signal and only makes the information available for the end-user (at the user network interface, UNI) which is intended for him (in Figure 6, the ONU makes for the red end-user only available the red information, for the green end-user only the green information etc.).



Source: PON standards, David Law (2010), p. 17

Figure 6: Principle of signal transmission in PON based on TDM

In upstream direction, each ONU transmits the information of the end-user with the same wavelength (different wavelength than the downstream wavelength) but at a different time and at the splitter location the signals of all ONUs are combined. At the CO the OLT receives the signal (one wavelength, the wavelength transmitted by the ONUs) with the information of all end-users connected to the PON.

In contrast to the other PON technologies, NG-PON2 uses more than one wavelength per direction (see section 2.1). However, in each wavelength TDM is used as described above and at the CO (OLT location) several OLTs per PON are used, each transmits and receives one wavelength (per direction). At the CO the different wavelengths are in downstream direction combined on one fibre and in upstream direction separated in different fibres based on WDM (see Figure 7). Therefore, NG-PON2 are TWDM PON which combine both multiplexing methods, TDM and WDM.

Optionally NG-PON2 can also support point-to-point (PtP) WDM PON which provide a dedicated wavelength (in both downstream and upstream direction) between CO (OLT) and customer premises (ONU) and uses for each customer a different wavelength (per direction).

Since NG-PON2 uses several wavelengths (per direction) the laser used in the customer premises equipment (ONU) must be able to be tuned to the wavelength selected for a specific customers. Tunable lasers, however, are rather costly. In case of the other PON technologies no tunable lasers are necessary, since they only use one wavelength (per direction).

2. Split ratio

The higher the split ratio the higher the number of subscribers connected to the PON (OLT) and therefore

- the lower the costs of OLT per subscriber;
- the lower the bandwidth available per subscriber;
- the lower the power of the signal between splitter location and customer premises and therefore also
- the lower the passive fibre reach of the PON.

PON with power splitters (e.g. G-PON) are typically deployed today with a split ratio in the range of 1:16 to 1:128 (ITU-T 2013, p. 12). According to the standard, NG-PON2 should support at least a split ratio of 1:256 (ITU-T 2013, p. 4).

3. Number of subscribers connected to a PON

In case of a PON which only uses one wavelength, all end-users of the PON are connected to the same OLT. Therefore, the network operator who operates the PON and the OLT knows exactly how many and where customers are connected to the PON.

NG-PON2 uses several wavelengths and OLTs and in principle different network operators can use and operate a different wavelength and their own OLT and ONUs (see section 2.2). In case two (or more) network operators share a PON fibre infrastructure (optical distribution network, ODN), for cost sharing purposes it may be of interest for them to know how many customers of each network operator are connected to the PON. Also with regard enforcement of SLAs and repair it is necessary to know the number and location of end users. Therefore, a method would be needed which enables to identify the number of subscribers connected to a PON.

According to Nokia, there are currently no reliable methods for an OLT to detect at NG-PON2 layer (physical layer or MAC layer) how many ONUs are connected to a wavelength that is terminated on another OLT of another operator. Nokia suggests conveying this information between the operators at the level of the Operation Support System (OSS).

ADTRAN's view is that in theory such methods are possible though this capability is still under development. An expansion of the messages passed over the Inter-Channel-Termination Protocol (ICTP, BBF TR-352) may potentially provide a solution, the Broadband Forum's draft specification WT-370 Fixed Access Network Sharing (FANS) may be a useful point of reference and in an SDN-controlled environment, platforms supporting multi-tenant/multi-operator may provide an attractive solution.

4. Migration from legacy PON to NG-PON2

In principle, NG-PON2 enables co-existence of NG-PON2 with the legacy PON technologies G-PON and XG-PON and also radio frequency (RF) video overlay on the same PON fibre infrastructure (ODN) which is possible since these PON technologies use different wavelength ranges (see ITU-T 2014b, p. 63).[25] Figure 7 provides an overview of the architecture used to achieve co-existence. The central element is the so-called co-existence element (CE) at the CO which in downstream direction combines the wavelengths of the G-PON, the XG-PON, the RF video overlay and the NG-PON2 based on WDM and in upstream direction it separates them.

However, in order to ensure co-existence, the ONUs of the legacy PON technologies must be capable to work properly in the presence of the wavelengths used by NG-PON2.[26] For example, the G-PON ONUs have to fulfil the requirements specified in G.984.5 (ITU-T 2014a, p. 8-9).[27] Therefore, whether co-existence of NG-PON2 with legacy PON is actually possible, depends on the legacy PON ONUs already deployed at the customer premises (see sections 3.1 and 3.2).

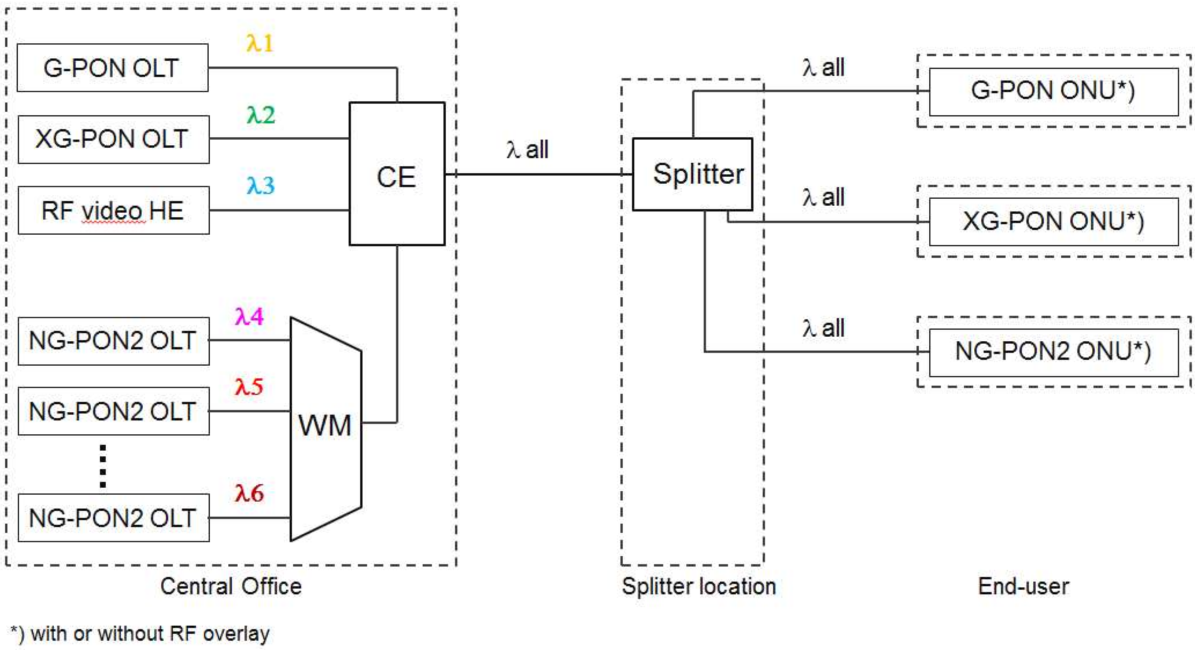
If the deployed ONUs do not enable co-existence, then it may be necessary that a network operator has to replace all ONUs connected to a PON even if it only wants to offer one (or a

[25] RF video overlay is a method of transmitting multi-channel television signals over optical access networks (ITU-T 2008, ITU-T, 2012). The co-existence includes also the optical time domain reflector (OTDR) which is used for test purposes (ITU 2013, p. 7).

[26] In case RF overlay is used, the ONUs of the legacy PON technologies must also be capable to work properly in the presence of the RF signal.

[27] A single NG-PON2 wavelength, no matter how many NG-PON2 ONUs used, could degrade operation of GPON ONUs which do not comply with G.984.5 (Nokia 2017).

few) customers services based on NG-PON2.[28] This, of course, may be a significant barrier for the deployment of NG-PON2 in case of existing PONs (not in case of new PONs).



Source: BEREC based on ITU-T 2013, p. 5

Figure 7: Co-existence of NG-PON2 with G-PON, XG-PON and RF video overlay[29]

5. NG-PON2 systems available on the market

Table 10 gives an overview of technical characteristics of NG-PON2 systems offered by vendors on a commercial basis.

Table 10: Technical characteristics of NG-PON2 system offered on a commercial basis

Technical characteristics	ADTRAN	Nokia	ZTE
Number of TWDM channels	Currently 4	Currently 4	Currently 4[30]
Down-/Upstream nominal line rate per TWDM channel	10G/10G	10G/10G and 10G/2.5G	10G/10G and 10G/2.5G
Number of point-to-point (PtP) WDM channels	Not supported	Not supported	No information
Passive fibre reach (in km)	20-40km	0-20km, 20-40km, 0-40km	No information
Supported split ratio	128	128	No information

Source: ADTRAN, Nokia, ZTE

[28] According to ADTRAN, in theory this could be avoided by inserting a connectorised external wavelength filter between the fiber drop and the ONU.
[29] In order to avoid making this figure difficult to understand, the following two simplifications are made: (i) For each PON technology, only one end-user (ONU) is shown. (ii) OTDR (see footnote 25) is not shown.
[30] 8 planned for 2019

All three vendors offer NG-PON2 systems based on TWDM PON with currently 4 wavelengths per direction and a (nominal) data rate per wavelength of 10G/10G (down/up), two of them also with 10G/2.5G. The passive fibre reach is up to 40 km and the split ratio 128 (two vendors).

NG-PON2 systems based on PtP WDM PON are currently not offered by two vendors, no information was made available on that by the third vendor.

6. Freedom to choose NG-PON2 equipment in case of WU

In case of NG-PON2 based on TWDM PON, according to ADTRAN, Nokia and ZTE[31] it is possible that different wavelengths are used by different network operators, i.e. WU. Each network operator can use its own NG-PON2 OLTs and NG-PON2 ONUs, however, according to Nokia and ADTRAN the following prerequisites need to be fulfilled:

- The wavelengths per direction each operator can use need to be defined;
- The wavelength multiplexer (WM; see Figure 7) need to be a separate device with fibre access which enables the operators to connect their NG-PON2 OLTs to it and one operator has to deploy and manage the WM.[32]
- The operators need to agree whether the WM is passive or active (OLT external optical amplifier), in order to be able to select the appropriate OLT optical transceivers.
- NG-PON2 ONUs use tunable lasers and therefore need to be tuned to a wavelength the operator is allowed to use. A fully automated ONU initialisation in a multi-operator environment would be possible e.g. based on the use of the ICTP across operators. This protocol, however, has just recently been standardised and interoperability testing has not yet been defined. Operators will also have to agree on how and where to host and manage the Wavelength Mobility Manager entity.
- One operator has to host a central management of the available Channel Terminations (i.e. OLTs and wavelengths that can be terminated) per operator per PON.
- In case of a “rogue” ONU that misbehaves and impacts other operators, a detection and protection is necessary involving (OSS level) communication between the operators. However, rogue ONU scenarios have not yet been elaborated in detail in standardization. ICTP could be a tool for detection and mitigation.
- The NG-PON2 standard allows several options which need to be pre-agreed.[33]
- Each operator’s OSS might need an interface with the OSS of the other operators, for allowing above points. This interface is not yet defined.

[31] ZTE plans to support WU.
[32] E.g. the NG-PON2 systems of Nokia and ADTRAN fulfil this prerequisite.
[33] E.g. options with regard to the upstream channel definition (on-grid or off grid), band plan (wideband, reduced band, narrow band for TWDM PON; expanded or shared for PtP WDM PON), channel spacing (50GHz, 100GHz, 200GHz).

According to ADTRAN and Nokia, in principle it would be possible that the operators use NG-PON2 equipment of different vendors. However, the equipment needs to fulfil the prerequisites discussed above.

According to their view, in principle it would also be possible that different wavelengths are used by different network operators in case of NG-PON2 based on PtP WDM PON. In this case also the prerequisites discussed above need to be fulfilled. However, the applicability of the ICTP protocol to PtP WDM PON is not yet standardised.

Nevertheless, WU may also be considered in case not all aspects mentioned above by the vendors are fulfilled e.g. in case a fully automated ONU initialisation is not used or in case an operator only uses one wavelength and therefore, in principle, the use of tunable laser may not be necessary.

7. Future PON technologies which are currently standardised

Both standardisation bodies, ITU-T and IEEE currently work on new PON standards. The ITU-T Study Group 15 develops a WDM-PON (G.metro) with multiple wavelengths per direction (up to 80), a data rate per wavelength (per direction) of up to 10 Gbps and which uses tunable lasers in the equipment at the customer premises (ITU-T 2017).

The IEEE P802.3ca 100G-EPON Task Force works on a new EPON standard with symmetric and/or asymmetric data rates of 25 Gbps, 50 Gbps and 100 Gbps (IEEE 2015). According to the current development the new P802.3ca standard shall enable 25 Gbps symmetric and 25/10 Gbps asymmetric both with one wavelength per direction. 50 Gbps and 100 Gbps will use wavelength channel bonding. 50 Gbps will be based on the same wavelength as the 25 Gbps plus one additional wavelength per direction and 100 Gbps will be based on the same wavelengths as the 50 Gbps plus two further wavelengths per direction. Therefore, this PON technology is not suited for WU. All ONUs and OLTs will use the same fixed wavelengths and, therefore, ONUs and OLTs do not need tunable lasers (IEEE 2017).

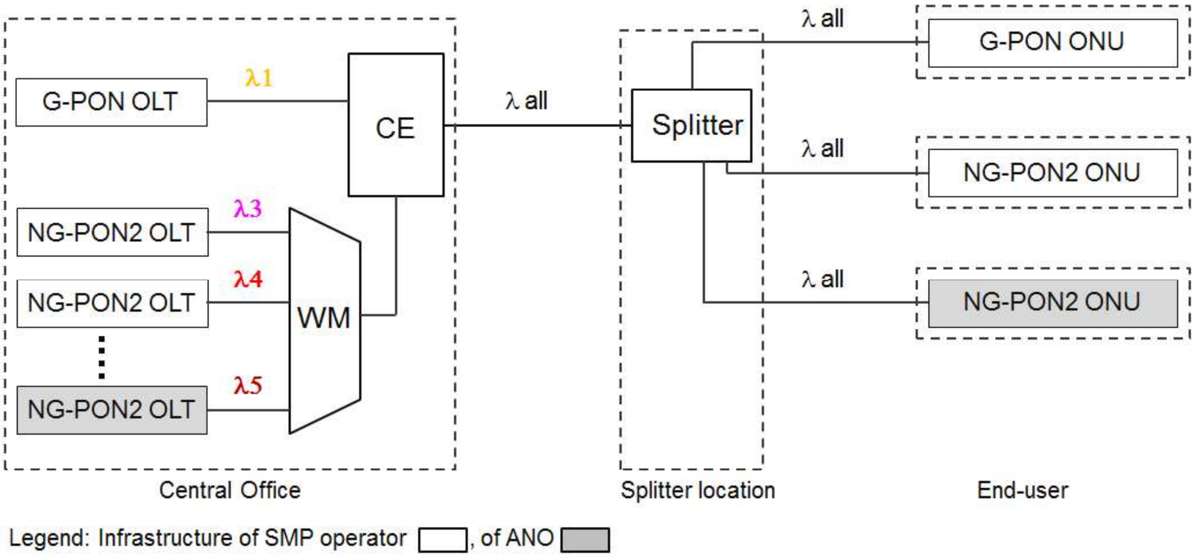
Annex 2: Examples of WU

This section discusses some examples of WU.

Example 1:

The SMP operator deploys G-PON and NG-PON2 on the same PON fibre infrastructure and one (or more) ANO(s) can use a NG-PON2 wavelength (see Figure 8). Based on this wavelength and the PON fibre infrastructure of the SMP operator the ANOs can build their own NG-PON2 with their own active NG-PON2 equipment (OLT, ONU). Solutions for some prerequisites are, however, currently still under development and in standardisation (see section 6 of Annex 1).

Example 1 may be relevant, when an SMP operator upgrades its existing G-PON to an NG-PON2 and the migration of all its existing customers is not planned or yet finished. In case of new built PON all customers may be connected to the NG-PON2 and, therefore, there would not be a need for the SMP operator to deploy G-PON. However, in this case also one (or more) NG-PON2 wavelength(s) could be used by ANO(s).



Source: BEREC

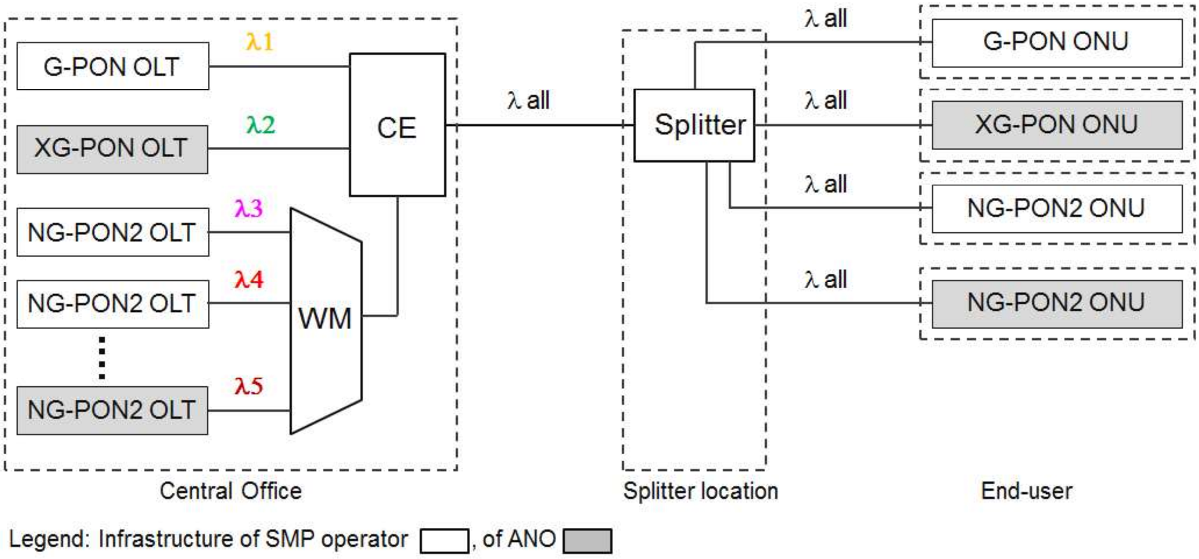
Figure 8: WU example 1 – SMP operator uses G-PON and NG-PON2, ANO uses NG-PON2[34]

Example 2:

Same example as example 1 above but in addition one ANO can use the wavelength (range) of XG-PON (see Figure 9). Based on this wavelength the ANO can build its own XG-PON or

[34] In order to avoid making this figure difficult to understand, for each PON technology and operator, only one end-user (ONU) is shown.

XGS-PON[35] with their own active XG/XGS-PON equipment. For ANOs, this option may be of interest, since they can achieve the same data rate of 10 Gbps symmetric as with one NG-PON2 wavelength with lower costs since the costs of XGS-PON equipment (ONUs do not



Source: BEREC

Figure 9: WU example 2 – SMP operator uses G-PON and NG-PON2, ANOs use XG-PON and NG-PON2[34]

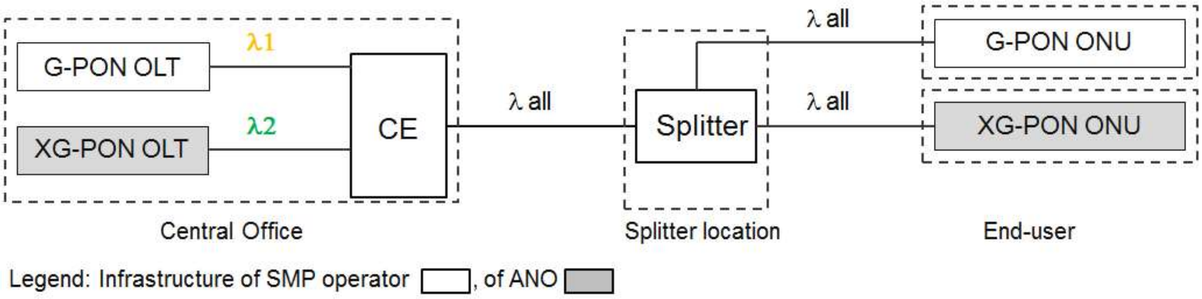
need tunable lasers) are lower compared to NG-PON2 equipment. However, since there is only one such wavelength (range), only one wavelength can be unbundled and only one ANO can use such a solution. Such a solution would also reduce the SMP operators' choice, since it would no longer be able to use XG-PON (or XGS-PON) on its own PON fibre infrastructure.

<u>Example 3:</u>

The SMP operator deploys G-PON but no NG-PON2. In this case, similar to example 2, also the wavelength (range) of XG/XGS-PON can be made available to ANOs (see Figure 10).

However, in this case the SMP operator would no longer be able to deploy XG/XGS-PON and it would be restricted with regard which PON technology it can use on its own PON fibre infrastructure.

[35] XGS-PON uses the same wavelength range as XG-PON (see ITU-T 2016, p. 1, 33). Optionally XGS-PON can use the GPON wavelength range instead of the XG-PON wavelength range.

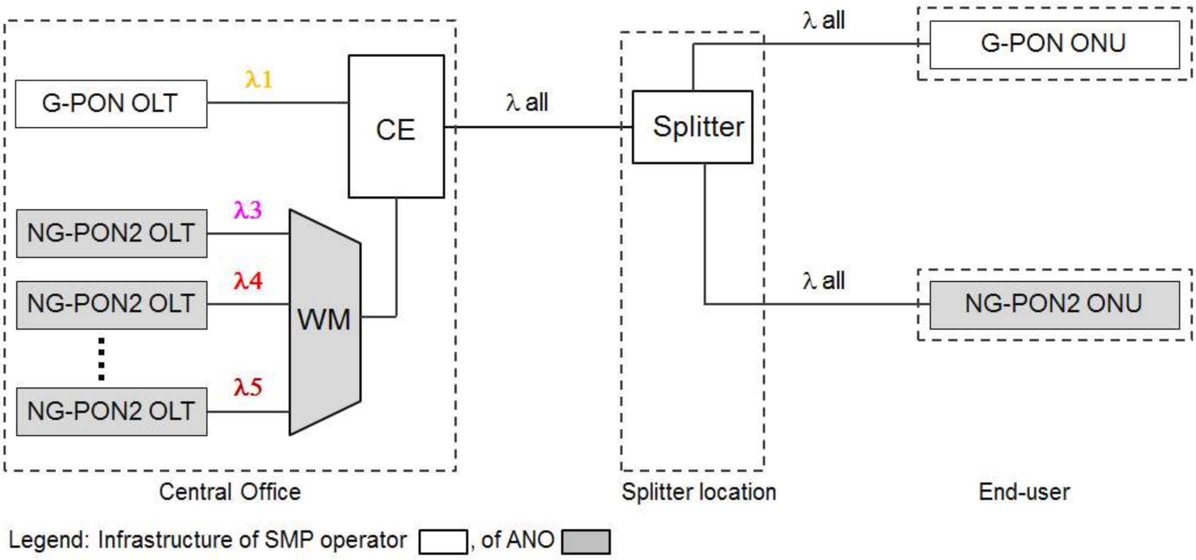


Source: BEREC

Figure 10: WU example 3 – SMP operator uses G-PON and ANO uses XG-PON[34]

<u>Example 4:</u>

As it is the case in example 3, the SMP operator deploys G-PON but no NG-PON2. In this case, an ANO may be allowed to deploy NG-PON2 on top of the PON fibre infrastructure of the SMP operator (see Figure 11). The G-PON technology of the SMP operator would co-exist with the NG-PON2 technology of the ANO, however, the customer premises equipment of the SMP operator (ONU) must be capable to enable this (see section 4 of Annex 1). In case the SMP operator has interest to deploy NG-PON2 at a later stage, then it may use one (or more) NG-PON2 wavelength(s).



Source: BEREC

Figure 11: WU example 4 – SMP operator uses G-PON and ANO uses NG-PON2[34]

<u>Example 5:</u>

An ANO is allowed to use the wavelength (range) of RF video (see Figure 7). This is possible independent from the PON technologies the SMP operator and ANOs use on the same PON fibre infrastructure (this means this solution could, for example, be combined with all examples above). This may only be appropriate if ANOs have interest in this wavelength (range) and the SMP operator does not use it.