WIK-Consult • Report

Study for The Netherlands Authority for Consumers and Markets (ACM)

Study into the current and future technological access options to all fixed telecommunication infrastructures in the Netherlands

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Final

NON-CONFIDENTIAL VERSION

This report has been reviewed by ACM, and all information classified as confidential has been removed by ACM. Redactions are marked with [✂].

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Abbreviations

ADSL	Asynchronous Digital Subscriber Line
ANO	Alternative Network Oprator
AON	Active Optical Network
BE	Best Effort
BEREC	Body of European Regulators for Electronic Communicatons
BNG	Broadband Network Gateway
BPI+	Baseline Privacy Interface Plus
BSoD	Business Services over Data
BSS	Business Support System
CAPEX	Capital Expenditure
CAS	Conditional Access System
CATV	Cable-Television
CCAP	Converged Cable Access Platform
CM	Cable Modem
CMTS	Cable Modem Termination System
CO	Central Office
CPE	Customer Premise Equipment
DMT	Discrete Multitone
DOCSIS	Data over Cable Service Interface Specification
DP	Distribution Point
DS	Downstream
DSID	Data Set Identification
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DVB-C	Digital Video Broadcast - Cable
DWDM	Dense Wavelength Division Multiplex
EAS	Ethernet Access Service
EC	European Commission
FD	Full Duplex
FDM	Frequency Division Multiplex

FTTB	Fibre to the Building
FTTC	Fibre to the Curb (Cabinet)
FTTDP	Fibre to the Distribution Point
FTTH	Fibre to the Home
FTTLA	Fibre to the Last Amplifier
FTTN	Fibre to the Node
FTTO	Fibre to the Office
FTTS	Fibre to the Street
Gbps	Gigabit per second
GPON	Gigabit Passive Optical Network
HD	High Definition
HFC	Hybrid Fibre Coax
HQ	High Quality
IGMP	Internet Group Management Protocol
IP	Internet Protocol
IPDR	Internet Protocol Detail Record
ITU-T	International Telecommunications Union-Telecommunications standards sector
Kbps	Kilobit per second
KPI	Key Performance Indicator
L2	Layer 2
L2VPN	Layer 2 Virtual Private Network
LDPC	Low Density Parity Check
LLU	Local Loop Unbundling
LQ	Low Quality
MAC	Media Access Control
Mbps	Megabit per second
MDF	Main Distribution Frame
MDU	Multi Dwelling Unit
MHz	Megahertz
MIMO	Multiple-Input Multiple-Output

MISO	Multiple-Input Single-Output
MLD	Multicast Listener Discovery
MPLS	Multi-Protocol Label Switching
MPoP	Metropolitan Point of Presence
MSAN	Multi-Service Access Node
MTR	Mean time to Repair
MTU	Message Transfer Unit
MTU	Message Transfer Unit
NBN	National Broadband Network (Australia)
NGA	Next Generation Access
NRA	National Regulatory Authority
ODF	Optical Distribution Frame
OFDM	Orthogonal Frequency Division Multiplex
OLT	Optical Line Terminator
ONT	Optical Network Terminator
ONU	Optical Network Unit
OPEX	Operational Expenditure
OSS	Operational Support System
OTT	Over the Top
PoI	Point of Interconnection
PON	Passive Optical Network
PoP	Point of Presence
PPPoE	Point-to-Point Protocol over Ethernet
PtMP	Point-to-Multipoint
PtP	Point-to-Point
QAM	Quadrature-Amplitude-Modulation
QoS	Quality of Service
RF	Radio Frequency
RFoG	Radio Frequency over Glass
SD	Simple Definition
SDF	Street Distribution Frame

SLA	Service Level Agreement
SLU	Subloop Unbundling
SME	Small and Medium Enterprises
SMP	Significant Market Power
SNMP	Simple Network Management Protocol
SNR	Signal to Noise Ratio
Tbps	Terabit per second
TDD	Time Division Duplex
TV	Television
US	Upstram
VDSL	Very high bit rate Digital Subscriber Line
VLAN	Virtual Local Area Network
VOD	Video on Demand
VoIP	Voice over Internet Protocol
Vplus	Vectoring plus
VULA	Virtual Unbundled Local Access
WBA	Wholesale Bitstream Access
WCA	Wholesale Central Access
WLA	Wholesale Local Access
XG	Extra Great/ Giga
XG.PON	Extra GPON
XGS.PON	XG.PON symmetrical
[✂]	Deleted confidential part

Management summary

Dutch telecom regulator ACM has assigned WIK Consult to assess the current and future technological access options for all fixed telecom infrastructures in the Netherlands. The infrastructures to be investigated encompass copper, fiber and coax–cable networks in the Netherlands. The access options to be considered are physically unbundled access (LLU), Virtual Unbundled Local Access (VULA) and Wholesale Bitstream Access (WBA) in the form of Wholesale Central Access (WCA), as they are defined in the EC market recommendation with the market 3a (wholesale local access (LLU/ VULA)) and 3b (wholesale central access).

Market 3a Wholesale Local Access is regulated. LLU and VULA services are available for alternative operators for KPN’s copper network and unbundled fibre for KPN’s fiber network. Market 3b Wholesale Central Access is deregulated, but incumbent KPN offers a commercial wholesale bitstream service for its KPN xDSL and FTTH networks. Today there is no access regulation on coax networks.

The relevant technical developments up to 2025 in fixed telecommunication infrastructures have been reviewed in the context of the currently deployed access technologies.

- Copper Access Network: KPN’s focus is on the implementation of Vplus (VDSL profile 35b) enabling data rates up to 230 Mbps. [✂]
- Fibre Access Network: A PtP fibre network is currently deployed in the Netherlands. The roll-out of FTTH by KPN has stopped (except for new construction areas). Passive PtMP topologies, e.g. GPON, might be implemented in the future.
- Cable Access Network: The VodafoneZiggo´s HFC network is based on DOCSIS 3.0. DOCSIS network architectures are shared medium architectures which in principle are not suited for physical unbundling. The alternative, virtual unbundling, can be offered by DOCSIS 3.1 Full Duplex. This however requires fibre to the last amplifier (FTTLA) with a huge fibre demand and investment, which is not expected to start to a sufficient extent in the Netherlands before [✂]. WCA/WBA can be offered based on a Layer 3 protocol (IP) without major technical restrictions. The bandwidth sold by wholesale is typically shared with all customers on that network. It is inefficient to use the IP-communication capacity for linear TV-Multicast. Such programs are expected to become available as resale offer.

In addition, business case modelling has been done to review the economic viability of the different wholesale access services over copper, fibre and coax networks in the Netherlands. This is done by modelling the business case for a hypothetical entrant based on the current network information of the Dutch copper, fibre and coax networks of KPN and VodafoneZiggo, existing wholesale tariffs and estimated costs for network and other costs. The modelling occurs in a steady-state approach assuming that the entrant has reached a certain scale and appropriate network roll out. Inefficiencies by ramp-up effects are not considered.

For all tested scenarios it is noted that the model results are sensitive for the applied ARPU and wholesale costs. Below table 0-1 displays for the tested business case scenarios what the margin is for the realistic base case scenario of 2% market share of homes passed.

Table 0-1: Overview of the tested business case scenarios and their respective possible margins

Scenarios	Margin (for base case of 2% market share)
1) National coverage with WCA KPN Copper & Fibre network	16.8%
2) National coverage with VULA KPN copper network	12.8%
3) Regional coverage with VULA KPN copper network	17.4% With 10 largest access points connected
4) Complete network coverage with Fibre LLU KPN fibre network	-55.6%
5) Partial network coverage with Fibre LLU KPN network	-25.8% With 10 largest access points connected
6) National coverage with WCA for VodafoneZiggo coax network	14.4%
7) National coverage with VULA for VodafoneZiggo coax network	-11.9%
8) Regional coverage with VULA for VodafoneZiggo coax network	18.1% With 10 largest access points connected

The colours indicate the level of margin possible; dark green for stark positive to dark red for stark negative.

As observed in the second column of above table, the scenarios in which an entrant targets the complete national market based on WCA are economically viable for KPN's copper and fibre networks but also for the (hypothetical) scenario for VodafoneZiggo's coax network (scenario 1 and 6). From small market shares onwards the business cases get positive and for a realistic market share of homes passed (2%) the margin reaches 16.8% and 14.4% respectively. The lower margin for the coax business case is explained by the significant volume discount (15%) on KPN's WCA service, which is applicable for KPN's copper network only.

An entrant could target the complete national market as well based on VULA for KPN's copper network (scenario 2), however this will not be motivated due to the lower margin compared to scenario 1, unless it decides that it requires the better product characteristics of VULA versus WCA (higher flexibility to design the retail product).

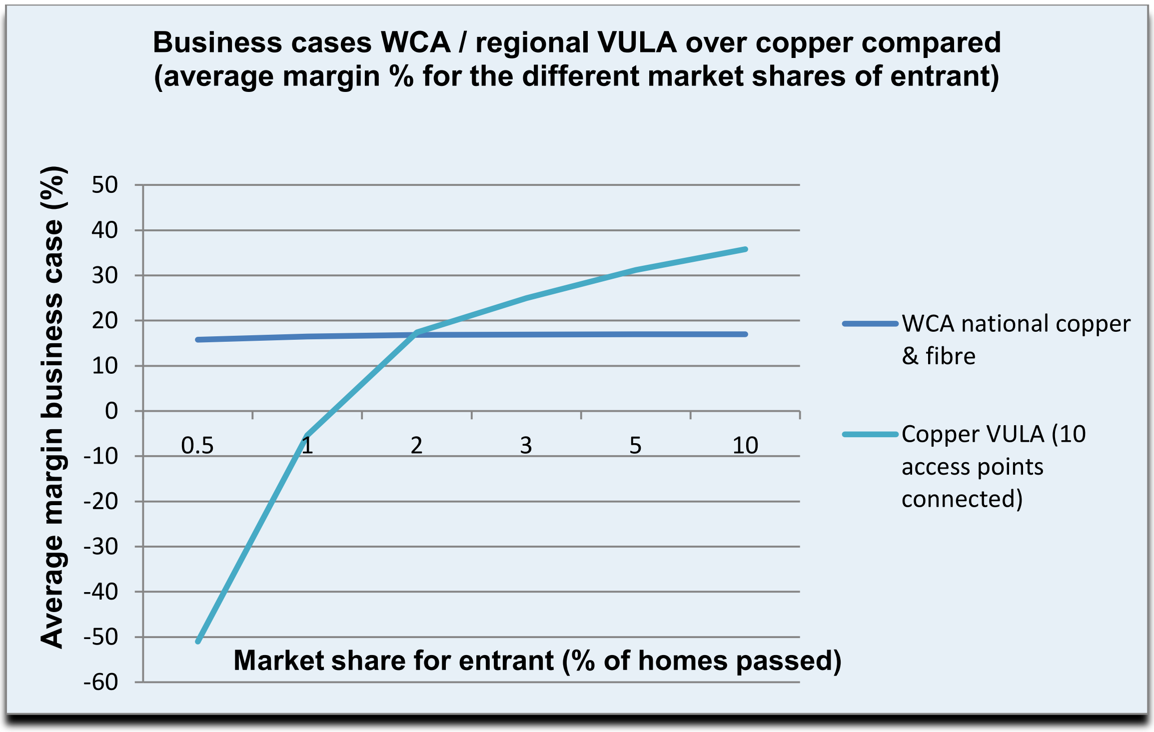
Due to the different geopgraphical coverage between the copper, coax and fibre networks in the Netherlands, different names have been used two distinguish a broad geographical coverage and a focused geographical scenario on certain areas. For the almost nationwide copper and coax networks, we have called these two options ‘national and regional coverage’. For the much smaller fibre network (30% of households covered), the two tested scenario’s are called ‘complete and partial network coverage’.

The complete network coverage scenario based on fibre LLU (scenario 4) is not economically viable for an entrant as the margin for the base case is strongly negative and even for 10% market share (of homes passed), the margin is only 2.7%. This is due to the significant connection costs of all access points and the limited coverage of KPN’s fibre network (30% of house holds in the Netherlands). For the national coverage scenario based on coax VULA there are also significant connection costs to connect all access points, however more homes passed are available for this nationalwide network. The break even point of the business case lies around 2.5% market share of homes passed. From a market share of 4% onwards, the resulting margin using coax VULA for nationwide coverage becomes higher (17.8%) than using WCA over coax.

In general, it is considered economically viable that an entrant starts with WCA and then with increasing market share targets certain geographic areas and starts using copper and coax VULA and or fibre LLU.

However, based on the current fibre LLU pricing and KPN’s fibre network structure, the business case is difficult for an entrant using fibre LLU. It only gets positive when an entrant has more than 5.5% market share in a targeted KPN fibre area, however the realistic margin will never be higher than 7% (even with 10% market share in the targeted KPN fibre areas. Hence, economically, it makes no sense for an entrant to combine WCA with Fibre LLU in targeted areas. For an entrant using the KPN networks combining the WCA service with copper VULA regionally does make sense as illustrated in below figure 0-1.

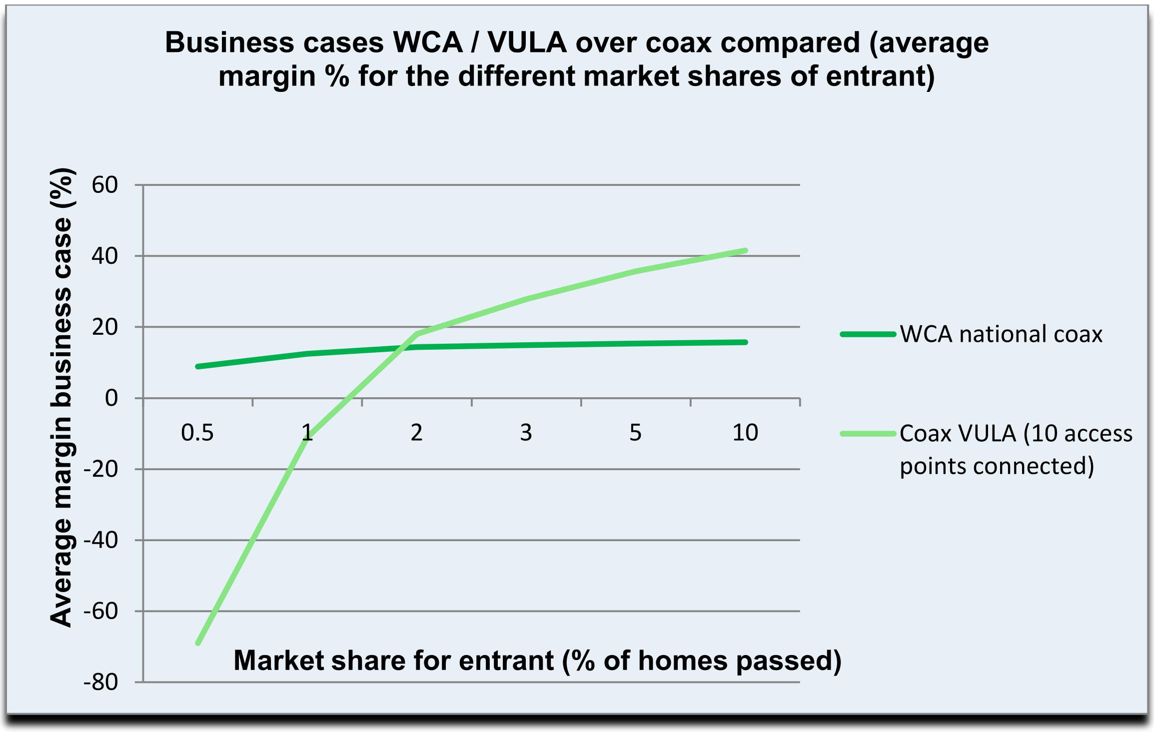
Figure 0-1: Comparison of using WCA by the entrant versus regional VULA for KPN's copper network



The dark blue line represents the business case of an entrant using WCA over KPN's copper and fibre network. It is clearly an economically viable option as an access seeker can achieve around 16% average margin from a low market share onwards (0.5%). If alternative operators scale up with WCA over KPN's networks to 2% market share of homes passed, they can achieve a higher margin by combining WCA (dark blue line) with copper VULA (light blue line) for targeted areas. However this is only if they take the effort of connecting to a minimum number of the 10 largest access points and or combine this with a higher market share (from 3% onwards) in the targeted areas. In those cases, an access seeker can achieve higher average margins compared to WCA (from 17% to 25%). As long as the alternative operator succeeds in growing and maintaining its market share of 3% in all areas, it can even roll-out to almost all 161 VULA access points with margins between 20% and 25%.

An alternative for access seekers is to use the VodafoneZiggo coax infrastructure. Below Figure 0-2 displays the results of the business case using a potential WCA service versus a potential VULA service over VodafoneZiggo's network.

Figure 0-2: Comparison of using WCA by the entrant versus VULA for VodafoneZiggo's coax network



When WCA over coax would be made available (dark green line in the above Figure 0-2), this would be an economically viable option as well although an entrant would need around 1.5% market share to reach a comparable average margin (14%) as with WCA over copper and fibre. As noted before, this is still lower than the 16.8% for copper WCA due to the significant volume discount (15%) for KPN's WCA service, which is applicable for its copper network only. So if a WCA service over coax is considered, this difference should be balanced out in order for an access seeker even to consider using VodafoneZiggo's coax infrastructure above KPN's copper/fibre infrastructure.

If an entrant has chosen for the coax infrastructure and is growing in market share, it might consider connecting to VodafoneZiggo's network at a lower level to save wholesale costs. This could be through a VULA service at the CMTS locations for which the business case results are displayed in light green in above Figure 0-2. Similar to copper VULA, an entrant would need at least 2% market share in targeted areas while connecting the 10 largest access points to achieve a higher margin (18%) compared to WCA over coax.

VULA, however will not be available before 2025 unless VodafoneZiggo's is forced to invest significantly in their network in the coming years and upgrade to DOCSIS 3.1 Full

Duplex. A bitstream service at CMTS locations however is a technical feasible option (but with different product characteristics as VULA).

1 Introduction

In the Netherlands nearly any household has access to two competing networks offering high quality telecommunication services. Almost every home has a xDSL- (from KPN) and a cable connection (from Ziggo, now VodafoneZiggo or some small suppliers) and if a FTTH-fiber connection (from KPN, former Reggefiber, and CIF) is available in most of these areas xDSL is still offered, but no FTTC upgrade with VDSL and its increased bandwidth. A large part of the business customers can choose from xDSL and fibre.[1] Regulation is aimed to allow entrants to use network access as an extra competitive pressure on top of competition between incumbent operator and cable operators. In this context the question arises whether wholesale access to cable networks would be technically feasible and would foster competition by entry into the market. A consecutive second question comes up how this would influence existing business cases in fiber and copper based markets and open options for new entrants.

Aim of the study is to assess and map current and future technological access options to all fixed telecom infrastructures in the Netherlands. The infrastructures to be investigated encompass copper, fiber and coax–cable networks in the Netherlands. The access options to be considered are physically unbundled access (LLU), Virtual Unbundled Local Access (VULA) and Wholesale Bitstream Access (WBA) in the form of Wholesale Central Access (WCA), as they are defined in the EC market recommendation[2] with the market 3a (wholesale local access (LLU/ VULA)) and 3b (wholesale central access).

The goal is to enable ACM to assess the effects of the future technological access options during the upcoming market 3a analysis (period 2019-2022) and beyond, up to 2025.

For this purpose the study first describes the current market situation and the regulatory environment in the access markets (section 2) and then analyses the current and foreseeable technological developments for copper (incl. FTTC etc.), fibre (FTTH) and coaxial-cable based infrastructures (section 3). Based on this, the possible effects of the technological developments on the wholesale access options for market 3 are assessed from a technical and operational point of view (section 3). In a business case developed for a new market entrant based on wholesale access (described in section 4.5.6) the study analyses which impact the different wholesale access options might have on a new entrant into the telecommunication market in the Netherlands (section 4.5.6). At the end the results are summarized in the final section 7.

1 BEREC (2016), Challenges and drivers of NGA rollout and infrastructure competition, BoR (16) 171, p.101, if fibre, FTTO only.

2 EC recommendation on relevant product and services markets, C(2014) 7174 final, 9. October 2014, with Explanatory notes on the EC recommendation on relevant product and services markets, SWD(2014) 298, 9. October 2014

2 Current market situation and regulation in the Netherlands concerning the fixed telecommunication infrastructures

2.1 Context

The Dutch telecom market is considered to be in the top 5 countries in Europe considering Next Generation Access (NGA) network coverage and take-up. The Netherlands has two almost nationwide NGA infrastructures; KPN's network consisting out of a, non overlapping, combination of copper (FTTC) and fibre (FTTH). Furthermore, there is VodafoneZiggo's cable network based on Docsis 3.0. These networks are complemented with smaller regionally acting cable networks. Incumbent KPN owns as well a point to point fibre network, which does not overlap with its FTTC VDSL network and covers approximately 30% of the homes.

There are 7,1 million retail broadband connections in the Netherlands. Cable is the most subscribed platform (46%), followed by xDSL (39%) and Fibre (15%)[3]. In the third quarter of 2016, for the first time, more than 1 million households were connected via a fibre connection in the Netherlands and more than 2.5 million homes passed. The majority of these fibre connections have a download speed between 30 and 100 Mbps (48%) or even above 100 Mbps (36%)[4].

In the last years the telecommunications market has consolidated strongly:

- In 2016 cable operator UPC (Liberty Global owned) took over the largest cable operator in the Netherlands Ziggo and continued as Ziggo. In January 2017, Ziggo and mobile operator Vodafone merged in a Joint Venture, called VodafoneZiggo with a broadband market share between 40 and 45%.
- XS4all and Telfort have been bought by KPN already in the past. In 2016 KPN integrated a previous joint venture partner Reggefiber, which owned a point to point fibre network mostly in the east and southern part of the Netherlands. The fibre network is complementary with KPN's VDSL network. KPN holds an equal overall retail broadband market share as VodafoneZiggo; between 40 and 45%.
- Remaining market parties are Tele2, T-Mobile, Delta, CAIW and Online. They hold together a retail broadband market share between 5 and 15%.

The related retail market development is the increasing amount of bundling in the market. Especially in 2015 and 2016, the number of quad play bundles (broadband, voice, TV and mobile) has grown beside the already popular triple play bundles

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(broadband, voice, TV)[5]. Almost all Dutch broadband subscribers (90%) have at least double play, the majority triple play bundle (63%) and already 12% a quad play bundle[6].

In line with the increasing amount of quad play bundles, all Dutch mobile operators have secured access to fixed network services and do offer fixed network services combined with their mobile services:

- T-Mobile has bought the fixed broadband unit from Vodafone in January 2017 (was a pre-condition for the VodafoneZiggo merger that Vodafone sold its fixed network). T-Mobile uses unbundled fibre from KPN as wholesale access service.
- Tele2 uses KPN's copper network based on local loop unbundling for copper and from 2015 onward also based on virtual unbundled local access.
- As mentioned before, Vodafone joint ventured with Ziggo, so has access to Ziggo's cable network; and
- KPN Mobile has access to KPN's own fixed copper and fibre network.

5 Bundeling van telecomdiensten en content in Nederland. Een analyse van de mogelijke gevolgen voor concurrentie, 28 February 2017, https://www.acm.nl/nl/publicaties/publicatie/16982/Bundeling-van-telecomdiensten-en-content-in-Nederland-een-analyse/

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2.2 Regulatory approach to NGA

The following paragraphs focus on the for this study relevant markets 3a/b in line with the definition by the European Commission. Table 2-1 displays the historically applied market definition and SMP designations from the market reviews in the Netherlands.

Table 2-1: Market 3 regulation history (overview)

Market 3a (ex 4) **Wholesale local access**	**Market 3b (ex 5)** **Wholesale central access**
2011 Relevant national product market defined: access to copper networks via LLU/SLU (MDF/SDF access) and fibre networks via FTTH unbundling (ODF access). First FTTO unbundling was not included in the relevant market in its 2011 analysis after being included in its 2008/2010 Decision, which were both challenged in court and annulled[7]. Incumbent KPN designated SMP as it is the only party with access to a country wide network capable of providing local access and the pressure from competition on the retail market is insufficient to restrict KPN in its position. 2015 update[8], No change in relevant product market, clarification that virtual unbundling is part of Market 3a as well. Hence unbundled and active connections over copper and fibre networks with a local handover point. KPN designated as SMP due to its nearly 100% stabile share of this market. KPN obliged to offer copper and fibre unbundling (MDF access and ODF access) and VULA for KPN's xDSL copper network. 2016 update FttO[9] ACM concluded that KPN is the largest suplier in the market for unbundled access to business fibre networks, however did not conclude that KPN also has SMP in this market. Therefore, the market for unbundled access to business fibre networks remains unregulated.	2008 Relevant national product market split in a low quality (contention ratio above 1:20) and a high quality WBA market over copper and fibre networks. LQ WBA part of Market 3b, HQ WBA part of Market 4 together with Wholesale Leased Lines.Incumbent KPN designated as SMP for both submarkets. 2012[10] Market for LQ WBA deregulated due to competitive pressure from LLU and cable. Decision was brought to court, but eventually on 15 January 2014, the Dutch Court confirmed ACM's Decision[11].

7 See ACM's Marketanalysis decision regarding unbundled access of 29 November 2011, https://www.acm.nl/nl/publicaties/publicatie/10307/OPTA-stelt-marktanalyse-ontbundelde-toegang-2011-vast/
8 See ACM 2015 final Market analysis on unbundled access, https://www.acm.nl/nl/publicaties/publicatie/15087/Marktanalysebesluit-ontbundelde-toegang-2016--2019/
9 See ACM's Marketanalysis decision regarding FttO of 1 September 2016, https://www.acm.nl/nl/publicaties/publicatie/16207/Marktanalyse-FttO/
10 27 April 2012, See https://www.acm.nl/nl/publicaties/publicatie/10352/Besluit-marktanalyse-lage-kwaliteit-wholesale-breedbandtoegang-LKWBT/
11 See https://www.acm.nl/nl/publicaties/publicatie/12546/Uitspraak-CBb-over-marktanalysebesluit-LKWBT/

Withdrawal FTTO access for Market 3a

Before 2011 ACM first included also unbundled fibre to the office (ODF access FTTO) in its market 4 (now 3a) regulation. However, after a long process, withdrew this obligation. ACM decided for a separate ODF-FTTO market and assigned KPN again as SMP, but eventually, the Dutch court decided on 18 December 2013, that ACM had gathered insufficient data to conclude that KPN has SMP on the ODF access (FTTO) market and nullified ACM's ODF FTTO Decision. However the court upheld the market definition[12]. In September 2016, ACM concluded in its market review FttO, that KPN is the largest suplier in the market for unbundled access to business fibre networks, however did not designate KPN as SMP and therefore this market remained unregulated.

Withdrawal of SDF access and introduction of VULA

At the time of the 2011 market review, ACM anticipated that access seekers would start with LLU (MDF Access) and at a certain scale would shift to SLU (SDF access). This however did not happen as the business case for SLU turned out to be too challenging.

In addition, KPN started investing in VDSL vectoring for its copper network in 2013 and as a consequence, access seekers were no longer able to place their own equipment at the street cabinet. Furthermore, in certain areas the LLU service would also be disrupted.

ACM in response allowed KPN to upgrade its copper network only if services to access seekers were not limited and indicated that VULA could be a solution. ACM also defined criteria for VULA; available for any bandwidth and all other parameters resembling LLU, being a layer 2 Ethernet with transparent transmission, allowing parties to implement their own CPE and some TV-signals and being available at all local handover points with a nationwide coverage[13].

As the network upgrade was central in KPN's business plans, the regulation motivated KPN in 2014 to start negotiations with the largest wholesale customers Tele2 and Online regarding the replacement of LLU and SLU with VULA. On 24 July 2015, KPN announced an agreement regarding the required VULA amendments for the WBA service, related co-location and pricing[14]. The agreed VULA service is a layer 2 Ethernet service offered for all (161) metro core locations and for all lines in KPN's copper network. All bandwidth and overbooking variants are available and alternative operators can use their own CPE.

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12 See http://uitspraken.rechtspraak.nl/inziendocument?id=ECLI:NL:CBB:2013:273

13 Commercial wholesale agreements in the Netherlands, ACM presentation 7 March 2017 at the WIK Investment Workshop in Brussels, http://wik.org/fileadmin/Konferenzbeitraege/2017/Interactive_Workshop/Presentation_Johan_Keetelaar__Director_ACM__for_the_WIK_Investment_Works....pdf

14 See https://www.kpn-wholesale.com/nl/over-kpn-wholesale/nieuws/introductie-vula-aanbod-en-uitrol-vdsl-binnenringen.aspx

ACM reviewed the negotiated offer and concluded that the offer complied with the non-discrimination and transparency obligations and approved it on July 28th, 2015.[15] KPN was now allowed to implement VDSL2 and vectoring at MDF/SDF locations where no alternative operators are present or where they have been migrated to VULA.

Therefore in the market review of 2015, ACM withdrew the obligation for SDF Access and related SDF backhaul and introduced the obligation to offer VULA for KPN's xDSL copper network.

Current access remedies

Regulator ACM focuses on unbundled, passive access to create incentives for access seekers to invest in their own infrastructure and equipment as far as possible. Special is that due to the point to point setup of KPN's fibre network, unbundled fibre is also possible. As of Q3 2016, measured in number of connections, the most popular wholesale access service of KPN used for offering retail broadband connections by alternative operators is (virtual) unbundled access (LLU and VULA) over copper (56%)[16]. Copper VULA is followed in popularity by active WBA connections over KPN's copper network (28%) and KPN's fibre network (11%) and lastly FTTH unbundling with the wholesale service ODF access (5%) Table 2-2 displays the current available access remedies.

Table 2-2: Current available access remedies

Market 3a (ex 4) **Wholesale local access**	**Market 3b (ex 5)** **Wholesale central access**
KPN copper xDSL network - MDF access (LLU) - Virtual unbundled access (VULA) KPN FTTH network - ODF access (unbundled fibre)	Deregulated, but commercial wholesale bitstream access (WBA) service available for KPN's xDSL and FTTH networks. WBA has a national and a regional variant (handover at metro core node, product name is WBA national/local WAP).

15 See https://www.acm.nl/nl/publicaties/publicatie/14545/Aanbod-KPN-virtuele-ontbundelde-toegang-kopernetwerk-VULA/

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2.3 Relevant regulatory aspects for the upcoming market review of market 3a/b (wholesale local/central access)

Following developments could play a role in the upcoming market review of markets 3a/b:

- Copper LLU is in the process of being phased out. It was mostly used by Tele2 and up to a half million subscribers in the Netherlands but after reaching the VULA agreement with KPN, Tele2 is migrating to VULA. Furthermore, KPN indicated that it would like to stop providing copper LLU as it hinders the vectoring implementation.
- In respect to cable wholesale access, Belgium is one of the few countries where access to the cable networks has already been regulated. The obliged cable wholesale access service is a resale service, where the three different cable operators are obliged to resale their basic TV Service, their interactive services and their broadband Services[17]. Regulator BIPT obliged cable operators to offer the analogue but also the digital content in the basic package due to technical inability of the cable operators to separate these signals. The access seeker is not obliged to pay for the digital services in the basic package as the end customers need a separate decoder to view the digital content (which is not offered in the basic retail service). Furthermore, due to the fact that the Conditional Access System (CAS) could be different for different cable operators, BIPT directed that access seekers have to deal with one CAS of a third party only. This third party CAS is then interfacing with the CAS systems of the different cable networks. Another topic which needs to be considered while designing or reviewing the reference offer is encryption of the signals as access seekers need access to the network's subscriber management system so that the encrypted cable signals are delivered to the end customers of the access seeker. A last aspect is Video on Demand (VoD) functionality for access seekers. This requires an agreement on data formats and other practical aspects as the data is stored on servers of the access provider and access seeker's VoD services need to be integrated in the interactive services of the access provider.
- Denmark is another country with wholesale obligations on the cable-TV network operator beside the copper and fibre networks. In Denmark the incumbent operator besides copper and fibre networks also operates the largest cable-TV network. DBA[18], the Danish NRA, obliged wholesale obligations on all access network technologies (see table 2-3 below for an overview). VULA is offered in a contended and uncontended manner, VULA and bitstream include Multicast.

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17 http://www.bipt.be/en/operators/telecommunication/Markets/Broadcasting/referentieoffertes-kabeloperatoren/communication-about-the-reference-offers-for-the-cable

18 Danish Business Authority

Table 2-3: Wholesale access obligations in Denmark[19]

Wholesale category	Wholesale product	Platform		
		Copper	Fiber	Cable
Duct access	Duct access in backhaul sections	√	√	
Unbundled local access	SLU	√		
	LLU	√	√	
VULA	VULA uncontended	√		
	VULA contended, layer 2	√		
	VULA contended, layer 3	√		
Bitstream access	Bitstream access, layer 2	√	√	
	Bistream access, layer 3 with regional handover	√	√	√
	Bitstream access, layer 3 with national handover	√	√	√

22 December 2009 the Danish NRA published a market decision which obliged incumbent TDC to provide third party access to broadband via TDC's cable network. This obligation was upheld with DBA's market decision of 16 August 2012 and is still valid. However, no third party has yet requested to deliver broadband access via TDC's cable network.

As announced in DBA's market decision from 16 August 2012, DBA assessed in 2013 the possibility and necessity of altering or supplementing the existing obligation to make it more attractive for third parties to deliver broadband via TDC's cable network. The assessment focused on the access obligation and price control obligation and the possibility of enabling alternative operators to broadcast TV and TV-related services via TDC's cable network.

The current regulated cable access obligation includes two conditions/ restrictions, which were deemed necessary because of technical issues in the existing setup of TDC's cable network.

- Firstly, the market decision of 16 August 2012 does not allow alternative operators to apply multicast or broadcast functionalities to deliver TV via TDC's cable network. This is due to capacity limitations.
- Secondly, it is a condition for access that retail end users, as a minimum, acquire a TV-package (typically TDC's basic TV package which currently includes radio-channels, public service TV channels and three

19 See https://erhvervsstyrelsen.dk/sites/default/files/afgorelse_tdc_engrosmarkedet_bredbaandstilslutninger_2012_08_16.pdf.pdf, p. 125.

commercial TV-channels). This is due to technical limitations from passive frequency filters.

In a report for the DBA of 10 December 2012, Gartner considered the possibility of altering the two existing conditions/restrictions mentioned above. With regard to the condition of end-users acquiring a TV-package, Gartner found that a frequency reallocation will be too costly and cause too much disruption for end-users. Furthermore, Gartner considered it also to be too costly to obligate TDC to use broadband only filters, which would also enable the alternative operators to sell a broadband only connection to end-users. Gartner concluded that multicast is not an option, since it would lead to an inefficient use of TDC's cable network. Gartner finally concluded that third party multicasting of a given TV-channel is inefficient since the same (popular) TV-channels would be distributed by both IP-TV via multicast and a DVB-C TV-signal. Instead, Gartner proposed to give alternative operators access to share TV-transmission signals of the "the same" content as TDC delivers to end-users. In Gartner's view, this solution could lead to a more efficient use of TDC's cable network.

However, in September 2015 TDC announced a commercial offer that gives the alternative operators access to deliver broadband via TDC's coax network as a broadband-only solution. This offer is based on a comprehensive reallocation of TDC’s frequencies in their coax network, which was implemented at the beginning of 2016. This made it possible for TDC as well as alternative operators to provide stand-alone broadband products to end users. TV would be possible via IP unicast.

TDC is right now upgrading the coax network from DOCSIS 3.0 to DOCSIS 3.1. In the upgraded areas, end-users can get broadband speeds up to 1 Gigabit. At the beginning of 2018, TDC’s coax network will be fully upgraded to DOCSIS 3.1. By then, approximately two thirds of Danish households will have access to Gigabit-speeds through TDC's coax network.

By beginning of May 2017, TDC has introduced a new commercial offer to the alternative operators, which also offers the access seeker a broadband-only solution[20]. The technical setup in TDC's new commercial offer is the same as in their initial offering (a layer 3 bitstream service). VULA is not included, TDC also offers IP transmissions as an add-on to the bitstream services.The major changes of the new commercial offer are in the pricing model and in the ordering procedures. TDC's new price model consists of a capacity element and a

20 For bitstream coax see https://wholesale.tdc.dk/Produkter/PT_BSA_Coax_Bilag_1a_Prod_spec_Adgang_v_301116.pdf. And for bitstream coax with TV see https://wholesale.tdc.dk/Produkter/PT_BSA_Coax_Bilag_1b_Prod_spec_Adgang_uden_samproduktion_v_301116.pdf (Danish language only)

subscriber element. Capacity is shared between all end-users. TDC reduced the price component for capacity and increased the price for the subscriber element with the intention to reduce economies of scale in order which is in the benefit of smaller operators (typically have higher average capacity usage per end-user compared to larger operators).

Currently, DBA is in the process of finalizing their market review for the broadband market which includes coax access regulation as well. Notification of proposed market review and related remedies to the European Commission is expected before the end of 2017.[21]

2.4 Wholesale offer of a cable-TV network operator (Caiway)

CAIW is a regional telecommunication operator[22] offering radio and TV-Services, telephony and data and internet access services both on fibre and coax cable infrastructure. The access infrastructure in general is rented and accesses approximately [✂] end customers, approximately [✂] of these by PtP fibre. Typically, there is a coax connection besides the fibre line. For the future CAIW intends to focus on fibre rather than on coax access.

Its retail services on fibre consist of interactive IPTV, telephony and data communication including internet access. There is no additional fibre or wavelength required for linear TV. If there is a coax access line in parallel it is used for linear TV downstreaming (classical cable-TV) and thus releases the IPTV traffic fibre load.

If the access is provided on a single coax cable only (without parallel fibre, 60% of the cases) the radio and TV service is provided in a linear downstream manner, standard in the DOCSIS architecture. Telephony and internet access are provided in the DOCSIS up- and downstream channels.

In the coax networks CAIW typically uses a DOCSIS 2.0 and 2.1 infrastructure and protocol, in a few locations it uses 3.0. Since its focus is on fibre instead of coax further upgrades to 3.0 are not planned.

CAIW also offers a wholesale access service (EAS: Ethernet Access service) on its fibre access infrastructure. This is a WBA service. This is motivated by a wholesale obligation of most infrastructure owner (e.g. a RABO Bank fund CIF) and by CAIW's conviction that a wholesale business is better than no business.

21 Source DBA, Department Business Development and Regulation, June 2017
22 Annual revenue of approximately 100 mn €

On the coax infrastructure (without parallel fibre links) it offers a PPPoE (Point-to-Point Protocol over Ethernet) wholesale access based on the DOCSIS data channels. This offer may be added by a radio and cable-TV resale of the CAIW poducts. This offer is driven by historic reasons and restricted to the former subsidiary CBIZZ (a B2B service provider), but could in princilple be opened to third parties on demand (keeping in mind that CAIW focusses on fibre and that in most coax connection cases there is a fibre link in parallel)[23].

The traffic is handed over at 2 (national) handover points. In principle handover at a lower level is also possible, but not demanded due to low traffic demand and a low number of customers connected by wholesale at all.

CAIW is not offering any BSOD (Business services over DOCSIS, an optional layer 2 access service for DOCSIS 3.0 and above) service, thus is not capable to do so for wholesale customers. This lack of service is also caused by the lack of capability of the underlying DOCSIS infrastructure.

Besides the passive infrastructure wholesale business CAIW is also buying wholesale access on a few coax networks of other smaller operators[24], who provide linear (cable-) TV and want to add their end customer services by telephony and internet access provided by CAIW or others, which they do not intend to provide by their own. In these cases the DOCSIS up- and dowmstream data channels respectively frequency spaces are not used by these operators. [✂] This business is a minor one, summing up to [✂] customers out of a potential of [✂] homes connected. This business segment will not increase.

[✂]. CAIW recognized that entering an FTTH business requires an already existing minimum customer based in order to overcome the critical market share for becoming profitable soon.

Summarizing CAIW’s wholesale business, they sell WBA (EAS) on fibre, PPPoE over coax to one customer (CBIZZ), for historic reasons and limited to a minor extent. They accompany their wholesale with a radio and TV resale, where appropriate.

CAIW wholebuys the passive infrastructure, and the active frequency spaces, the full DOCSIS data channels for bidirectional communications to a minor extent ([✂]

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23 The quality of PPPoE over DOCSIS will not meet VULA QoS requirements, see section 4.2.3.2.2 and footnote 139.

24 Stichting Kabeltelevisie Pijnacker (which services Pijnacker and Delfgauw), Rekam (which services Gouda and surroundings) and CAI Harderwijk (which services Harderwijk and surroundings)

customers), the remainder of a historic business. Their future view on wholebuy focusses on fibre, where available, and on other wholesale products coming close to it.

3 Current and foreseeable future technical developments in fixed telecommunication infrastructures

The Internet access to residential users was introduced in the 1990s. The first mechanism to get access to the Internet was based on a dial-up connection through the standard analogue telephone line. This type of access delivered data rates up to 56 Kilobits per second (Kbps)[25], which cannot be considered broadband access.

Broadband access service was first introduced by the late 1990s, which delivered data rates in the range of a few hundred kbps to a couple of megabits per second (Mbps) over a twisted copper pair access network. The different fixed telecommunications infrastructures deployed across the years, i.e. copper, hybrid fibre coaxial (HFC), and fibre, made possible to offer higher data rates from hundreds of Mbps up to Gigabit and multi-Gigabit per second (Gbps) speeds. In this section a description of the currently available access technologies is provided, together with an introduction to the foreseeable future technologies up to the year 2025.

3.1 Copper based infrastructures

The first option of operators to offer broadband access is to reuse their existing infrastructure. In the late 1990s the incumbent operators started to implement Digital Subscriber Line (DSL) technology over their existing copper networks. This technology was based on 1 MHz of spectrum bandwidth above the 4kHz voice channel. The following sections provide the reader with a description of the different technologies of the xDSL family, that are relevant in the Netherlands.

3.1.1 ADSL

The ITU-T standards G.992.1 and G.992.2 define the Asymmetric Digital Subscriber Line (ADSL). ADSL technology standardization was first published in July 1999 (G.992.1), and provides data rates up to 8 Mbps downstream and 1 Mbps upstream, based on 1.1 MHz spectrum bandwidth. ADSL access nodes are located in the central office (CO) covering a typical service area radius up to 5 kilometres.

25 With 2 ISDN B-channels dial up was up to 128 Kbps

3.1.2 ADSL2 / ADSL2+

The second version of ADSL, known as ADSL2, was ratified by the ITU-T[26] in July 2002 (G.992.3 and G.992.4). This technology is still based on a spectrum bandwidth of 1.1 MHz, and it provides maximum data rates of 12 Mbps downstream.

The ADSL2+ standard was first published by the ITU in 2003 (ITU G.922.5). It uses a spectrum bandwidth of 2.2 MHz, allowing a maximum data rate of 25 Mbps downstream and 1 Mbps upstream. The service area radius is about 5 km as in the case of ADSL and ADSL2.

3.1.3 VDSL / VDSL2

Very-high-bit-rate DSL (VDSL) enhanced the data rates provided to the end-user. VDSL technology (ITU G.993.1) was approved in 2004, and it supports both options: (1) symmetric services up to 26 Mbps for each communication channel, and (2) asymmetric service with downstream data rates up to 55 Mbps (short copper loops), and upstream up to 19.2 Mbps. The increased data rate is the most relevant advantage of this technology in comparison to ADSL, ADSL2 and ADSL2+.

The performance increase is possible through the implementation of shorter copper loops, i.e. the DSL equipment is deployed much closer to end customers. The typical VDSL network architecture uses a fibre-optic transmission from the central office to an intermediate point, e.g. a street cabinet, where a Digital Subscriber Line Access Multiplexer (DSLAM) is installed. Twisted copper pair infrastructure is used to connect the cabinet to the end-user. In addition to the shorter copper line, the following features are required to support the enhanced data rate:

- 12 MHz spectrum bandwidth in downstream, instead of the 1,1 or 2.2 MHz channels used in case of ADSL/2 and ADSL2+ respectively
- Use of four different frequency bands, i.e. two frequency bands for each communication channel, upstream and downstream

VDSL technology never reached the maturity required to be deployed in a large-scale manner. The main reason was the modulation to be used for data transmission. VDSL modulation options were Quadrature-Amplitude-Modulation (QAM) and Discrete Multitone (DMT). Legacy xDSL technologies, i.e. ADSL, ADSL2 and ADSL2+, used DMT to transfer data. This reason forces the evolution to a second version of VDSL.

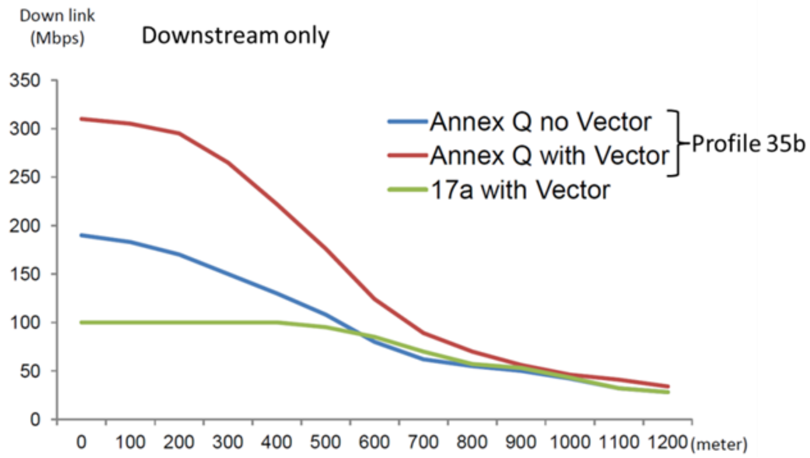
The second generation of VDSL, known as VDSL2 (ITU G.993.2), was first approved in 2006, with a number of amendments between 2007 and 2011. It supports symmetric

26 International Telecommunications Union – Telecommunications standardisation sector

and asymmetric aggregate data rates up to 200 Mbps with copper based loops up to 300 meters. The enhanced data rate is possible by means of 30MHz spectrum bandwidth. VDSL2 technology defines eight different profiles. The spectrum bandwidth used depends on the implemented profile and ranges from 8.8 MHz to 30 MHz.

An enhanced version of VDSL2, known as VDSL2 Annex Q or Vplus (ITU-T VDSL2 Profile 35b standard), was introduced in 2015. Vplus was developed by Alcatel-Lucent (now Nokia) and widens the spectrum bandwidth to 35.3 MHz, which supports (without vectoring) downstream data rates up to 150/200 Mbps in short loops (see Figure 3-1). In case of no vectoring it is worth to note the increase of the achievable data rates at distances shorter than 600 metres in comparison to the widely deployed VDSL2 profile 17a with vectoring[27].

Figure 3-1: Performance metrics of Vplus with and without vectoring compared to VDSL2 profile 17a with vectoring

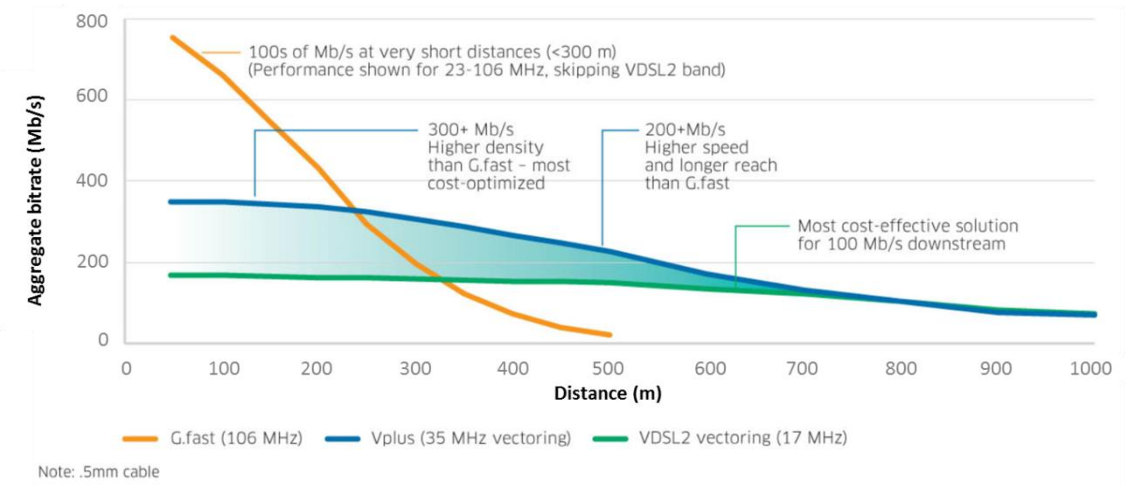


Source: Huawei (2015)

Vplus together with vectoring supports minimum aggregate data rates of 300 Mbps (at distances shorter than 250 meters). It extends the spectrum bandwidth to 35.3 MHz in order to achieve higher data rates. Vplus outperforms newer technologies, i.e. G.fast, which will be described in detail in section 3.1.4, at distances larger than 300 meters, and doubles the data rate offered by VDSL2 17a on short loops. Figure 3-2 shows a comparison between G.fast, VDSL 17a (vectoring) and VDSL 35b (vectoring).

27 The case of no vectoring may be of interest because it allows for SLU from a technical point of view, while with vectoring only one operator has to control all access lines, see below.

Figure 3-2: Data rate comparison between G.fast, VDSL 17a and VDSL 35b



Source: Nokia (2014)

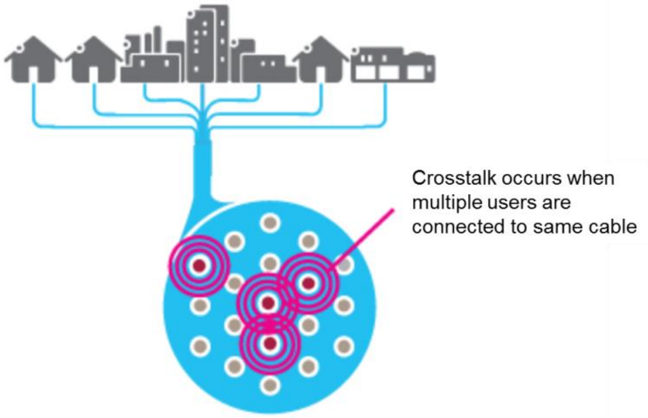
A set of acceleration techniques has been developed in order to boost end-user data rates. A first technique is known as bonding. Bonding is based on the use of multiple copper pairs, i.e. two or four, and their combination into a single bigger data pipe. It allows either to increase the maximum distance between the end-user and the intermediate point without signal degradation, or to double the data rate received by the end-user at a given distance. Bonding is standardized by the ITU in the G.bond series (G.998):

- G.998.1: ATM-based multi-pair bonding
- G.998.2: Ethernet-based multi-pair Bonding (ADSL2+, VDSL2)
- G.998.3: Multi-pair bonding using time division inverse multiplexing

A second option to improve the performance of the VDSL technology is known as vectoring. The objective of vectoring is to eliminate the far-end crosstalk (FEXT). A signal transmission over a copper pair radiates outside its own pair and it is added to the signal on adjacent pairs as noise, which is known as FEXT (see Figure 3-3). While crosstalk had little effect on ADSL, it is the dominant disturber for VDSL2, increasing quadratically with the frequency[28].

28 J. Maes, M. Guenach and M. Peeters, “Statistical MIMO Channel Model for Gain Quantification of DSL Crosstalk Mitigation Techniques”, in Proc. IEEE International Conference on Communications, Dresden, Germany, pp. 1-5, Jun. 2009

Figure 3-3: Crosstalk effect in copper lines

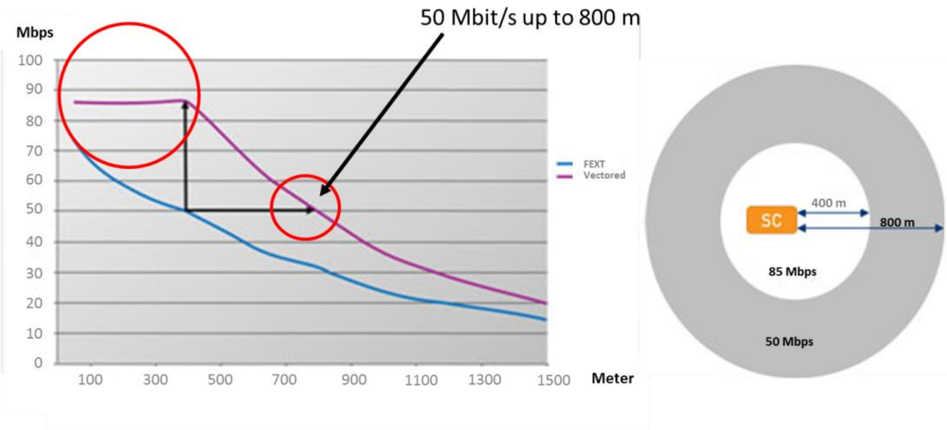


Source: Nokia (2013)

In 2010 the ITU standardized the vectoring technique in G.993.5, *Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers* (also known as G.vector). The crosstalk signals of the neighbouring copper pairs is to be subtracted from the original signal of a given copper pair. Vectoring requires then continuous monitoring of the signals of all pairs. Once the signal of a given copper pair is known, a suitable compensation “anti-noise” signal is determined. This “anti-noise” signal cancels out the crosstalk between all pairs. It follows that vectoring requires access to all pairs in a cable, which might be seen as a disadvantage from a competition point of view, because it disables local loop and local subloop unbundling. An exchange of vectoring information between the vectoring DSLAMs of different suppliers (sometimes called “node level vectoring”) is neither standardized nor available. Thus only one operator may use the VDSL frequency space. The others are excluded. Vectoring VDLS2 has been commercially available since 2011[29]. Figure 3-4 and Figure 3-5 show the typical gains achieved due to vectoring and a comparison of full vectoring with vectoring with uncontrolled lines respectively.

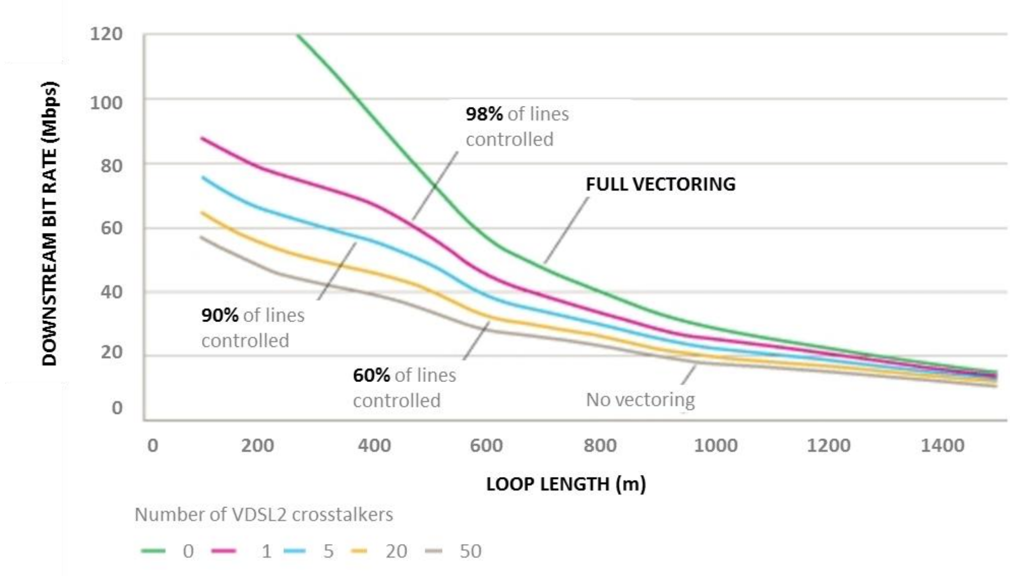
29 T. Plückebaum, S. Jay, K-H. Neumann, “Benefits and regulatory challenges of VDSL Vectoring (and VULA)”, RCAS 2014/69, June 2014
T. Plückebaum, VDSL Vectoring, Bonding und Phantoming: Technisches Konzept, marktliche und regulatorische Implikationen, wik Diskussionsbeiträge Nr. 374, Bad Honnef, Januar 2013

Figure 3-4: Gain achieved due to vectoring



Source: Can (2012)

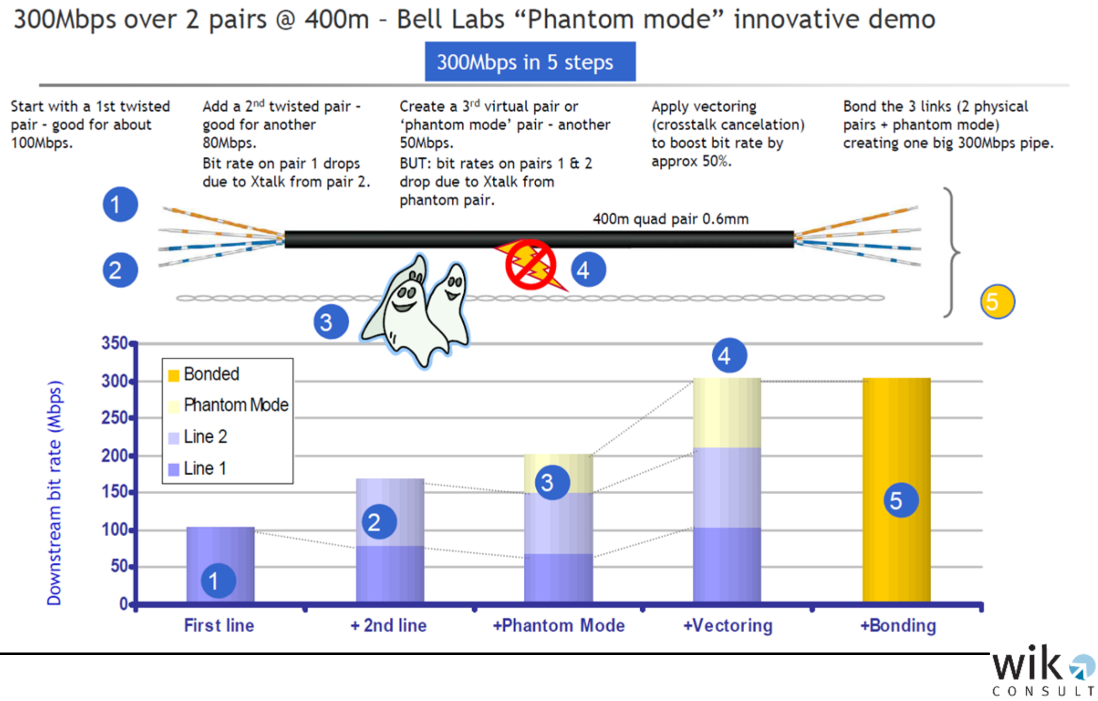
Figure 3-5: Performance comparison of full vectoring versus vectoring with uncontrolled lines



Source: Nokia(2012)

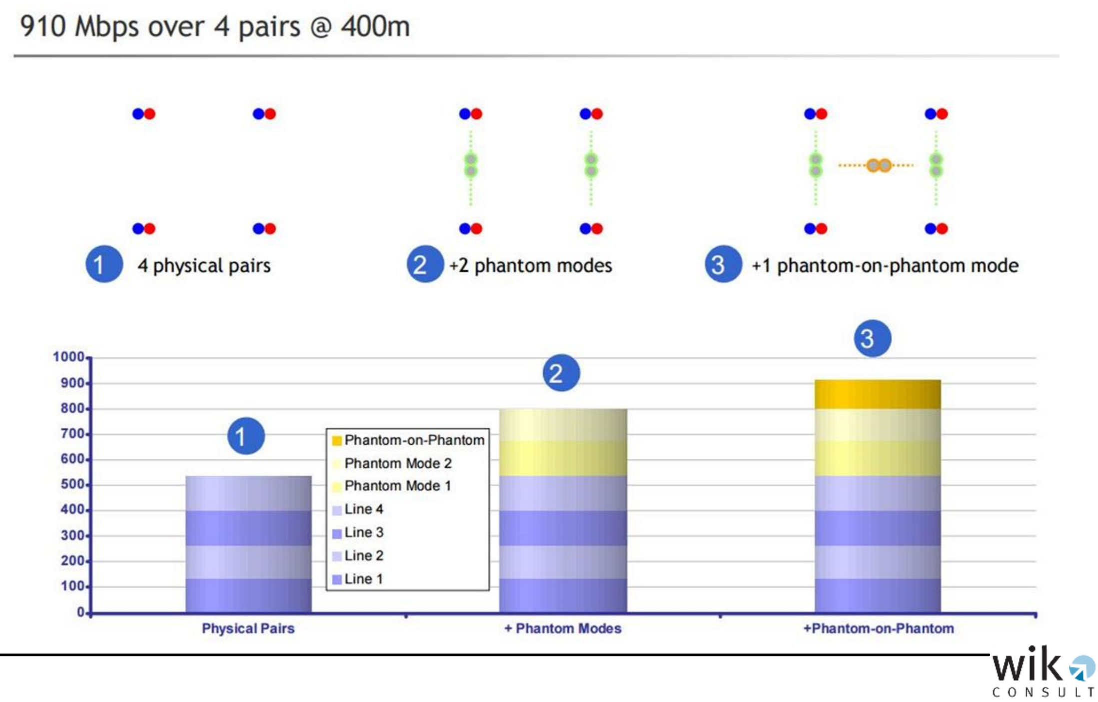
Besides vectoring and bonding, Alcatel-Lucent Bell Labs developed the Phantom-Mode technique in 2010. Phantom mode is based on the use of two or more twisted copper pairs to virtually create an additional copper pair or “phantom” pair.

Figure 3-6: Phantom Mode over 2 copper pairs up to 300 Mbps



Source: Alcatel-Lucent (2011)

Figure 3-7: Phantom Mode over 4 copper pairs up to 910 Mbps



Source: Alcatel-Lucent (2011)

In combination with VDSL2 vectoring and bonding it allows maximum downstream data rates of 300 Mbps over two copper pairs shorter than 400 meters[30] (see Figure 3-6), or 1000 Mbps at maximum distances of 1 km[31]. Moreover data rates up to 910 Mbps are achieved in a four copper pair based scenario at 400 meters (see Figure 3-7).

Table 3-1 shows a summary of the profiles of the VDSL2 technology (G.993.2), the main features of each profile and the different recommended deployment scenarios:

Table 3-1: VDSL2 Profiles

Profile	8a,b,c,d	12a, b	17a	30a	35b
Bandwidth	8.8 MHz	12 MHz	17.7 MHz	30 MHz	35.3 MHz
Aggregated data rate (Mbps)	50	68	100 - 150	200 - 250	300 - 400
Standardization Year	2004	2004	2006	2006	2015
Recommended Network Architecture	Fibre to the Node (FTTN)	FTTN	Fibre to the Cabinet (FTTC)	FTTC and/or Fibre to the Building (FTTB)	FTTB

VDSL technology is widely deployed in the Netherlands. VDSL implementations include: (1) profile 17a with vectoring, achieving data rates up to 120 Mbps over average distances of 600 meters; and (2) VDSL together with bonding and vectoring with downstream data rates up to 240 Mbps. Profile 35b is not yet deployed in the Netherlands, however the network nodes are currently being upgraded to enable Vplus in the near future[32]. In 2015 KPN together with Alcatel-Lucent carried out a successful Vplus lab test in The Hague achieving data rates up to 230 Mbps[33]. In an interview with WIK[34] [✂].

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30 Nokia, “Alcatel-Lucent´s DSL Phantom Mode named “Broadband Innovation of the Year”, 27 October 2010, https://networks.nokia.com/press/2010/002246

31 Nokia, “Alcatel-Lucent Bell Labs achieves industry first: 300 Megabits per second over just two traditional DSL lines”, 21 April 2010, https://networks.nokia.com/press/2010/002043

32 Interview with KPN, in addition: KPN Annual report 2016, p.4 states: “Download speeds of 400 Mbps are available with the new technology Vplus”; this can be only achieved in combination with Vectoring on short loops.

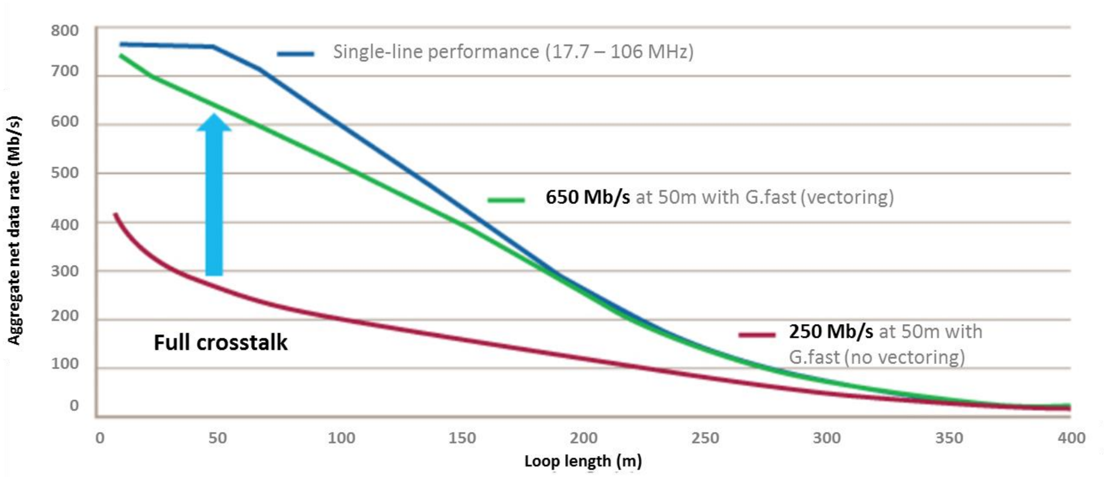
33 KPN, “Snelheidsrecord op koper in testomgeving met nieuwe technologie“, 01 April, 2015, http://corporate.kpn.com/kpn-actueel/nieuwsberichten-1/snelheidsrecordop-koper-in-testomgeving-met-nieuwe-technologie.htm

34 WIK interviewed KPN and some other operators as part of this project.

3.1.4 G.fast / XG.fast

The next generation broadband access over copper-based architecture is G.fast. In 2014 the ITU-T standardized the G.fast technology in the G.9700 and G.9701 specifications. G.fast is presented as the first ultra-broadband technology. It supports aggregated data rates up to 1 Gbps (up- and downstream) in case of copper loop lengths less than 100 meters. The first phase of G.fast provides data rates up to 500 Mbps making use of 106 MHz spectrum bandwidth. In a second phase G.fast will widen the spectrum bandwidth to 212 MHz in order to provide gigabit data rates. G.fast also includes additional enhancements such as vectoring (see Figure 3-8), and it is mainly deployed in Fibre to the Distribution point (FTTdp) and Fibre to the Building (FTTB) scenarios, because the high bandwidth benefit is only achievable over relatively short copper loop length.

Figure 3-8: Vectorting gain in G.fast technology



Source: Nokia (2013)

Operators have conducted multiple G.fast worldwide tests during the years 2015 and 2016. In Europe, Swisscom tested its G.fast service in Bibern in April 2015, offering data rates up to 500 Mbps. In October 2016 Swisscom announced the first European G.fast commercial deployment as part of the Fibre to the Street expansion[35].

BT Openreach together with Alcatel-Lucent started G.fast trials in the North-East of England in 2015. In addition, BT announced in December 2016 the deployment phase

35 Swisscom, "Swiscomm to be the first European telecommunications service provider to launch G.fast", 18 October 2016, https://www.swisscom.ch/en/about/medien/press-releases/2016/10/20161018-MM-Gfast.html

of its latest G.fast pilot in England, providing data rates of 330 Mbps to 138,000 homes[36].

Huawei and M-net announced in June 2016 the deployment of the first G.fast access network in Germany[37]. NetCologne and its technical partner ZTE announced the beginning of the G.fast pilot phase in March 2017[38]. NetCologne expects to cover 260,000 households in Cologne in 2017[39].

Telekom Austria began with G.fast trials in October 2014[40]. In Norway the operator Homenet ran a G.fast pilot in Oslo in 2015, and it was planned to be commercially launched by the end of 2016.

In Australia NBN (National Broadband Network) conducted its first G.fast trial in October 2015, providing aggregated data rates of 600 Mbps at distances shorter than 100 meters[41]. NBN expects to be able to lauch G.fast service in 2017.

Energia Communications (EneCom) together with Nokia ran G.fast trials in 2015. EneCom announced in February 2016 plans to deploy the first nationwide commercial launch of G.fast in Japan. In February 2017 EneCom signed a partnership and reseller agreement with Nokia for G.fast broadband access[42].

Despite the multiple G.fast tests conducted and the few commercially G.fast services launched worldwide, [✂]. G.fast would require a significantly deeper fibre roll out closer to new distribution points in front of the buildings and the appropriate investment.

The next step in the evolution of broadband technologies is known as XG.fast. XG.fast technology is capable of delivering multi-gigabit data rates over short twisted copper

36 Openreacht BT, “NGA2004/16 G.fast pilot deployment begins 9 January 2017”, 9 December 2016, https://www.openreach.co.uk/orpg/home/updates/briefings/ultrafastfibreaccessbriefings/ultrafastfibreaccessbriefingarticles/nga200416.do

37 Huawei, “Huawei and M-net will deploy the first G.fast access network in Germany”, 08 June 2016, http://www.huawei.com/en/news/2016/6/the-first-Gfast-access-network-in-Germany

38 ZTE, “ZTE and NetCologne commence G.fast pilot phase”, 22 March 2017, http://www.zte.com.cn/global/about/press-center/news/201703ma/0323ma1

39 TeleGeography, “NetCologne and ZTE lauch G.fast pilot”, 24 March 2017, https://www.telegeography.com/products/commsupdate/articles/2017/03/24/netcologne-and-zte-launch-g-fast-pilot/

40 Telekom Austria, “First Ultra-Broadband Customer in the World with G.fast”, 15 October 2014, https://www.telekomaustria.com/en/newsroom/2014-10-15-first-ultra-broadband-customer-in-the-world-with-g-fast

41 NBN, “nbn takes first steps towards G.Fast launch”, 21 October 2015, http://www.nbnco.com.au/blog/the-nbn-project/nbn-takes-first-steps-towards-g-fast-launch.html

42 Nokia, “Nokia and Energia Communications sign distributor agreement for G.fast fixed ultra-broandband access technology in Japan”, 09 February 2017, https://www.nokia.com/en_int/news/releases/2017/02/09/nokia-and-energia-communications-sign-distributor-agreement-for-gfast-fixed-ultra-broadband-access-technology-in-japan pairs, about 70 meters, and 10 Gbps with bonding and phantom mode over 30 meters of copper cable[43]. The standard is expected to be released in 2020.

XG.fast widens the spectrum to 500 MHz and is compatible with acceleration techniques such as bonding and phantom mode. Moreover, Multiple-Input Multiple-Output technique (MIMO) as well as adaptive modulation are also applied to XG.fast.

Crosstalk cancellation in VDSL2 and G.fast is based on signal coordination at the access node. This is simply a Multiple-Input Single-Output (MISO) scheme. In XG.fast signal coordination can be carried out in both the access node and the receiver, which corresponds to a MIMO scheme.

Although XG.fast is not yet commercially deployed, there exist trials that demonstrate the capability of this technology to provide fibre-like data rates over copper networks. Nokia together with Deutsche Telekom demonstrated an aggregated data rate exceeding 11 Gbps at 50 meters and 8 Gbps over 50 meters. Moreover, symmetric data rates of 1 Gbps were possible in copper loops shorter than 70 meters[44].

Telekom Austria conducted a trial achieving data rates of 10 Gbps on copper cables based on XG.fast technology in March 2017[45].

In Australia Nokia and NBN conducted a XG.fast trial achieving data rates of 8 Gbps at 30 meters, and 5 Gbps at 70 meters of copper cable[46]. WIK expects XG.fast to start being deployed by 2022.

[✂]. WIK understands XG.fast as an FTTB technology (beside others) which requires fibre rolled out to the buildings. So such technology will be relevant for those buildings where the building owners refuse to deploy fibre in the inhouse segment (FTTH) when the fibre approaches the buildings and may be of poor relevance at all, at least in the Netherlands, because for single homes FTTB is without

43 W. Coomans et al., “XG-Fast: Towards 10 Gb/s Copper Access”, in Proc. IEEE GLOBECOM, Austin, TX, USA, pp. 715-520, Dec. 2014

44 Nokia, “Nokia and Deutsche Telekom show how XG-FAST technology can extend copper network speeds and meet future data demands”, 01 February 2016, http://www.nokia.com/en_int/news/releases/2016/02/01/nokia-and-deutsche-telekom-show-how-xg-fast-technology-can-extend-copper-network-speeds-and-meet-future-data-demands

45 European Communications, “Telekom Austria hits 10 Gbps on copper with Nokia G.Fast technology”, 23 March 2017, http://eurocomms.com/industry-news/12196-telekom-austria-hits-10gbps-on-copper-with-nokia-g-fast-tech

46 Nokia, “Nokia and nbn demonstrate power of XG-FAST with successful lab trial of technology in Australia”, 18 October 2016, http://www.nokia.com/en_int/news/releases/2016/10/18/nokia-and-nbn-demonstrate-power-of-xg-fast-with-successful-lab-trial-of-technology-in-australia relevance and for MDU[47] the relevance is declining because according to the European Cost Reduction Directive (2014/61/EU)[48] on measures to reduce the cost of deploying high-speed electronic communications networks of 15 May 2014, new MDUs have to be equipped with in-building fibres and over time or other MDUs have to be equipped with it when major renovations take place.

The following Table 3-2 provides a summary view of the different available copper based network technologies described in the previous sections of the document together with the corresponding year of standardisation.

Table 3-2: Overview copper based transmission technologies

	Bandwidth	Max. DS Data rate	Max. US Data rate	Standardisation Date
ADSL	1.1 MHz	8 Mbps	1 Mbps	1999
ADSL2	2.2 MHz	12 Mbps	2 Mbps	2002
ADSL2+	2.2 MHz	25 Mbps	1 Mbps	2003
VDSL	12 MHz	55 Mbps	19.2 Mbps	2004
VDSL2	8.8 – 30 MHz	250 Mbps (aggregate DS + US)		2006
VDSL2 (17a vectoring)	17.7 MHz	150 Mbps (aggregate DS + US)		2010
Vplus	35.3 MHz	350 Mbps (aggregate DS + US)		2015
G.fast 106	106 MHz	1 Gbps		2014
G.fast 212	212 MHz	2 Gbps		2016
XG.fast	500 MHz	10 Gbps		Expected 2020

3.1.5 History and status of DSL technology in the Netherlands

The first ADSL connections were provided by Demon in 2000. Demon used the network facilities of Baby XL Broadband. The data rates provided by this first ADSL service were 512 kbps downstream and 64 kbps upstream. In the same year, XS4ALL provided ADSL connections up to 1024 kbps downstream and 256 kbps upstream. KPN tested ADSL first in 1998, and started the deployment of the first commercial ADSL, branded as Mxstream ADSL, in 2000. It covered the cities of Amsterdam, Rotterdam and Utrecht[49]. Later in 2004 third parties deployed ADSL2 and ADSL2+ technologies in order to increase the data rates provided to the end-customers.

47 Multi Dwelling Units
48 European Commission, “Directive 2014/61/EU of the European Parliament and the Council of 15 May 2014 on measures to reduce the cost of deploying high-speed electronic communications networks“, 15 May 2014, electronically available under: https://ec.europa.eu/digital-single-market/news/directive-201461eu-european-parliament-and-council
49 W. Lemstra, W.H. Melody, “The Dynamics of Broadband Markets in Europe: Realizing the 2020 Digital Agenda”, Cambridge University Press, 2015

The introduction of VDSL from the cabinet first happened in 2005 as a result of regulatory measures. VDSL2 from the central office was deployed in 2007 and with bonding by the end of 2010.

Newer technologies such as G.fast and XG.fast are not yet deployed in the Netherlands. [✂].

Currently the xDSL access represent about the 39% of the broadband connections in the Netherlands with more than 2,700,000 subscribers, which makes it the second most widespread access technology in the Netherlands, only surpassed by the cable access technology. In terms of end-user data rates, the majority of the xDSL connections, about 60%, offers transfer rates between 10 and 30 Mbps, and only 2% of them provide the end-user with data rates above 100 Mbps. It follows, that despite the fact of being the second most widespread access technology in the Netherlands in terms of subscribers, the performance of the xDSL access is quite poor compared with the cable and the fibre access technologies providing end-users with data rates above 100 Mbps[50] to 56.7% (cable) and 36.3% (fibre) of the subscriptions respectively[51].

Copper networks cover the whole country with close to 100% of home passed, which is in line with the copper coverage provided in the majority of European countries – the copper network coverage is below 90% only in nine European countries, due to the emerging uptake of NGA access technologies instead.

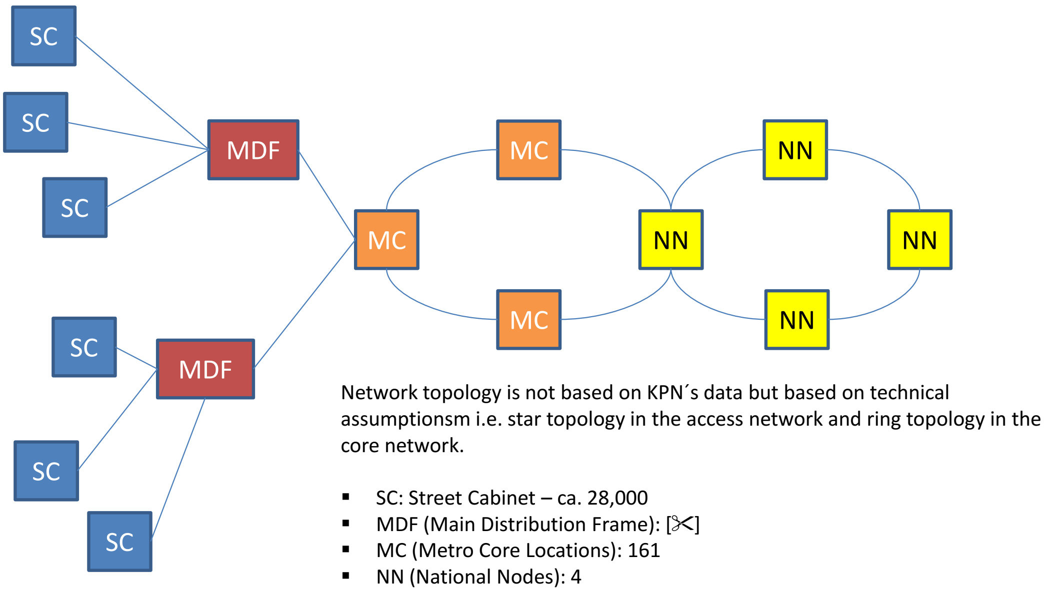
The KPN copper network architecture consists of [✂] main distribution frame (MDF) locations and 161 metro core (MC) locations where the wholesale products, e.g. VULA and WBA (also possible at national level), are offered. Based on KPN data[52], more than [✂] of households are covered by its copper network. Figure 3-9 shows a schematic view of the KPN´s copper network. It shall be noted that the network topology of KPN is not known by WIK, and that shown in the figure is based on reasonable assumptions.

50 While copper is a dedicated medium, i.e. a twisted copper pair per end-user, cable is a shared medium, i.e. the data rate is shared between several end-users. It follows that in high load periods of the day, when the majority of the subscribers are connected simultaneously, copper might outperforms cable in terms of data rate.

51 ACM, “Telecommonitor Q3 2016”, 31 March 2017

52 [✂]

Figure 3-9: Schematic view of the KPN´s copper network



Source: WIK

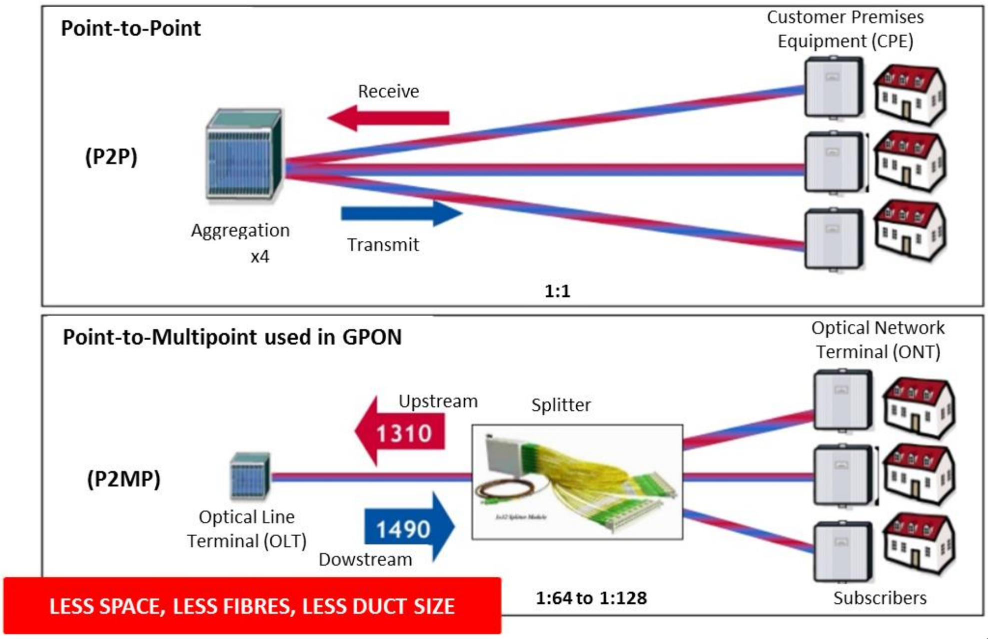
3.2 Fibre based infrastructures

The prevailing optical fibre access technology in the Netherland is Fibre to the Home (FTTH). Three main fibre-based network architectures in general are possible when deploying a FTTH network:

- Point to Point (PtP) topology,
- Point to Multipoint (PtMP) Active Optical Network (AON) with tree topology and active electrical switching equipment, and
- PtMP Passive Optical Network (PON) with tree topology and passive fibre split

Figure 3-10 provides a schematic view of the PtP and PtMP PON network architectures.

Figure 3-10: PtP and PtMP optical network architectures



Source: Alcatel-Lucent University

The PtMP topology, typically a tree topology, allows the operator to save some costs associated with network deployment. While in a PtP optical network a single fibre strand is required to carry the traffic between each end-customer and the central office (CO, MPoP), i.e. each customer is connected to a dedicated port on a central switch, in a PtMP network the feeder fibre going from the Optical Line Termination (OLT), located at the CO, to an intermediate point, commonly known as the Distribution Point (DP), is shared among a given number of users.

In case of PON the DP is based on a passive optical splitter, which splits the signal into 32 or 64 distribution fibres. The distribution fibres connect the DP with the customer premises, i.e. Optical Network Unit (ONU) or Optical Network Terminal (ONT). Therefore, a single feeder fibre is typically shared by 32 or 64 customers[53].

In case of AON the DP is based on an active electrical equipment, e.g. Ethernet switches. The active equipment manages the signal distribution and route data to each customer. A single distribution fibre onnects the DP with each customer.

In the Netherlands there is no relevance for PtMP (active or passive) architectures. Therefore, in the following section we provide a description of the point-to-point FTTH architecture, which corresponds to the fibre state-of-the-art infrastructure deployed in the Netherlands.

53 For a comparison of both topologies see also the source given in footnote 54.

3.2.1 PtP FTTH optical network

As mentioned above, in a PtP FTTH network a single (or multiple) optical fibre connects the CO or point of presence (PoP) with the customer, i.e. the minimum number of fibre strands required is the same as the number of customers. This constitutes the first advantage of PtP over PtMP, since the full bandwidth available is not shared but dedicated to each individual customer premises. PtP architecture presents additional advantages over PtMP PON architectures:

- It provides virtually unlimited symmetrical data rates, which is critical for given applications such as HD video conferencing, online gaming and content sharing
- It allows flexibility in order to allocate different data rates to different users, i.e. the migration of each customer to more powerful service does not affect the rest of the customers
- Since a single fibre strand is dedicated to each customer, optimal security can be provided, which is critical for high quality customers such as large businesses, universities and local authorities
- It allows full unbundling at Optical Distribution Frame (ODF) level, i.e. it supports an open-access approach
- It is the most future proof solution, since it is technology agnostic as future needs, i.e. future bandwidths requirements of residential and business customers, evolve
- The majority of PtP FTTH deployments uses Ethernet, but it can be mixed with other transmission schemes such as SDH/ SONET
- PtP Ethernet solutions allow to reach larger distances (about 80 km) than typical PtMP PON solutions (20 km)

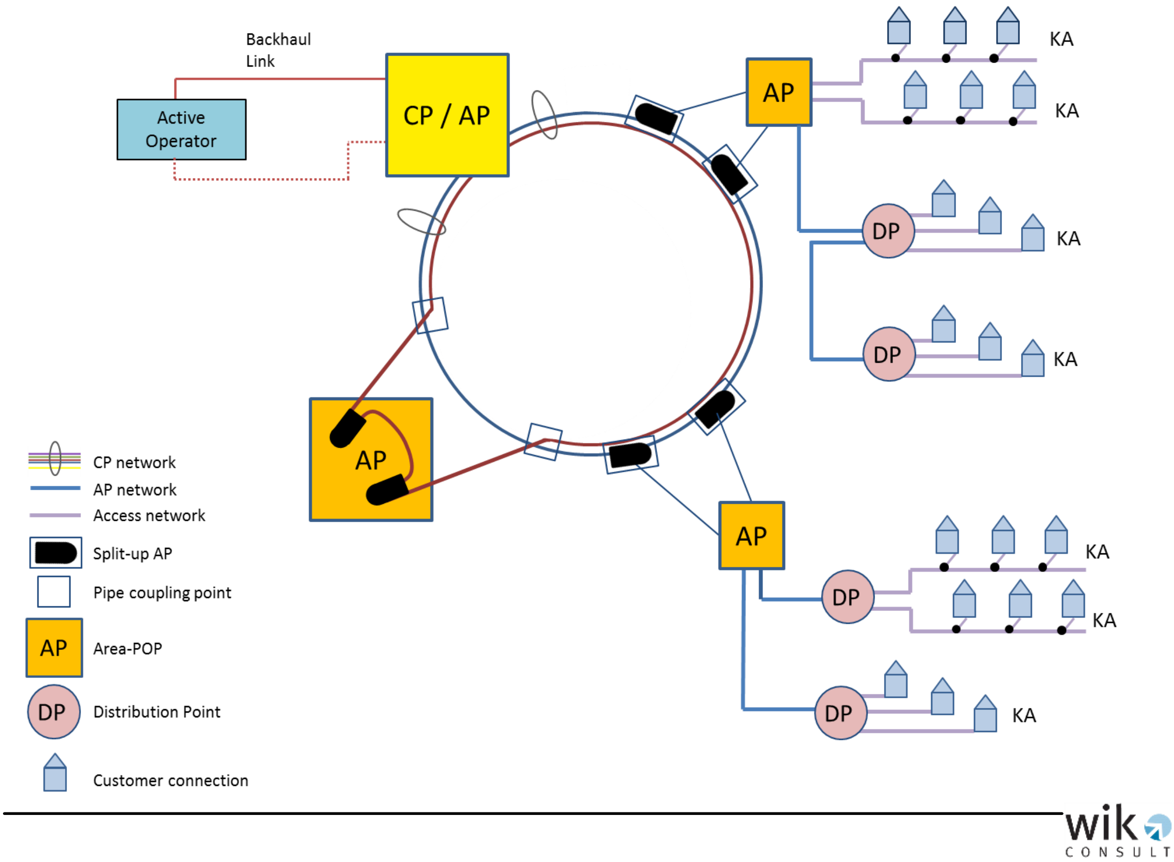
However, the PtP architecture requires the installation of larger amount of optical fibre in comparison to the PtMP architectures. Moreover, it also requires the installation of active equipment, which are more expensive than the passive splitters used in the PtMP PON. These two aspects translate into higher capital expenditure costs (CAPEX). A combination of both, using GPON equipment over a PtP fibre topology with the splitters deployed at the local exchange sites, seems to be an ideal compromise allowing a high flexibility at less than 1% additional cost[54].

54 See: Jay, S.; Neumann, K-H.; Plückebaum, T.;
"Comparing FTTH access networks based on P2P and PMP fibre topologies", Journal on Telecommunications Policy (JTPO), 8. Juli 2013
Hoernig, S.; Ilic, D.; Neumann, K.-H.; Peitz, M.: Plückebaum, T.; Vogelsang, I.;
"Architectures and competitive models in fibre networks", Bad Honnef, Dezember 2010

3.2.2 FTTH deployments in the Netherlands

The first FTTH projects in the Netherlands were developed in 2008. Current KPN´s fibre network architecture is based on Reggefiber´s architecture. Figure 3-11 shows a schematic view of the FTTH architecture in the Netherlands.

Figure 3-11: Schematic view of Reggefiber network architecture



Source: NERA (2014)

The FTTH network in the Netherlands is deployed in a PtP manner. Reggefiber built and operated passive FTTH networks in the Netherlands. The passive infrastructure was delivered to active operators in an open access model. Currently the incumbent operator, KPN, bought over time the entire FTTH network of Reggefiber with about 30% of Dutch households covered. The FTTH network architecture consists of: (1) a first network level comprising the [✂] City PoPs, and (2) a set of [✂] Area PoPs that constitute the second network level. The ODF is installed at each Area-PoP providing the access seeker with unbundling fibre access at these network level. The Area PoPs are connected to the City PoPs with a maximum of eight Area PoPs per City PoP[55].

55 ACM, "Tariefbesluit ontbundelde glastoegang (FttH) 2012, 16 May 2013

FTTH access lines in the Netherlands surpassed more than 1,000,000 active connections in Q3 2016 for the first time[56]. It represents about 14.5% of the active connections in the Netherlands and it is above the European average of 9.4%. However, the Netherlands occupies the tenth position in Europe in terms of FTTH uptake. The leading countries are Norway with 29.3%, Latvia with about 27.1%, Portugal with 25.9% and Spain with 24.9%[57].

Regarding FTTH coverage The Netherlands holds the seventeenth position in Europe with about 30% of home passed. Baltic countries, i.e. Lithuania (100%) and Latvia (100%), together with Portugal (98%) and Spain (98%) are the leading countries in Europe[58].

In terms of performance, FTTH is currently the most attractive and future proof access technology in the Netherlands providing more than 80% of end-users with data rates above 30 Mbps, from which more than 36% above 100 Mbps. However, it shall be noted that the coax networks in the Netherlands currently outperform fibre networks regarding end-user data rates. Cable networks provide more than 90% of end-users with data rates larger than 30Mbps, from which more than 50% of connections with data rates over 100 Mbps. The situation may change in the future, due to the fact that fibre is the end solution, and PtP fibre architectures, i.e. the case in the Netherlands, are able to easily grow in capacity and bandwidth needs, which does not apply in case of PtMP topologies.

Passive PtMP topologies in the Netherlands might be implemented in the near future. KPN confirmed that GPON technology has been tested, and it might be considered to be implemented in the future[59]. It shall be noted that the implementation of PON PtMP architectures, e.g. GPON, makes easier the re-establishment of a monopoly in terms of physical access to the local loop. The physical access implemented in classic copper networks, i.e. local loop unbundling (LLU), and FTTH networks, could only be realised at the splitter location closest to the end-customer in case of GPON. Collocation at that point is typically not economically feasible for new entrants intending to access the fibre distribution lines in an unbundled manner. Wavelength unbundling is identified as an alternative to LLU providing the same benefits, i.e. service differentiation and

56 ACM, "Telecommonitor Q3 2016", 31 March 2017

57 FTTH Council Europe, "Breaking news from the FTTH Conference 2017: Austria & Serbia join the Global FTTH Ranking, Latvia reaches pole position in European FTTH penetration", Press Release, 15 February 2017, http://ftthcouncil.eu/documents/PressReleases/2017/PR20170215_FTTHranking_panorama_award.pdf

58 FTTH Council Europe, "European FTTH Panorama – update figures at September 2016", 2017

59 Tweakers, "KPN experimenteert met dsl van 400 Mbit/s", 04 February 2015, https://tweakers.net/nieuws/101189/kpn-experimenteert-met-dsl-van-400mbit-s.html

innovation[60]. Since GPON and future PtMP technologies are out of scope of this study, no further details are provided.

3.3 Coax based infrastructures

The traditional CATV network was the first coax based infrastructure used for broadcast TV and radio signals. It comprises four main parts: (1) the headend, (2) the trunk, (3) the feeder or distribution network and (4) the drop cable. Shielded coaxial cables were used originally to transport TV signals from the headend to the end-user in the downstream direction.

Coaxial networks are not capable of dealing with high-speed broadband services, which constituted a great disadvantage when compared with the capabilities of xDSL and fibre technologies. The introduction of fibre in coaxial networks, turning these systems into hybrid-fibre-coaxial networks, first happened in the 1980s. The coaxial cable in the trunk was replaced by optical fibre providing the following advantages:

- Availability of higher bandwidth
- Lower losses or signal degradation
- Larger distances, which in turns means less amplifiers

The introduction of fibre required the replacement of coax amplifiers in the trunk by fibre-capable amplifiers. Finally, in order to allow two-way communication, the typical communication type in xDSL and fibre systems for telephony and internet access, bi-directional optical amplifiers were required. Moreover a new standard, DOCSIS 1.0, defining the transmission of data over HFC networks were specified by CableLabs in March 1997. DOCSIS 1.0 allowed the bidirectional transmission of data and voice over a hybrid fibre coaxial (HFC) network infrastructure. HFC networks are based on optical fibre connecting in a ring topology the headend to an intermediate point or optical distribution point, and coaxial cable from the optical node to the end-customer – amplifiers are required in both segments of the network. It shall be noted that the coaxial segment of the network is shared by all the subscribers attached to a given optical node, which turns into a degradation of the quality of service provided to the end-user in case of simultaneous connection of all subscribers with regard to bandwidth, latency, jitter and packet loss.

The DOCSIS standard has evolved to the current time allowing the access to a larger amount of spectrum, new modulation and coding schemes and providing the end-customer with higher data rates. This has solved partially the disadvantage of HFC networks in terms of achievable data rates when compared with fibre networks.

60 T. Plückebaum, J.E. Sánchez, “GPON and TWDM-GPON in the context of the wholesale local access market”, Study for the Irish Regulator (ComReg), 2016

However, the upstream achievable data rate is still a drawback. A more in detail description of the evolution of CATV networks to the DOCSIS standards, as well as an overview of the current status of HFC networks in the Netherlands, is provided in the following sections.

3.3.1 Evolution of DOCSIS technology up to DOCSIS 3.0

Traditionally, coaxial CATV networks have been used to broadcast analogue radio and TV signals from a central headend down to the end-customers. The coaxial cable medium was chosen because of its suitable transmission behaviour for high-frequency signals. For downstream broadcast signal distribution, one common cable string (tree structure) design has been and still is ideal and efficient. For longer reach, such string requires intermediate signal reamplification or regeneration. Such infrastructure is called shared medium. Everybody connected to it can easily select the appropriate broadcast service.

When competition for traditional telecommunication services (telephony, data) arose, there was soon demand to use these CATV networks as an additional transmission medium for intermodal competition. According to its capacity of transmitting signals ranging from several hundred to some thousand MHz, it was able to carry additional telecommunication services.

For this purpose, frequency space at both ends of the frequency band, typically framing the existing TV and radio channels, was defined in the DOCSIS standard for data communication use. DOCSIS allows for downstream data communication in the upper frequency band and also enables upstream communication in the lower frequency band. To enable upstream communication, the CATV network had to be upgraded:

- all amplifiers had to be upgraded regarding the transmission direction (upstream amplifying was also required),
- some frequency filters had to be added in order to separate data from TV and radio bands, and
- the TV and radio channels had to be reorganised to host those channels that had to be removed from the bands now assigned for data communication, if channels had to be removed at all.

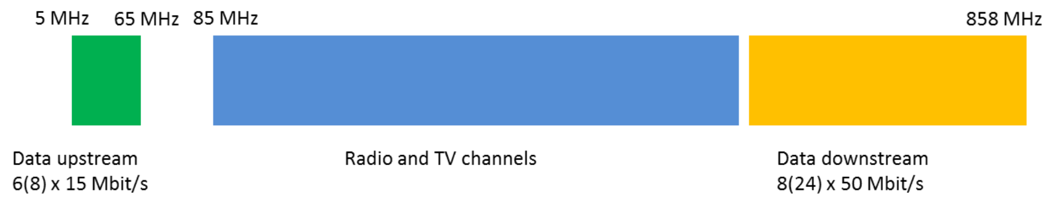
A new network component is required to organise and administrate the bidirectional communication – allowing end-user access to the common upstream channel for only one end-customer at a time per channel – and address the downstream information to the end-customer to which the traffic is dedicated. This system is called the Cable Modem Termination System (CMTS).

At the end-customer sites, a new cable modem now interacts with the CMTS, announcing upstream communication demand and picking the downstream end-customer messages from the downstream broadcast channel.

DOCSIS as a bidirectional communication standard on coaxial CATV networks organises the side channels for bidirectional communication; however, it does not deal with the radio and TV channel frequency space in between (see Figure 3-12).[61] Because of the anticipated communication behaviour of residential customers, all DOCSIS systems have been designed for asymmetric communication, giving upstream capacity of approximately 10% of the downstream capacity. This is inherent in the frequency spaces allocated.

DOCSIS 3.0 is the state-of-the-art release implemented today. It typically bundles up to six upstream communication channels with 15 Mbps[62] each to 90 Mbps upstream and eight channels with 50 Mbps each downstream to 400 Mbps.

Figure 3-12: DOCSIS 3.0 frequency use and data communication capacity allocation



Source: Plückebaum (2016)

There are several options to increase the bidirectional data (and Voice over Internet Protocol (VoIP)) communication:

1. Use more of the already designed data communication channels in DOCSIS 3.0,
2. Reduce the frequency space for radio and TV channels,
3. Decrease the number of end-customers sharing the coaxial cable segment, or
4. Define (and implement) the use of a wider frequency range than the 860 MHz defined today.

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61 Although most operators organise the frequency distribution as described here, the data communication channels could also be included somewhere in the radio and TV channels, but this does not change the principles discussed.

62 WIK assumes an average case of 3.2 MHz channel width with QAM64 coding, but there are also solutions with 6.4 MHz channel width, QAM64 coding and consequently 30 Mbps. The upper limit for upstream are eight upstream channels, each transporting 30 Mbps upstream, totalling 240 Mbps. WIK is not aware of any operator having changed and expanded its upstream frequency management like this. (65 MHz - 5 MHz)/6.4 MHz = 9.374 channels, but realistically eight channels remain due to interferences and the non-linear characteristics of the spectrum.

The following provides further description of the above options.

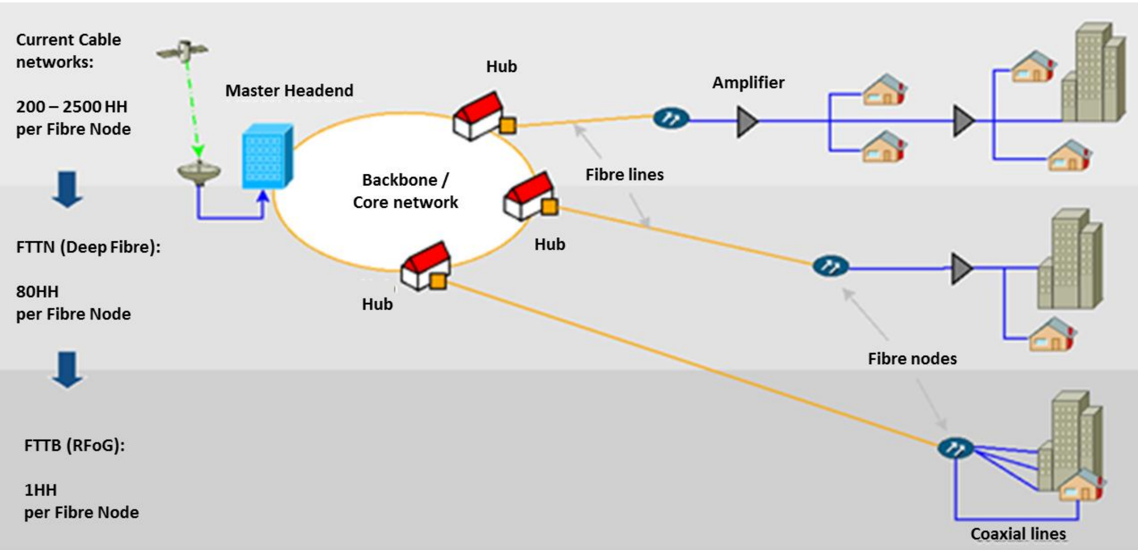
1. While upstream communication could be expanded by another two channels to 120 Mbps, there is still much more space for downstream capacity, going up to 24 channels, totalling a maximum of 1.2 Gbps. Today's configuration already demonstrates that there is much more upstream demand than originally designed for (10%). While the upstream capacity in DOCSIS 3.0 is nearly exhausted (90 of max. 120 Mbps (75%) in the typical example above), there would be more space for downstream capacity (only 400 of max. 1,200 Mbps (33%) used so far in the typical example above). Keeping the relation of current upstream and downstream traffic, the full use of the upstream capacity (120 Mbps) would require a comparable downstream capacity increase of 25% to 600 Mbps. This would mean that half of the theoretically designed 1.2 Gbps of downstream capacity would remain unused. Upstream traffic demand today is often the limiting factor of using DOCSIS CATV network capacity for data communications.

2. Replacing traditional analogue radio and TV channels with digital channels would allow for higher signal quality and picture resolution with less frequency consumption. This effect of frequency space-saving is also called digital dividend. Because of the fixed upper frequency of the CATV network (i.e. restricted by the amplifier capabilities), additional use of DOCSIS 3.0 downstream channels would require either deleting radio or TV channels or making use of the digital dividend. The latter requires the reorganisation of the program set to keep the program bouquet offered. In any case, the frequency space used by the radio and TV channels has to be reduced. This might mean that the operator has to resolve conflicting interests.

3. The coaxial cable segment is a shared medium, meaning the upstream and downstream customers' communication capacity is always shared by all customers connected to it. If one part of the capacity is dedicated to a customer for a longer time or even permanently, it reduces the remaining capacity for the other end-customers. In the reverse, reducing the number of end-customers connected to a coaxial segment by reducing its size increases the capacity an end-customer can use over time. However, the user will never be able to exceed the total channel bandwidth, so the peak bandwidth is limited.

   Today, the coaxial cable segments are fed by fibre nodes, which are connected to the central sites and to the CMTS located there. These fibre nodes are intermediate systems converting the coaxial cable signals into optical signals and vice versa. Therefore, decreasing the number of customers per coaxial cable segment is typically called fibre node splitting. An existing fibre node is divided into two or more nodes (see also 2). It could require additional fibre links to be installed to move the fibre nodes closer to the end-customer locations. Such fibre node distributions are also called "deep fibre". Moving the fibre nodes down to the end-customer premises is called “RFoG” (Radio Frequency over Glass[63]), offering the capacity to one user or a small group of end-customers (multi-dwelling) only. This capacity enhancement requires investment in new fibre nodes[64] and fibre lines, depending on the string or star topology of the coaxial network segment.

Figure 3-13: Fibre node splitting



Source: Plückebaum (2016)

4. State-of-the-art coaxial cables operate up to frequencies of 2.5 GHz. The cable itself would even allow for higher frequencies. A new DOCSIS 3.1 standard has been finalised recently and the first systems on the market now offer frequency space up to 1.2 GHz. A further upgrade is already included in the standard documents. This new standard allows a smooth upgrade of the systems, the CMTS, the cable modems, the reamplifiers and fibre nodes, on a segment-per-segment and customer-per-customer basis. It offers compatibility not only with DOCSIS 3.0 but also with older releases (2.1, 2.0). Most operators now offer products in line with DOCSIS 3.0. Due to the capacity still inherent in release 3.0, there is no need for an immediate upgrade to release 3.1, but it might be an option for future infrastructure use and time for a long-term upgrade strategy. DOCSIS 3.1 will allow for up to 10 Gbps shared downstream and 1 Gbps upstream capacity. A detailed description of DOCSIS 3.1 is provided in section 3.3.2.1. As the end-customer demand in Europe typically tends towards more symmetric communication relations between upstream and downstream or even towards symmetric behaviour, DOCSIS 3.1 in its original design is not necessarily the ideal solution. This deficit might be overcome

63 Any transmission of analogue radio or TV signals over fibre is called RFoG, but here it is used as a synonym for the architecture also.
64 More specifically called RFoG micro nodes or fibre-optic micro nodes.

with a symmetric DOCSIS (see below). For the Netherland the dominant cable-TV network operator contradicted this expectation of increasing symmetry by its observation of increased asymmetry[65].

DOCSIS is not well suited for supporting business customer or high-quality individual end-customer demand: DOCSIS is a data communication standard designed for asymmetrical IP-based communications. There is very limited space for symmetrical communication because the upstream is typically limited to a maximum of 90 Mbps. If capacity is exclusively reserved for some end-customers, then this reduces the capacity for the remaining connected customers. The remaining customers then share reduced communication channel capacity with reduced peak capacity, resulting in a poorer burst behaviour and a higher probability of congestion and packet loss, thus having a poorer quality experience.

In order to illustrate this restriction, assume one single business customer is demanding an exclusive 100 Mbps access line (like a leased line terminating segment, symmetrical). If one uses DOCSIS 3.0 with today's 90 Mbps upstream capacity, it would be impossible to provide this product. Even after upgrading to 120 Mbps, the remaining customers would have to share the remaining upstream communication channel with 20 Mbps capacity and with a peak bitrate of 20 Mbps, which would not satisfy today's customer demand.

Also, communication based on the Layer 2 Ethernet protocol is not part of the standard, but technically feasible. There is an optional feature besides the DOCSIS standard without being part of it, called BSoD (Business Services over DOCSIS), which allows for dedicated bandwidth allocated to an end-customer communicating over the Layer 2 Ethernet protocol. The BSoD capacity and features are embedded in the DOCSIS framework and specified by CableLabs under Layer 2 Virtual Private Network (L2VPN) in 2006. The implementation of BSoD requires: (1) the configuration of cable modems to support BPI+, and (2) L2VPN capable CMTSs and CMs.

The following summary table provide an overview of the different DOCSIS technologies, their key innovations and most relevant features.

65 WIK interview with VdodafoneZiggo

Table 3-3: DOCSIS Standards evolution

	DOCSIS 1.0	DOCSIS 1.1	DOCSIS 2.0	DOCSIS 3.0
Highlights	Initial cable broadband technology	Added voice over IP service	Higher upstream speed	Greatly enhances capacity
DS Capacity	40 Mbps	40 Mbps	40 Mbps	1 Gbps
US Capacity	10 Mbps	10 Mbps	30 Mbps	100 Mbps
Production Date	1997	2001	2002	2008

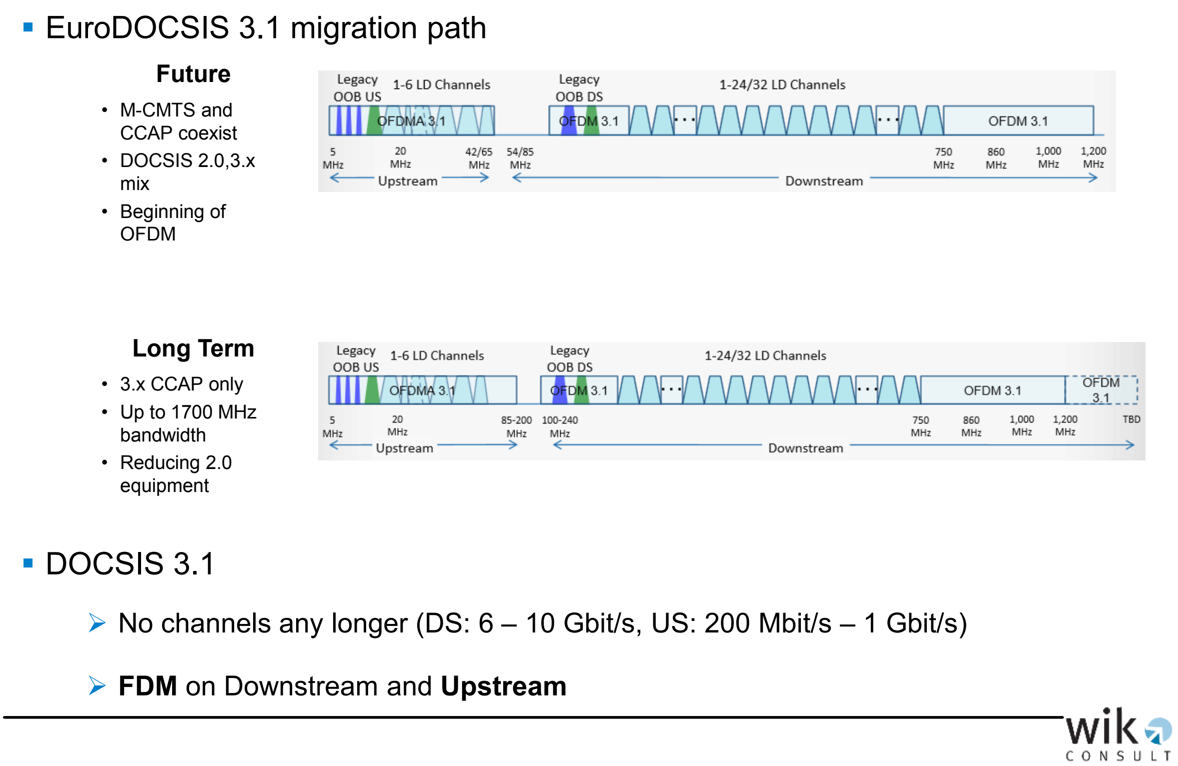
Source: CableLabs (https://www.cablelabs.com/full-duplex-docsis/)

3.3.2 DOCSIS 3.1, Full Duplex DOCSIS 3.1 and XG-Cable

3.3.2.1 DOCSIS 3.1

The DOCSIS 3.1 standard was firstly published in October 2013. It enables transmission speeds of up to 10 Gbps downstream and 1 Gbps upstream making use of 1.2 GHz spectrum bandwidth (see Figure 3-14). This represents a great advantage in comparison with the maximum transfer speeds offered by the previous DOCSIS standard, and allows cable operators to compete with fibre operators in terms of bandwidth offered to end-costumers, i.e. DOCSIS 3.1 provides cable-based operators with the possibility to compete in the Gigabit era. This reason together with greater operational efficiencies, improved quality control, lower costs and backward compatibility with DOCSIS 3.0 have driven the wide adoption of DOCSIS 3.1 in a record time.

Figure 3-14: DOCSIS 3.1 evolution, frequency use and data communication capacity allocation



Source: Plückebaum (2016)

The most significant improvements enabling the above mentioned increase of data rates are:

- A new error correction method called Low Density Parity Check (LDPC), already used in WiMax, WiFi and Digital Video Broadcasting. As an example of the efficiency of this method it shall be noted that 2bps/Hz can be saved, which means 12Mbps in a 6MHz channel and 16Mbps in a 8MHz (EuroDOCSIS) channel.
- A new set of modulation and coding schemes. DOCSIS 3.0 was based on 64 Quadrature Amplitude Modulation (QAM) upstream and 256-QAM downstream. Due to the use of an improved error correction method, which provides the possibility to add higher order modulations, the DOCSIS 3.1 technology supports up to 4096-QAM (with future support of 8192-QAM and 16384-QAM) downstream, and 1024-QAM with enhanced modulation schemes up to 4096-QAM in the future for the upstream.
- Introduction of Orthogonal Frequency Division Multiplexing (OFDM). OFDM has been already used by other network technologies, e.g. mobile networks with LTE and WiFi technology, but has been never used in cable networks until DOCSIS 3.1. It splits the available spectrum into 20kHz to 50kHz sub-carriers, which can

be bonded up to 192 MHz channels. These 192 MHz channels provide cable operators with the possibility of offering higher data rates than those that they can offer through bonding classical 6 MHz or 8 MHz channels

- Moreover OFDM allows adaptive modulation profiles. It follows that lower modulation schemes are allocated to users (cable modems) with poor Signal to Noise Ratio (SNR), and higher order modulations to those with better SNR. This feature provides a great flexibility regarding the use of the available spectrum

As it was noted in section 3.3.1, DOCSIS is not well suited for supporting business customer or high-quality individual end-customer demand: DOCSIS is a data communication standard designed for asymmetrical IP-based communications. This is also applicable to the case of DOCSIS 3.1. Extrapolating the 100 Mbps example of section 3.3.1 only a few customers could be supported. For a more detailed discussion – also including the Full Duplex approach described in the next section - see section 4.2.3.2.4 below.

DOCSIS 3.1 cable technology is being commercialized now. The following paragraphs provide a short overview of the current commercial deployments or roll-out plans regarding DOCSIS 3.1 cable networks around the world:

Comcast is currently offering "Business Internet 1 Gig" and "Business Internet 500" with transfer speeds of 1 and 0.5 Gbps respectively by means of DOCSIS 3.1 in Atlanta, Chicago, Detroit and Nashville. Comcast plans to deploy DOCSIS 3.1 across 39 states in the USA by 2018. The commercial deployment of DOCSIS 3.1 began in late 2015.

In Canada about 2 million households had access to DOCSIS 3.1 cable networks with data rates of 1 Gbps by mid-2016[66]. Gigabit transfer speeds are reached by means of the removal of analogue TV channels.

Vodafone New Zealand in partnership with Huawei reached an agreement to upgrade Vodafone´s cable network to DOCSIS 3.1[67]. The service based on this upgrade is known as FibreX. By October 2016 about 70% of the upgrade was completed, and the expectation was to have 100% complete by the end of 2016[68].

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66 Rogers Communications, “Rogers Q2 2016 Results”, 21 July 2016, http://netstorage-ion.rogers.com/downloads/IR/pdf/slide-deck/Rogers-2016-Q2-Earnings-Presentation-Slides.pdf

67 Vodafone, “Vodafone´s $22 million network upgrade paves the way for Wellington and Christchurch to become New Zealand´s first gigacities”, 09 November 2015, http://www.vodafone.co.nz/press-release/vodafones-22million-network-upgrade-paves-the-way-for-wellington-and-christchurch-to-become-new-zealands-first-gigacities/

68 Vodafone, “Vodafone unveils competitive pricing and commits to three day connection of FibreX services in Wellington, Kapiti and Christchurch”, 20 October 2016, http://www.vodafone.co.nz/press-release/vodafone-unveils-competitive-pricing-and-commits-to-three-day-connection-of-fibrex-services-in-wellington-kapiti-and-christchurch/

In Europe, the TDC Group in Denmark and Huawei announced in January 2016 a deal to upgrade the TDC´s coaxial network to deliver transfer speeds of 1 Gbps[69]. It is expected that by the beginning of 2018, two thirds of all Danish households will have access to 1 Gbps data rates[70]. In addition, these two companies together with Cable Euro announced in June 2016 the launch of the first DOCSIS 3.1 network in Europe[71].

Vodafone Spain announced in September 2016 the upgrade of the ONO´s hybrid-fibre-coaxial (HFC) network to offer symmetrical speeds higher than 1 Gbps[72][73]. Since the largest operators in Spain have set a maximum symmetrical data rates of 300 Mbps, this upgrade gives Vodafone an important advantage over the rest of fixed service providers. The upgrade has already begun in the main cities of Spain and will be extended to the whole country in the next 24 months (by the end of 2019).

Liberty Global has plans to upgrade its cable networks to DOCSIS 3.1[74]. The upgrades are scheduled for 2017 and expected to be finished in the vast majority by the end of 2018[75]. Liberty Global will begin with the deployment of DOCSIS 3.1 in the twelve networks that the company has across Europe. In this regard the first upgrade to DOCSIS 3.1 is expected to happen in the German city of Bochum and is to be finished by early 2018, which will be the first DOCSIS 3.1 upgrade across the Liberty Global European footprint[76][77].

Based on the current worldwide trend regarding the deployment and/or upgrade to DOCSIS 3.1 and the interview with VodafoneZiggo, WIK´s expectations are that an upgrade will be prepared smoothly by first upgrading the amplifiers in the field, accompanied by the deployment of new cable modems being ready for DOCSIS 3.1 (without symmetry). The CMTS will be exchanged on demand. WIK expects the upgrade will proceed hand in hand and coordinated with the upgrade towards full

69 Huawei, "Huawei and TDC Group, Denmark´s largest telecoms operator, announce breakthrough deal to upgrade the broadband network to delive speeds of 1 gigabyte per second", 28 January 2016, http://www.huawei.com/en/news/2016/1/Huawei-and-TDC-Group
70 Danish Business Authority (DBA), Department Business Development and Regulation, June 2017
71 LightReading, "TDC Denmark launches DOCSIS 3.1 with Huawei", 06 August 2016, http://www.lightreading.com/cable/docsis/tdc-denmark-launches--docsis-31-with-huawei/d/d-id/723940
72 PRISA, "Vodafone refuerza su oferta de TV con las series HBO y todo el motor", 06 September 2016, http://www.prisanewsservices.com/info.php?id=298204
73 Huawei, "Vodafone and Huawei demonstrated fibre-based 10 Gbps speed at Mobile World Congress", 08 March 2017, http://www.huawei.com/en/news/2017/3/Vodafone-Huawei-Fiber-based-10Gbit-s-Speed
74 Broadband TV News, "Fries: 'DOCSIS 3.1 will come in 2017'", 14 September 2016, http://www.broadbandtvnews.com/2016/09/14/mike-fries-docsis-3-1-will-come-2017/
75 ISP Review, "UPD Virgin Media´s Parent Commits to Gigabit Speed Broadband by 2018", 24 November 2016, http://www.ispreview.co.uk/index.php/2016/11/virgin-medias-parent-commits-gigabit-speed-broadband-2018.html
76 Broadband TV News, "Liberty Global starts DOCSIS 3.1 rollout in Germany", 20 March 2017, http://www.broadbandtvnews.com/2017/03/20/liberty-global-starts-docsis-3-1-rollout-in-germany/
77 Stadtwerke Bochum already implemented, sells and operates its optical fibre network. Unitymedia is supposed to make use of the existing fibre infrastructure to upgrade its network to DOCSIS 3.1. It follows, that no competition between fibre and coaxial network will take place in Bochum, but a collaboration between them.

duplex DOCSIS 3.1, because it makes no sense to upgrade amplifiers which will be bypassed by fibre to the last amplifier quite soon later on. Thus we refer to a time frame of upgrading the network including full duplex in the next section.

3.3.2.2 Full Duplex DOCSIS 3.1

The next generation broadband technology is currently being specified at CableLabs, which will increase the upstream data rate allowing the provision of symmetric Internet access to the end-user. This technology, which will be an extension of DOCSIS 3.0, is known as "Full Duplex DOCSIS 3.1", and its specification is expected to be released by the middle of 2017. It will enable symmetrical access with data rates up to 10 Gbps over existing HFC networks[78].

The capacity increase provided by Full Duplex DOCSIS 3.1 is possible through the use of the same spectrum at the same time for both communication channels, down- and upstream. Since the spectrum is no longer split between the up- and downstream, the efficiency of spectrum use is then doubled. This technical aspect constitutes an advantage in comparison to the currently HFC deployed technologies. A Full-Duplex approach combines the advantages of TDD (Time Division Duplex) solutions, i.e. peak speeds and flexibility, and it doubles the capacity due to the simultaneously use of the whole amount of spectrum for downstream and upstream.

The implementation of Full-Duplex presents the following challenges: echoes and interference. In a Full-Duplex environment, the CMTS is transmitting at high power and receiving signals from cable modems at low power. In order to be able to understand the signals coming from cable modems, the CMTS has to be able to remove its own transmitted signal from the one it receives. CISCO announced in August 2016 the development of a multi-slice scalable echo canceler for the Full Duplex DOCSIS specification that integrates with DOCSIS CMTS architecture[79]. No further details describing the implementation or working of the echo canceler is provided.

Moreover CableLabs proposes the intelligent scheduling technique of DOCSIS 3.1 together with the echo canceler to demonstrate the viability of Full-Duplex DOCSIS 3.1[80]. It shall be noted that Full Duplex DOCSIS 3.1 will be optimized for passive HFC, i.e. networks without active amplifiers between the fibre node and the end-user. For this the fibre nodes have to be located close to the end customer homes

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78 CableLabs, “Featured Technology Full Duplex DOCSIS 3.1”, http://www.cablelabs.com/full-duplex-docsis/

79 CISCO, “Full Duplex DOCSIS enables fibre optic capacity over existing cable plant infrastructure”, 09 August 2016, https://newsroom.cisco.com/press-release-content?type=webcontent&articleId=1783429

80 CableLabs, “Full Duplex DOCSIS 3.1 Technology: Raising the Ante with Symmetric Gigabit Service”, 16 February 2016, http://www.cablelabs.com/full-duplex-docsis-3-1-technology-raising-the-ante-with-symmetric-gigabit-service in a FTTDP like manner. With less efficiency it will also support amplifier based topologies. The symmetry characteristic will allow to overcome the bandwidth scarcity problem in upstream communication, one major reason why DOCSIS was so far not really prepared for providing VULA based solutions with symmetric traffic reserved for single customers.

WIK does not expect the launch of this technology before 2022, because it is not yet standardised and there still is a longer way to go overcoming the challenges, but it may play an important role for cable operators for the years after, and if the infrastructural conditions are met. This requires upgrade of the amplifiers to full duplex and deployment of nodes close to the end customer connected by fibre in a wide area roll out, not necessarily to full national coverage at the first step, when addressing the own retail customers. For a national wholesale access offer a large coverage is however a key prerequisite.

3.3.2.3 XG-Cable

XG-Cable for HFC networks is a solution provided by Nokia Bell Labs[81], which enables full duplex transmission to provide 10 Gbps symmetrical services. Nokia´s approach began in 2014, and it constitutes a separate solution to Full-Duplex DOCSIS 3.1.

In order to increase upstream data rates, Nokia proposes full duplex transmission together with advanced echo cancelation techniques and interference management. Although there are no further details regarding the echo cancelation techniques, these are similar to those provided by Nokia´s solution in case of vectoring. The echo at the transceiver is measured and compensated, similar to the noise cancellation principle used in headphones.

Interference can be caused by upstream signals from nearby cable modems. Nokia proposes a centralized solution based on coordination provided by the CMTS. The whole set of cable modems are grouped into “interference groups”. An interference group comprises all those cable models that can disturb each other. The CMTS will schedule cable modems within a given interference group in such a way that their transmissions has no impact on each other.

The implementation of this technology requires to take into account the following technical aspects: (1) full bi-directional amplifiers in order to support full-duplex; and (2) passive HFC network architecture, i.e. fibre to the last amplifier or beyond is required.

Nokia´s solution is still a proof of concept, and it was only demonstrated in laboratory. Nokia is currently working together with CableLabs to align its approach with the Full-

81 Nokia, “XG-Cable for HFC networks – Technology White Paper”, 2016

Duplex DOCSIS 3.1 proposal. As mentioned by Nokia, a commercial implementation of XG-Cable can be expected around 4 years from now, however this approach shows the feasibility of symmetrical Multi-Gigabit services over HFC networks and increase the lifetime of cable networks.

As in the case of Full Duplex DOCSIS 3.1, and due to the fact that both Nokia Bell Labs and CableLabs are working together to find an harmonized solution to the challenges presented in a full duplex environment, WIK does not expect XG-Cable to be commercially deployed before 2022 (see above).

Table 3-4 shows a comparison of the legacy DOCSIS 3.0 standard with the new DOCSIS 3.1, Full Duplex DOCSIS 3.1, and XG-Cable solutions.

Table 3-4: Future DOCSIS technology standards

	DOCSIS 3.0	**DOCSIS 3.1**	**Full Duplex DOCSIS 3.1**	**XG-Cable**
Highlights	Greatly enhances capacity	Capacity and efficiency progression	Symmetrical data rates	Symmetrical data rates
DS Capacity	1 Gbps	10 Gbps	10 Gbps	10 Gbps
US Capacity	100 Mbps	1-2 Gbps	10 Gbps	10 Gbps
Production Date	2008	2016	Not before 2022	Not before 2022

3.3.3 HFC networks in the Netherlands – The VodafoneZiggo Case

This section provides a general introduction to the main milestones of the development of HFC networks in the Netherlands, as well as a detailed description of the current status of VodafoneZiggo´s HFC network.

In 1996 CAI Westland provided end-users with the first internet access based on cable network. However, this service can hardly be considered a broadband access due to the low data rate offered (up to 115 kbps). The next step in the evolution of cable networks in the Netherlands was the implementation of DOCSIS 1.0 in 2002, and the introduction of the voice over IP (VoIP) service over DOCSIS 1.1 by Caiway in 2004, which forced KPN to include this service based on ADSL on a flat-fee basis as countermeasure.

In 2007 the upgrade to DOCSIS 2.0 was carried out. The last relevant milestone regarding the development of HFC networks in the Netherlands took place in 2009. VodafoneZiggo (formerly only Ziggo without UPC) announced the upgrade of its network from DOCSIS 2.0 to DOCSIS 3.0 in April, and UPC upgraded its network to provide up to 120 Mbps DS (downstream) and 10 Mbps US (upstream) in September[82].

Cable networks uptake in Europe has increased significantly in the last ten years. While in January 2006 European cable subscriptions represented about 13% of the fixed broadband subscriptions, the percentage of cable subscriptions in July 2015 reached the 20% of the total[83].

In the Netherlands fixed broadband access based on cable is mainly provided by VodafoneZiggo. In addition, regional cable operator such as Caiway and Delta (DOCSIS 3.1 ready[84]) cover small areas of the country. Cable internet access is available to 95.1% of Dutch households, of which 100% of them are DOCSIS 3.0 based[85]. Cable represents the second largest network in rural areas with 92.4% coverage, just after the DSL technology. The Netherlands occupies the fourth position in terms of cable coverage in Europe. The list of the three leading European countries comprises Malta (100%), Switzerland (98.1%) and Belgium (96.3%)[86].

In the European context Cable DOCSIS 3.0 is the most widespread NGA technology in Europa in terms of coverage and uptake with 45% of the European NGA subscriptions. Cable networks in the Netherlands provide access to more 3 million subscribers, which represents more than 46% of the Dutch market, being the first access technology in the country in terms of uptake. Moreover, cable access provides the end-user with the best performance in terms of data rates. Data rates above 30 Mbps are provided to more than 90% of end-users, from which about 57% of the connections achieve 100 Mbps or more[87].

3.3.3.1 VodafoneZiggo HFC network

VodafoneZiggo´s HFC network penetration achieves 94.4% of Dutch households, with more than three millions active end-users, which represents about 42% of the broadband access connections in the Netherlands. It is based on the DOCSIS 3.0 standard, and currently operates at 862 MHz (see Figure 3-15), with an extension to 1.218 GHz for DOCSIS 3.1 coming in the future. It is today able to provide total share data rates of 1.2 Gbps downstream and 204 Mbps upstream.

82 W. Lemstra, W.H. Melody, “The Dynamics of Broadband Markets in Europe: Realizing the 2020 Digital Agenda”, Cambridge University Press, 2015

83 European Commission, “Connectivity Broadband market developments in the EU”, Report 2016

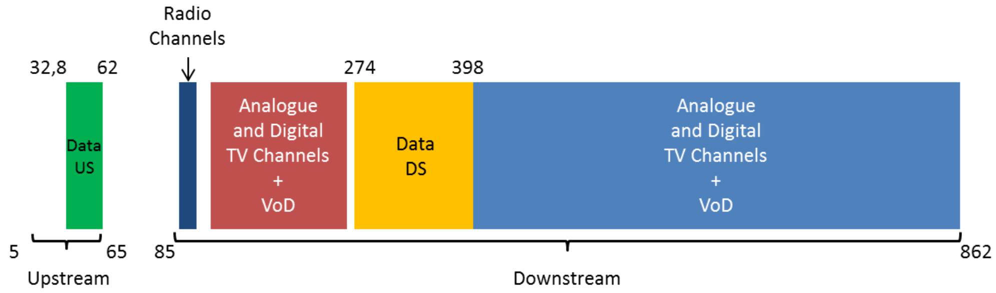
84 Delta Kable announced an agreement with Teleste to upgrade its network to DOCSIS 3.1 in 2015, http://www.broadbandtvnews.com/2015/07/06/teleste-to-deliver-docsis-3-1-to-delta/.

85 Information according the Eruopean Comission in 2015. However, as mentioned in Chapter 2, CAIW´s coaxial network is based on DOCSIS 2.0 (2.1). This represent a minor percentage of the total coax homes passed. It could be concluded that almost 100% of cable access is based on DOCSIS 3.0.

86 European Commission, “Broadband coverage in Europe 2015 – final dataset”, 30 September 2016

87 ACM, “Telecommonitor Q3 2016”, 31 March 2017

Figure 3-15: VodafoneZiggo´s spectrum distribution in the region of Alkmaar in Dec. 2015



	Radio Channels	Digital TV	Analogue TV	VoD	Internet Data
Upstream					
32,80 MHz – 62 MHz					4 Channels of 6,40 MHz
Total US					**4 Channels of 6,40 MHz**
Downstream					
87,50 MHz – 108 MHz	X				
118,75 MHz – 270 MHz		5 Channels of 8 MHz	8 Channels of 7 MHz	4 Channels of 8 MHz	
274 MHz – 398 MHz					16 Channels of 8 MHz
398 MHz – 861,75 MHz		34 Channels of 8 MHz	16 Channels of 7 MHz	4 Channels of 8 MHz	
Total DS		**39 Channels of 8 MHz**	**24 Channels of 7 MHz**	**8 Channels of 8 MHz**	**16 Channels of 8 MHz**

Please note the existence of unused spectrum between the different channels

wik CONSULT

Source: Ziggo Forum (2015)

VodafoneZiggo´s HFC network is based on the network topology described in Section 3.3.1, more precisely VodafoneZiggo´s network comprises up to five different levels[88]:

- A highest IP MPLS based core backbone level that comprises a given number of IP regional core locations
- The second level of the network is formed by the regional centres connected with the regional core locations in a ring manner, making use of a Dense Wavelength Division Multiplexing (DWDM) optical network for the signal transport
- The third level comprises the CMTS or local centres. VodafoneZiggo´s network comprises [✂] CMTS locations. A CMTS provides broadband access to a given HFC network segment, in which approximately [✂] home passed (HP) are covered
- The fibre nodes are located at the fourth level, connected to a CMTS in a ring topology basis.

88 Network information provided by ACM, and data provided by VodafoneZiggo

- Finally, the fifth level corresponds to the feeder coaxial segment of the network. It includes a cascade amplifier structure, the multi taps and the last mile from the taps to the end-user cable modems

A ring topology based on optical fibre is deployed to carry the signals from the highest level of the network to the fibre nodes located in the fourth level, and from there on forward a tree topology based on coaxial cable is used to transport the signals to the end-customers. Figure 3-16 show a schematic view of the VodafoneZiggo´s HFC network.

Figure 3-16: Schematic view of VodafoneZiggo´s HFC network

[✂]

Source: ACM

As mentioned above, the VodafoneZiggo´s HFC network is based on DOCSIS 3.0, and [✂]. The implementation of DOCSIS 3.1 requires the installation of DOCSIS 3.1-capable cable modems, which are already available in the Netherlands, [✂].

Full Duplex DOCSIS 3.1 and/or XG-Cable require fibre to the last amplifier or beyond together with the installation of fully bi-directional amplification. [✂][89].

[✂][90]. Moreover, a first attempt to provide an Ethernet Wholesale product was already carried out in the past. The product was not a layer 2 service but a layer 3 (pseudowire) best-effort service offering up to 2 Mbps symmetric communication. The lack of provisioning of QoS, the complex and time consuming manual processes associated to it, together with the impossibility of offering the service everyone everywhere made VodafoneZiggo to stop provisioning this service in 2015.

As introduced in Section 3.3.1, VULA-similar products, i.e. layer 2 (Ethernet) wholesale products over cable are technically possible. For providing it VodafoneZiggo would be required to replace its currently installed CMTSs and CMs by L2VPN-capable equipment and would also have to adapt its OSS and BSS significantly in order to sell, provide and operate this type of service.

89 WIK interview with VodafoneZiggo during this study
90 WIK interview with VodafoneZiggo during this study

4 Assessment of the effects of the technical developments on the options of providing access via ULL, VULA and WCA

In 1988, the EU started to liberalise different segments of the telecoms market, which culminated in 1998 with the liberalisation of the voice service and the access network infrastructure. National Regulatory Authorities (NRA) had to establish a fair competitive market situation. The NRAs have defined mechanisms of wholesale services that allow alternative operators to access the network of the incumbent operator. This enabled the access of new entrants into the telecom market without the need of constructing a complete new network from the scratch. Wholesale services can be used instead in a fair and non-discriminatory manner. As a result it boosted competition. Competition implied a reduction of the end-customer prices, a wider choice of services, better quality of service and it promoted investment in technology evolution.

In its recent market recommendation of 2014[91] The Commission defines the wholesale access market 3 at fixed locations, subdivided into (a) local and (b) central access (WCA). The accompanying staff working document[92] details the local access market into physical unbundled access and a virtual unbundled local access (VULA). The wholesale central access is comparable to the already well known wholesale bitstream access (WBA), both are characterized by best effort traffic behaviour. But WBA is a more general expression for the type of service, while WCA is restricted to the regulatory context.

The first section (4.1) of this chapter provides an overview of today's types of wholesale access to the incumbent's network: (1) physical unbundling in legacy copper and fibre based unbundled access networks, i.e. Local Loop Unbundling (LLU); (2) Virtual Unbundled Local Access (VULA); and (3) Wholesale Broadband Access (WBA/ WCA). The section following (section 4.2) analyses the capabilities of the technical systems and components described in section 3 with regard to providing this wholesale access services, which are then summarized in a table in section 4.3. Section 4.4 tries to estimate, how the wholesale access market in the Netherlands might change over the time period up to the year 2025. Section 4.5 assesses which economic effects this technological developments might have on new market entrants.

91 EC recommendation on relevant product and services markets, C(2014) 7174 final, 9. October 2014
92 Explanatory notes on the EC recommendation on relevant product and services markets, SWD(2014) 298, 9. October 2014

4.1 Definition of the access options ULL, VULA and WCA by the EU-Commission and NRAs especially ACM

4.1.1 Local Loop Unbundling

The physical LLU constitutes a wholesale product based on an obligation of the incumbent operator to lease passive telecom facilities concerning the local loop. The local loop, also known as 'last mile', comprises the wires respectively fibre strands and the passive equipment that connect the customer premise equipment (CPE) to the local exchange, the Main Distribution Frame (MDF) respectively Optical Distribution Frame (ODF) location. It typically includes a collocation option at these locations for the wholesale seekers. These facilities grant a new entrant operator access to the incumbent´s local loop, and give it the possibility to provide broadband services to end-customers.

4.1.1.1 Copper unbundled local loop

Copper LLU can be classified as full and shared local loop unbundling. The differentiating point between these two cases is the bandwidth of landlines. On the one hand, the new entrant operator access the full frequency band, which allows to provide both the telephone and broadband services (full LLU). On the other hand, the new entrant has access only to the high-frequency band, enabling to offer broadband services (incl. VoIP), while the lower frequency band remains with the incumbent (shared LLU). Therefore, in the shared LLU case only broadband services can be offered. Inside the broadband services an operator can offer telephony services too, based on VoIP.

SLU is defined by NRAs as an alternative methodology to grant access to the last mile. It provides access to the segment of the network from the CPE at the end-customer's home to an intermediate point, known as street cabinet, placed on the side of pavements. While this type of access seems not to present relevant advantages over LLU in order to offer telephony services, it gets important in case of fibre to the curb (FTTC) networks. In this type of networks fibre cables connect the local exchanges to the street cabinet, and copper cables connect the street cabinet to the CPE. The copper lines to the end-customers are getting significantly shorter. This network architecture therefore allows to offer higher bandwidth services, e.g. VDSL, VDSL2. While incumbent operators benefit from this infrastructure, competition on the basis of SLU unbundling in most cases is not economically feasible[93] and thus not considered in the

93 Analysys: The business case for sub-loop unbundling in the Netherlands, OPTA, January 2007
Analysys: The business case for sub-loop unbundling in Dublin, ComReg, 20. December 2007
WIK: The economics of next generation access, 2008/ 2009,

Netherland's market, like in many other markets in Europe (e.g. Austria, Belgium, Denmark, France, Ireland, Portugal, Spain, Sweden, U.K.).

Copper local loop unbundling occurs at the MDF, where the wholesale access seeker collocates with own electronic equipment and accesses the copper loops by a patch cable onto the access line. [✂][94] for LLU. Because copper LLU is limited in the bandwidth with increasing bandwidth demand the operators using unbundling will have to migrate to a VULA or even a bitstream wholesale product in order to keep pace with the end-customer demand and secure their end-customer base, if they cannot change to fibre local loop unbundling. Since the copper MDF and fibre ODF locations are not at the same site[95], but at different locations, the wholesale access seeker would have to access different, new locations (hosting the ODF) for migrating its customers from copper to fibre LLU.

The strength of using physical unbundled infrastructure is the high degree of independency an access seeker and competitor has from the incumbent wholesale provider, or from another, volunteer wholesale provider. Of course some degree of dependency is unavoidable and relates to the quality of the physical access provided. But there are no additional electronics at the end points of the LLU operated by the wholesale provider and limiting the access product quality. All electronic systems are provided and operated by the access seeker. It therefore enters the value chain at a very early stage (see also section 4.1.1.3).

Weakness of the copper LLU is the poor bandwidth characteristics of the transmission medium which is becoming outdated for meeting increasing higher and higher broadband demand. Technical problems of interference between neighbouring copper pairs of a copper cable can be solved by vectoring, but only by losing the capability of unbundling. Operating the copper pairs by different operators is no longer possible (see section 3.1.3).

4.1.1.2 Fibre unbundled local loop

Fibre to the Home (FTTH) in a point-to-point topology connects any home of an access area by an individual fibre strand to an Optical Distribution Frame (ODF), so that there is an individual physical fibre strand connection between the ODF port and the home.

WIK: Implications of a nationwide fibre roll out and its subsidy requirement, wik, Bad Honnef, October 2011,
WIK: Der dynamische Investitionswettbewerb als Leitbild der zukünftigen Entwicklung des Telekommunikationsmarktes, November 2013,
WIK: Benefits and regulatory challenges of VDSL vectoring (and VULA), Florence School of Regulation, March 2014, Florence, EUI Working Papers RSCAS 2014/ 69

94 Exactly [✂] locations

95 Reggefiber originally designed its fibre access network independently from the existing KPN copper access network

To this extent a copper access network and such FTTH network are comparable, also with regard to the option of physical unbundling of any of the fibre access lines. A transparent fibre can offer the full bandwidth flexibility a fibre has, individually per end customer, so in principle the highest state of the art 100 Gbps bandwidth could be offered per end customer. Fibre strands in practice do not suffer from any electromagnetic interference or noise and only from a low signal attenuation compared to copper. So FTTH fibre unbundling allows all operators using the FTTH access network a wide degree of product definition freedom.

In the Netherlands the FTTH access network has been originally constructed by Reggefiber and later has been completely taken over by KPN. Approximately 30% of the homes in the Netherlands are connected to the FTTH access network. [✂]. Area and City PoPs of the FTTH access network are not at the KPN copper network locations. In the case the number of fibre access lines aggregated is below 10,000 there is also an option to access these lines at one of the 161 metro-core locations of KPN, where these lines are allocated to. Doing so makes use of the fact that fibre (access) lines allow to transmit high bandwidth over a significantly longer distance[96] than copper lines.

In other countries there often exist FTTH fibre point-to-multipoint topologies, which combine many fibres of homes in a passive optical element called splitter onto one single fibre line backhauling to the ODF location. There can be several splitters cascaded in a line. The shared use of the backhaul fibre requires an administration unit organising that only one end-customer is sending at a given time. This unit is called OLT, and its counterpart at the end-customer location is called ONU or ONT. Physical unbundling of such fibre plant only is theoretically possible at the last splitter closest to the end-customer. This is economically even less viable than the copper SLU. Such fibre topologies do not exist in the Netherlands and thus are not included in the business case considerations (sections 4.5.6 and 4.5.6).

The strength of a PtP fibre access line first of all is caused by the high degree of product differentiation an access seeker has from its wholesale provider (see also section 4.1.1.3) and by the bandwidth independence already described above.

There is no weakness like in the copper access sphere, except the dependency of the provider regarding the provision of the physical fibre infrastructure, which is comparable to the copper network. All disadvantages of the technical constraints of the copper line disappear. So far not relevant for the Netherlands, this situation would change in case of a PtMP topology, being operated by a GPON family product. In fact the bandwidth is

96 The distance depends on the power of the optical transmitters and the sensitivity of the receivers – so also on cost. Typical distances cover the range between 20 and 100 km, special fibres and transmission systems e.g. for sea cables allow a distance of around 2.000 km.

limited because of deploying OLT and ONU/ ONTs as intermediate systems. These systems could be operated by a wholesale access seeker itself, in case of being operated over unbundled wholesale wavelengths – which is technically feasible and standardised today. But nevertheless the maximum bandwidth is limited by the GPON family transmission systems used and by the sharing of a commonly used access infrastructure.

4.1.1.3 Common strength aspects of copper and fibre LLU

The technical characteristics of a physical unbundled loop are relatively straightforward as the wholesale product involves access to a unique cable at the physical layer. Physical access provides the maximum degree of transparency and control for the access seeker. Compliant CPE[97] may be freely installed and the access seeker is free to install and operate its own DSLAM or optical equipment subject only to criteria designed to avoid interference.[98] The access seeker can freely set bandwidths (asymmetric and/or symmetric) and profiles up to the maximum capability of the copper or fibre cable[99] and can keep pace with the technological progress of equipment suppliers. The access seeker pays a typically cost-oriented flat monthly rental fee for a line which is fully configurable (subject to the limitations of the copper technology), and is free to set its own retail tariff structures independently from the supplier of the unbundled loop. The access seeker also has full visibility concerning the 'line state' (faults in the equipment and on the line), and can therefore rapidly identify, if, when and where repairs are needed. It can organize and prioritise such work with reference to its own criteria.

The physical access allows a new entrant to deploy any non-interfering equipment on both the network side and the end-customer side. The possibility to access and manage both the CPE and the equipment relevant to the broadband service enables among others service differentiation and innovation, e.g. provision of any technically feasible speed (including symmetric services for business customers), new functionalities such as multi-VLAN, and upgrade from classical DSL internet access service to Dual- or Triple-Play services. This feature is a key point to be considered by new entrants in order to draw the attention of end-customers. Moreover, offering a wider range of differentiated services instead of replacement services already provided by the incumbent will assure the survival of new entrants. On the other hand, the incumbent is

97 At the end-customer premise a CPE (customer premise equipment, typically a router) and a modem (may be integrated into the CPE) are installed, which build the interface between the inhouse network and the wide area network of a network operator. The modem and Router have to interact with the DSLAM at the network operators side following predefined and standardised rules. Modem and router respectively the CPE have to be compliant with these interworking rules.

98 Spectral management plans are used to limit cross-talk in the context of copper local loop unbundling.

99 For copper see Figure 3-1 and the appropriate explanations, depending on line length and technology, relevant are the values without Vectoring (profile 35b appr. 150 Mbps down and 50 Mbps upstream below 500m; for fibre 100 Gbps symmetrical.

to some extent forced to analyse the services offered by new entrants, and improve their own network/services to be able to provide an equivalent quality of service to their end-customers.

Service differentiation and innovation are very attractive for new entrants. However, NRAs are responsible to guarantee that the access will be non-discriminatory, i.e. equal treatment of operators regarding access and with respect to offering services and access information on conditions not worse than applied internally. In presence of discriminatory access to the incumbent´s network, other wholesale products, e.g. bitstream (WCA/ WBA), might be preferred by new entrants. This type of products does not allow service differentiation and innovation, which limits the improvement of the quality of offered services and reduces investment in technology evolution compared to LLU.

Based on the characteristics of the physical unbundling access described in this section it can be concluded that LLU boosts competition and thus leads to improvement in the quality of the services offered to end-users.

4.1.2 Virtual Unbundling Local Access – VULA

Active access is provided because physical unbundling is not technically or economically feasible. The choice of DSL equipment, technical, bandwidth and to some extent the pricing characteristics[100] of the wholesale product are determined then by the access provider. This has an impact on who is able to monitor the network operation, identify and analyse failures and take appropriate action for repair, including repairs to the active equipment. In markets in which there is likely to be insufficient competition at the network level to constrain the conduct of the access provider (including state aid areas in which investment in ‘step change’ NGA services is not commercially viable in the absence of subsidies), criteria are needed to determine whether active wholesale access provides a level of control which at least approaches that which would be offered through physical unbundling.[101]

In this section we summarise the main characteristics of VULA as defined in the explanatory memorandum accompanying the EC 2014 Relevant Market Recommendation. As the resulting core characteristics are still high level, we further elaborate the metrics based on BEREC analysis and more detailed statements already made by the Commission regarding the German VULA/ Vectoring state aid case.

100 In ex-ante regulation the prices are strictly controlled by the regulator, but typically basing on the operator’s application, and the prices should cover at least efficient cost.

101 Wholesale active access is unlikely to be fully functionally equivalent to physical access, because the choice of the exchange equipment lies with the access provider. Control over the active equipment also implies that the access provider has control over the interfaces used to calibrate the service or detect faults.

4.1.2.1 The EC Decision (2014 Relevant Market Recommendation explanatory note)

In its State Aid Decision of 2015, DG Comp refers to the characteristics of VULA described in the 2014 explanatory memorandum accompanying the EC Recommendation on Relevant Markets. This identifies the following characteristics as distinguishing wholesale products which functionally replicate key features of traditional physical and local unbundling access from other forms of access, such as bitstream.

1. ***Access occurs locally**. This means that traffic is handed over at a level which is much closer to the customer premises than access at the national or regional level as generally granted with traditional bitstream access. Such "localness" is typically given in a scenario where access is granted at or close to the central office/MDF (including newly built ODF) or the street cabinet. However, while the virtual access product should aim to replicate LLU effectively, the number of interconnection points does not necessarily need to be equivalent to the copper network's points of interconnection.*

2. ***Access is generic and provides access seekers with a service-agnostic transmission capacity uncontended in practice**, i.e. providing guaranteed bandwidths according to the access seekers' needs, whereby respective access requests are subject to the principle of proportionality, and would normally not require the SMP operator to deploy new physical infrastructure. Uncontended access requires in principle the establishment of a dedicated logical connection between the customer facilities and the point of handover. The technical features of the connection (backhaul connecting the street cabinet and central office and capacity dimensioning in particular) should only be limited by the inherent capabilities of the access technologies deployed and support LLU-like services (e.g. **multicast**[102] **where appropriate**).*

3. *Access seekers need to have sufficient **control over the transmission network** to consider such a product to be a functional substitute to LLU and to allow for product differentiation and innovation similar to LLU. In this regard, the access seekers' control of the core network elements, network functionalities, operational and business process as well as the ancillary services and systems (e.g. customer premises equipment) should allow for a sufficient control over the end user product specification and the quality of service provided (e.g. varying QoS parameters).*

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102 Multicast is a feature typically used for IP-TV transmission. Instead of transmitting all TV-channels down to each customer (Broadcast) it is only transmitted to those having subscribed for it. Thus there may be branches of a broadcast tree from the IP-TV server to all end-customers which are not occupied by the TP-TV signal. The branches used can be further optimized by only transmitting those channels being requested at that time by end-customers. This is controlled by the Internet Group Management Protocol (IGMP), which supports to reduce the bandwidth requires and makes the transport more efficient. On bandwidth restricted access lines (like the copper access lines) such feature is in any case required. Typically the number of channels is restricted to 4 in parallel at the same time. In case of LLU the access seeker is free to deploy its own equipment supporting multicast frame replication. In case of wholesale active access the access providers equipment should support it also, at least at network levels where the bandwidth savings are significant.

Only those wholesale products meeting the above criteria should be considered to fall within the Wholesale Local Access market (market 3a). Active products not meeting these criteria might fall within the Wholesale Central Access market, which encompasses access products enabling access seekers a less direct and more standardised control over the access line.

4.1.2.2 The BEREC definition

In October 2015, BEREC released a report on the common characteristics of layer 2 wholesale access products[103] and one year later the common characteristics on Layer 2 Wholesale Access Products[104]

In its first report BEREC noted that the analysis is descriptive, analysing the situation of 10 European countries regarding VULA and L2 bitstream access, and does not aim at being normative or recommend a best practice. In its second report however, it defines common positions imposed on market 3a and 3b L2 access and identifies 10 'common technical characteristics' that would normally be identified with Layer 2 wholesale access, both local and regional:

1. Technology:	Ethernet
2. CPE:	determined by Alternative Network Operator (ANO)
3. Bandwidth:	differentiated, ANO controlled, up to the maximum of the technical capabilities of the access line
4. QoS:	"ostensibly" uncontended bandwidth, at least of the same standard as the incumbent's retail products
5. Traffic prioritisation:	ANO determined
6. Multicast:	frame replication functionality (if necessary and proportionate)
7. Number of VLAN:	several per end-user
8. Customer identification:	for each ANO and its customers
9. Security:	ANO able to apply security measures
10. Fault management:	ANO received actual state reports of access line

103 BoR (15) 133 http://berec.europa.eu/eng/document_register/subject_matter/berec/reports/5439-berec-report-on-common-characteristics-of-layer-2-wholesale-access-products-in-the-european-union

104 BoR (16) 162 http://berec.europa.eu/eng/document_register/subject_matter/berec/regulatory_best_practices/common_approaches_positions/6482-berec-common-position-on-layer-2-wholesale-access-products

4.1.2.3 EC statements regarding German VULA submissions

The European Commission went beyond the BEREC specifications for VULA by describing the explanatory note ciriteria in more detail in a state aid case for public subsidies in a Vectoring roll-out scenario:

In May 2016 the European Commission responded on a Wholesale Local Access notification of the German NRA BNetzA[105] (Vectoring II, near shore area) expressing its serious doubts on the notified access products.BNetzA replaced its proposal. In response to the second notification approach of BNetzA, the European Commission stated in July 2016[106] significant improvements regarding the newly notified products, but still criticized the VULA products proposed. Thus the Commission demands for an effective economic and functional substitute for physical unbundling, which shall meet the criteria of the market recommendation.

In a December 2016 statement made in response to BNetzA's proposals for remedies (changes to the Reference Offer) in the Wholesale Central Access market,[107] the European Commission further specified characteristics that should be associated with a fully adequate functional substitute in the context of Vectoring (in the near shore area). Since it is the only L2 product this view is also relevant for the far shore area, applied in both cases (with and without state aid). From WIK's point of view the L2 bitstream access must have VULA characteristics in order to become a full functional substitute for physical unbundling.

Concerning 'generic access', the Commission noted that relevant features were:

- Layer 2 protocol
- Maximum MTU[108] size
- Availability per end customer access connection (up-time in %)

105 Case DE/2016/1854, C(2016) 2929 final: https://circabc.europa.eu/sd/a/055249f0-8448-4f3e-844c-c4d12cc001af/DE-2016-1854%20Adopted_EN.pdf
106 Case DE/2016/1876, C(2016) 4834 final https://circabc.europa.eu/sd/a/4642d853-cd70-4d7a-9ef3-f11c64e59be3/DE-2016-1876%20ADOPTED_EN%20for%20publication.pdf
107 Case DE/2016/1934, C(2016)8366 https://circabc.europa.eu/sd/a/679cca47-d2c0-4895-a9fc-4d5d1c10d922/DE-2016-1934%20Adopted_EN.pdf
108 The Maximum Transmission Unit is the size of the largest network layer protocol data unit that can be communicated in a single network transaction. The standard Ethernet frame MTU has 1,500 Byte. The higher level applications can use this transport volume per frame without any restrictions. If i.e. wholesale seekers want to add additional protocol features within the layer 2 protocol element they can make use of so called Jumbo-frames, which allow for larger MTU. The additional space is used for additional protocol features. If such additional frames are required in the context of wholesale services, where layer 2 frames are encapsulated by additional layer 2 frames, this has to be performed outside the higher layer data frame. By this no volumes will be taken away from the higher level data transfer space. Admitting larger MTU sizes brings the wholesale seeker into a comparable position as it it would operate its own equipment and making full use of the MTU size for further product differentiation.

- Obligation to increase the backhaul capacity between the MSAN[109] and BNG, in order to avoid contention[110]
- Multicast frame replication

Concerning 'access control', the Commission identified the following features that should be reflected in an offer in order for it to considered to functionally substitute for VULA:

- Control of service profiles and DSL profiles
- Fault management: diagnosis data, choice to change system parameters, MTR targets, definition of faults (severe fault: significant decrease of speed), inclusion of ESS (Elektronische Entstörschnittstelle) access into reference offer

4.1.2.4 Metrics for assessing VULA specifications

On the basis of the EC letter to the German authorities, the 2015 BEREC report, and our own experience, WIK has identified the following characteristics as relevant in comparing VULA specifications and drawing conclusions on best practice as regards the three core VULA criteria identified in the 2014 EC Explanatory Note.

109 MSAN: Multiservice Access Node aggregating the single copper access lines into a larger data (and voice) stream up to the central network. An MSAN supports additional functions compared to a DSLAM (Digital Subscriber Line Access Multiplexer) and replaces it in modern copper access networks. The MSAN are then aggregated at an Ethernet switch or an BNG (Broadband Network Gateway, aggregation node at a regional network level). MSAN and BNG are used in case of LLU by the wholesale seekers also. In case of VULA they are intermediate equipment of the access provider.

110 Contention refers to an overbooking situation where more customers demand for capacity than the link or the systems connected to it can transport. In such case priorities help the important traffic to pass through, while less important traffic is delayed or deleted. In case of active wholesale access this contention ratio is controlled by the access provider. So he could control the product quality of the access seekers. Therefore he could be obliged to offer sufficient capacity so that the traffic is in effect uncontended at any time.

Point of handover	Location of handover (e.g. cabinet, local exchange, regional level) Number of access seekers per handover point Common handover point for all VULA access technologies Common product family across all VULA access technologies
Generic access	L2 protocol Approach to contention. Obligation to increase backhaul capacity in case of contention Number of VLAN per access seeker and end-customer, VLAN tagging[111] Maximum MTU size Dedicated logical connection per end customer/availability per end user connection Customer identification for each access seeker and its customer Multicast support: Frame replication functionality
Access seekers' control	CPE by ANO Bandwidth (potential for ANO control), Guaranteed bandwidth classes, symmetric bandwidth (for business) Control of service, DSL profiles by ANO, traffic prioritisation ANO determined Security: ANO able to provide security means Fault management: ANO receives actual state reports of any access line, access to diagnostic data, clear definition of faults, SLAs, KPIs and compensation over repair times BSS[112] support (order interface)

111 VLAN tags are an address extension of the Layer 2 (Ethernet) protocol allowing to define subaddresses for networks within a network (Virtual Local Area Network, VLAN). The standard allows for an outer tag (S-VLAN) and an inner tag (C-VLAN) of the same size (4094 addresses), which can be managed independently. In case of a wholesale business the outer VLAN i.e. could be managed by the access provider, and the inner by the access seeker. This allows for some product definition independence between access provider and access seeker. But both will not get the full address space available. They have to share it among themselves. In case of DT's proposed use of the tags each S-tag identifies and addresses one end-customer behind a handover interface – which is dedicated to one access seeker, so it can address a limited number of end-customers per access seeker (max. 4094). There are no options that any S-tag could address a group of end-customers, as required for multicast support. The C-tags are free of use for the access seeker. These i.e. are typically used to separate data, video, IP-TV and voice traffic, and also for business customer VLANs. 4094 VLAN is a quite high number per end-customer. It also allows to transparently transmit access seeker specific and end-user specific priorities. Another subdivision of the S and C address spaces could enable i.e. to increase the number of addressable customers per access seeker or to establish additional Multicast VLAN.

112 Business Support Systems (BSS) manage ia the order, change and contract termination processes and the service provisioning in an automatic manner. Operation Support Systems (OSS) are ia relevant for support regarding network monitoring and failure analysis and repair. For the active elements in the access seeker's value chain an interaction between the systems and processes of the wholesale partners should replace the complete internal process structure of the access seeker in a passive LLU access scenario.

Additionally, on the basis that vectoring technology may necessitate forced migration to VULA from physical unbundling, and noting that pricing is a core issue affecting the viability of VULA for access seekers as a potential substitute for unbundling,[113] we have identified the following migration and pricing characteristics as relevant.

Migration	Advance notification Bulk Migration Planning Who pays for the migration cost? Compensation for stranded investment Migration KPI monitoring
Price	Price structure bandwidth dependant Monthly rental charge Relationship of the monthly rental charge to LLU

4.1.2.5 VULA in the Netherlands

As described before in 2.2, ACM motivated KPN with regulation to agree with market parties on a VULA product with certain specifications[114] in order to be allowed to upgrade its copper xDSL network with vectoring functionality.

The VULA service is a layer 2 Ethernet service offered at the 161 metro core locations and for all lines in KPN's copper network. The access bandwidth per customer is offered in two quality classes: (1) Best Effort and (2) Premium/ Priority traffic. It supports Multicast. All bandwidth variants are available and alternative operators can use their own CPE.

KPN intends to make use of any technology available for its FTTC deployment in order to make utmost use of the copper subloop access infrastructure and its inherent bandwidth. It deploys bonding on several copper pairs, where demanded, since there typically are spare copper lines, and already prepares its nodes to migrate to VDSL profile 35b including Vectoring in the future. All these bandwidth profiles in principle can be made available over the VULA products to other wholesale customers also.

[✂]. But if they would deploy it somewhere in future there are no technical

113 This is acknowledged in the EC letter to BNetzA of December 2016 https://circabc.europa.eu/sd/a/51112946-265d-45c7-9a2f-0e36592b4eb1/DE-2016-1954%20Adopted_PUBLIC_EN.pdf

114 Commercial wholesale agreements in the Netherlands, ACM presentation 7 March 2017 at the WIK Investment Workshop in Brussels, http://wik.org/fileadmin/Konferenzbeitraege/2017/Interactive_Workshop/Presentation_Johan_Keetelaar__Director_ACM__for_the_WIK_Investment_Works....pdf

reasons for not making it accessible as well for wholesale seekers over a VULA product.

Despite not being immediately relevant for the Netherlands, we do want to point out that in case physical unbundling of a fibre access network is not economically feasible (i.e. PtMP fibre topology with GPON) a VULA product might be an alternative, which could be offered in one single VULA product family[115]. Another option would be using wavelength unbundling (see section 3.2.2).

4.1.2.6 Strength and weakness of VULA

Certainly the strength of the VULA is providing a regulated access option for competitors in areas where the unbundled physical access is not feasible for technical or economic reasons. This access could provide a higher access speed than would be achievable else (in case of copper access line and vectoring). A special strength of the VULA in some countries[116] is the rather regional handover compared to a copper LLU[117]. The VULA access will allow for more freedom of competitor's product definition than a WCA can do. A WCA would be the next best wholesale alternative to LLU otherwise.

The weakness of a VULA is coming close to LLU, but not meeting its product definition freedom. There always is an intermediate level of electronic systems, influencing capacity, provisioning, stability, transmission quality and maintenance and being provided and operated by a competitor, i.e. the incumbent.

4.1.3 Wholesale Broadband Access – WBA/ WCA

Wholesale Central access (WCA) is a bitstream access service typically handed over with the layer 3 IP-Protocol, and handed over at central sites or in some countries at regional sites, too. It is typically determined by best effort characteristics. It differs from VULA product characteristics by having no availability guarantees, a higher contention ratio, no symmetrical speeds and no resilience, with low or no control of the traffic flow nor access line state offered for the wholesale seekers. And it differs in price. It is intended to only enable standardised retail services[118]. Nevertheless, there shall be no discrimination allowed compared to the traffic of the incumbent respectively the wholesale access provider or of other wholesale access seekers. Multicast support is

115 See Austria, A1 TA Reference Offer of December 2016

116 The Netherlands, Austria, U.K. Denmark, …

117 NL: Handover at 161 metro core locations for VULA, but [✂] MDF locations for copper LLU. This reduces the collocation effort of wholesale seekers and improves its scales compared to a MDF collocation. The fibre LLU might also be handed over at the metro core locations, and there is no VULA required for fibre.

118 See 4.2.2.2, Explanatory notes on the EC recommendation on relevant product and services markets, SWD(2014) 298, 9. October 2014 no feature mentioned in the Commission's explanations for the wholesale central access market.

4.1.3.1 WCA position in the infrastructure competition value chain

The value chain of competitive telecommunications operations starts with the simple resale of network services of wholesale providers. WCA already requires some own infrastructure in order to handle the traffic of the customers connected by the bitstream service. Behind this point major investments are required to expand the wholesale seekers infrastructure closer to the end-customer locations, over the metro core locations to area PoPs respectively MDF locations for LLU down to the end-customer homes. According to this (theoretical) model a wholesale seeker would deploy its own (broadband) infrastructure down to the end-customers when it has achieved a market position and success that allows for such high investment. The reality and cost models also have shown that the wholesale seekers stop at a point before, relying on wholesale products of access providers instead of rolling down their own infrastructure to the end-customers. This behaviour depends on the population density of an area. The less dense populated, the more expensive the access line per customer, the more likely to address the customers per higher level wholesale products. Studies have shown that except in very dense populated areas the roll out of parallel infrastructures is rarely economically viable[119]. Those investing in new broadband access infrastructure should offer wholesale access in order to increase the penetration of the fixed cost block of access network and thus share the cost[120]. In the Netherlands such approach has been taken by Reggefiber in rolling out its FTTH network.

4.1.3.2 Strength and weaknesses of wholesale central access

As strength can be seen that a WCA bitstream is taken over at a national or at least regional handover point and thus enables a relatively easy market entrance for new competitors. They only have to connect their network to the central handover interconnection points and at once can address the whole national broadband market, at least when the incumbent operator is addressing the national market by its own network. In the Netherlands this is the case[121]. So the access seeker does not need a larger own network infrastructure, but a small backbone network with sufficient capacity

119 Elixmann, D; Ilic, Dragan; Neumann, K.-H.; Plückebaum, T.: The Economics of Next Generation Access; Report published by ECTA, Brüssel, 16. Sept. 2008, Addendum 2009

120 Plückebaum, T.; Jay, S.; Neumann, K.-H.: Benefits and regulatory challenges of VDSL vectoring (and VULA), Florence School of Regulation, Communications Media 2014 Scientific Seminar, March 28 – 29, 2014, Florence, EUI Working Papers RSCAS 2014/ 69, http://fsr.eui.eu/Publications/WORKINGPAPERS/ComsnMedia/2014/WP201469.aspx
Plückebaum, T.: Countrywide Broadband - Parameters for Success, 8th FTTH Conference, FTTH Council Europe, München, 14. - 16. Februar 2012

121 In eastern European countries the fixed network telecommunication infrastructure does not in any case pass all homes.

for its own customers. Migrating closer down to regional handover points allows to benefit from lower prices and makes sense, if the cost for the additional infrastructure are lower than the savings. Typically this occurs at a critical number of end-customers being handed over at the regional point.

Being present at a metro core location also allows to switch the customers aggregated there from wholesale bitstream to VULA access, if the improved features of VULA are important and outweigh the additional cost. The entrant may climb up the ladder of investment region per region (metro core location per metro core location), addressing the remaining regions on a national level by WCA. So using the WCA for the remaining areas at relatively low cost makes it attractive for wholesale seekers even when advanced in their value chain.

From a wholesale providers point of view WCA is attractive because it allows to share the cost of its entire access and aggregation network and to quickly increase the penetration and return of investment in new (broadband) investment areas.

Major weakness of WCA is the relative poor degree of differentiation of the products and services offered to the end-customers by the access seekers. They only can offer me-too like services and cannot get beyond the level the wholesale provider offers for his own customers. If the access provider defines higher level products for his own retail customers it is not said that such quality will also be provided for the wholesale product also. This is often a source of disputes.

A weakness of WCA from a wholesale providers point of view certainly is that it enables competitors the market entrance in total or to regions without major a priori investment, so lowering the barrier of entry. From a regulatory point of view this effect is intended and justified in case of Significant Market Power (SMP) and the access bottleneck situation of an incumbent. A competitive access provider has to outweigh this weakness against its need of additional penetration and income (the strength described above).

4.1.3.3 Wholesale central access in the Netherlands

Wholesale broadband access services can be offered over all access network technologies operating on the layer 3 protocol or below. In the Netherlands KPN offers WBA over all copper and fibre access platforms it uses. It is handed over on the central level at 4 national sites and at the regional level at the 161 metro-core locations, where VULA is handed over too. Almost all[122] wholesale seekers access the WBA service at the central sites. This is not surprising from a national market approach, since general there is no quality difference in the WBA moving the handover closer to the end-customers to the regional sites, but it causes additional costs for a wholesale seeker to

122 [✂]

access the regions which are justified only if its market share is sufficiently large. In the Netherlands the KPN metro-core location WBA differs from the VULA product in its characterics[123] and regarding the underlying access technology. VULA is only based on the copper access lines, while the WBA includes fibre access. Both have common that the handover protocol is using layer 2 Ethernet.

4.2 Hypotheses on the effects of the technological developments on the access options

This section considers the effects of the technological development described in section 3 for the access technologies copper, fibre and coax on the wholesale access options of ULL, virtual unbundled local access (VULA) and Wholesale Central Access (WCA). taking into account the characteristics which have to be met for the wholesale access options as detailed in the section before (section 4.1).

4.2.1 Copper unbundling, xDSL technologies up to G.fast (incl. Vectoring)

The existing copper access lines of the telephone network, which had been constructed on the background of transmitting analogue telephone signals of up to 4 KHz, suffer from restrictions to transmit high bandwidth signals (several MHz) over a longer distance (section 3.1). To overcome this deficit the access network electronics move closer to the end customer, into the cabinets (FTTC) or even further on to the street edge (Fibre to the Street respectively to the Distribution Point, FTTS resp. FTTDP). Doing so would require the wholesale access seekers demanding for LLU, who also want to implement higher bandwidth access lines, to collocate at the same locations accessing the subloop. This typically is economically not feasible. So they have to rely on a VULA product instead. When the incumbent deploys Vectoring technologies in addition to the VDSL and G.fast profiles in order to eliminate crosstalk and further increase the transmission bandwidth and the transmission reach, Vectoring requires one operator to have exclusive access to all copper access lines, thus subloop unbundling is also not possible due to technical reasons.

4.2.1.1 Copper ULL

One can state, that physical unbundling of copper access lines for high bandwidth access services (above the capabilities ADSL 2+ is offering) making use of the technological development described in section 3.1 is not feasible for economic reasons, and with Vectoring for technical reasons also. Nevertheless, until the copper

123 i.e. own multicast channels, premium VLAN for telephony, SLA for business lines, premium lines, etc., see also section 4.1.2.5

access lines have been exchanged by fibre (FTTB/H) access lines they keep their importance at least for KPN and those wholesale access seekers relying on the copper technology for accessing the end customers, but not as physical unbundled local access infrastructure, but as an active unbundled access option on a higher level.

4.2.1.2 Copper VULA

A VULA offer based on FTTC can replace physical unbundling of copper access lines within market 3a. It has therefore to meet the criteria set out in section 4.1.2. [✂][124]. Even when proceeding beyond this technological level by deploying G.fast or even XG.fast the last copper meters are relevant for getting access to the end customers, and a VULA product will have to be provided for the wholesale access seekers. The VULA will benefit from the bandwidth increase of the access lines due to the technological improvements.

4.2.1.3 Copper WCA

All the access technologies used on copper lines today and in the foreseeable future up to 2025 (FTTC, FTTS/dp with VDSL2 Profile 17a, 35a or b, G.fast or even XG.fast)) can be also used to provide a bitstream as wholesale central access at regional or central sites. The bitstream will benefit from the higher bandwidth capabilities of the access lines, thus the access seekers will benefit also. Higher bandwidth typically will improve the wholesale and retail product qualities regarding latency, jitter, and packet loss. This will be expected for VULA and WCA in the future years, if the wholesale access products will not be offered in a discriminated manner.

4.2.2 Fibre unbundling

Fibre access network infrastructure like FTTH is ideal future proof because it allows to transmit Tbps bandwidth on a single fibre strand[125]. So it is the ideal future infrastructure in access networks if deployed in the right manner.

4.2.2.1 Fibre ULL

In its point-to-point topology fibre is ideal to be physically unbundled. So each end customer will neither be affected by the traffic the neighbours are transmitting, nor by

124 Interview with KPN during this study

125 While 40 Gbps per wavelength is state of the art and 100 Gbps becomes state of the art soon, there are Dense Wavelength Division Multiplex (DWDM) systems transmitting more than 160 parallel wavelength (light of different colours) over a single fibre strand.

the line protocol used by them, as it is with copper. Fibre is simply insensitive for electromagnetic interference. It also can offer a significantly longer reach for the access lines than copper pairs can do, so that access to the (unbundled) fibre lines can be offered at more central sites like the city PoPs or even the metro core locations. This makes the physical unbundled access to fibre lines even more economically attractive than the unbundled access to copper lines. A significantly lower number of handover points would have to be accessed by a wholesale seeker if access to fibre would be generally granted at the 161 metro core locations instead of the (no longer possible) physical unbundling of the copper lines at [✂] MDF locations.

Any future fibre transmission technology, also those of the xGPON family, can be used on such fibre topology platform[126].

4.2.2.2 Fibre VULA

In a point-to-multipoint topology this capability of fibre unbundling gets lost because unbundling at locations close to the end-customer (at the last splitter) is economically not feasible. This could be overcome by also mandating a fibre VULA[127]. Because the GPON technology family experienced significant progress regarding its capabilities (see section 3.2, NG-PON2 respectively TWDM-PON) in the recent years now a multiple of standardised wavelength are defined which allows for wavelength unbundling, which already had been foreseen in the explanatory notes of the EC market definition of 2014. In such cases instead of a VULA wavelength unbundling shall be mandated. However, this restricts the wholesale products for the next future (2022) to the capabilities of a XGS.PON system with its shared bandwidth and the resulting constraints compared to real unbundled fibre access.

So far PtMP fibre topologies are not deployed in the Netherlands, so this considerations may only become relevant in the future if KPN decides to continue its FTTH roll-out instead of PtP in a PtMP topology.

4.2.2.3 Fibre WCA

Based on any FTTH access network higher level wholesale access products can be provided without any constraints. Thus there exists a fibre access line based Wholesale Bitstream Access (WCA) product already today, handed over at the 161 metro core or at least one of the 4 national node locations. Its coverage may be expanded to all those areas being deployed by FTTH in future. [✂]

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126 S. Jay, K-H. Neumann, T. Plückebaum, “Comparing FTTH access networks based on P2P and PMP fibre topologies”, Journal on Telecommunications Policy (JTPO), 8. Juli 2013

127 See Austria vULL

[✂][128].

4.2.3 Coaxial cables and DOCSIS 3.0 and 3.1 transmission technologies

4.2.3.1 Unbundling

Compared to a telephone copper pair access line a coaxial cable is significantly better suited to transmit high frequency signals. Today's state of the art for the cable itself is more than 2.5 GHz, while the existing DOCSIS 3.0 networks just make use of up to approximately 900 MHz, DOCSIS 3.1 will use in a first step 1.2 GHz and finally a range up to 1.7 GHz (see section 3.3). The coax network typically is a "bus" network topology, where one single cable transmitting the signal is branched out at different access points to many end-customers, so that all of them receive the same signal. This ideally suits for TV-signal or other broadcast signal distribution. Amplifiers reinforce the signal enabling to bridge longer distances (up to 160 km with several amplifiers)[129]. These facts reason and describe why the coax cable networks in any case are a shared transmission medium, and why physical unbundling of the coax cable is not feasible at all. In theory there is an option to unbundle the last meters of the coax segment, the individual cables from the last coax distributor (multi tap) to the single homes (single dwellings). Such multi taps aggregate some homes (less than 10[130]) onto one upstream coax cable. Unbundling at this level is not economically viable, since these points are deeper in the access network structure than the street cabinets of a copper network. It would require another DOCSIS provider accessing the last coax segement, but cannot be used by non-DOCSIS operators.

Of course there may be options to use spare ducts and even dark fibre of cable-TV networks, if they exist at all. When rolling out fibre closer to the end-customer in case of fibre node splitting or RFoG and if spare capacity is available these may be used in an unbundled manner. There is no market dominance regulation required for it, because requests for access could already be justified by the national implementation of the EC Cost reduction Directive[131] and have to be met accordingly. Access to frequencies of the DOCSIS spectrum and access to amplifiers or the CMTS as sometimes discussed are not unbundling of a passive network infrastructure, but below the level of

128 Interview with KPN during this study
129 There are also star topologies where at least each home is connected to a star point (amplifier or fibre node) individually. But since the coax cables have a significantly higher diameter than a twisted copper pair there are soon space restrictions for such topologies, besides the significantly higher cost per cable.
130 WIK reasonable assumption
131 EC Directive 2014/61/EU of 15. May 2014

cooperation on the level of stacked telecommunication protocols at layer 1[132]. Nevertheless WIK studies show these to be no reasonable options[133]. “The direct amplifier or frequency access can be supported by the network infrastructure equipment, but has a high degree of complexity and manual operational work and coordination and is error-prone, so should be excluded from a general wholesale approach. In addition, it also reduces bandwidth for the wholesale operator, thus remains an option only if there is a lack of traffic load in the network.”[134] This even is true when considering the larger frequency and thus bandwidth space of DOCSIS 3.1, as pointed out in these studies also. When taking into account that the frequency and resulting bandwidth scarcity of the upstream path compared to the downstream path is overcome with Full Duplex DOCSIS 3.1 respectively the XG-Cable approach nevertheless the other complexities of these approaches still hold and from WIK’s point of view the probability of cable-TV network operators voluntarily choosing one of these approaches is quite low, and the probability of wholesale access seekers going for such approaches is even less likely. One can assume that a Full Duplex DOCSIS 3.1 network in the Netherlands will not be available before the end of the consideration period of this study (2025), because it will require not only complete migration of the DOCSIS network to 3.1, but also the market availability of Full Duplex or XG-Cable equipment and its successful roll-out, requiring an fibre access topology deeper into the network than the deep fibre topology described in Figure 3-13, approaching a RFoG type of access structure (FTTLA). One can assume that the access seekers prefer the established and standardized approaches for wholesale access in form of VULA or WBA/ WCA instead. So we conclude that there will not be any unbundling-like approach with coax-cable based networks in the period considered.

4.2.3.2 Coax networks with DOCSIS 3.0/3.1 and VULA

Based on the metric defined in section 4.1.2.4 the following sections analyse if and to what extent the DOCSIS 3.0. and 3.1 systems meet the most important characteristics of a VULA[135], which are

- Local handover
- Layer 2 protocol (service-agnostic transmission)

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132 Here we refer to the Open System Interconnection (OSI) protocol stack, where layer 1 is the physical layer protocol, layer 2 the link layer protocol (Today typically Ethernet) and layer 3 the network protocol (today typically the IP (internet) protocol.

133 T. Plückebaum, H. Kohl, M. Muckhoff, „Technical feasibility of providing wholesale access over a cable TV infrastructure”, study for ComReg, Bad Honnef, February 2016
T. Plückebaum, H. Kohl, M. Muckhoff, „Options of wholesale access to Cable-TV networks with focus on VULA – Summary and additional questions”, Study for ACM, 5. February 2015

134 T. Plückebaum, H. Kohl, M. Muckhoff, „Technical feasibility of providing wholesale access over a cable TV infrastructure”, study for ComReg, Bad Honnef, February 2016, p. 25

135 T. Plückebaum, H. Kohl, M. Muckhoff, „Technical feasibility of providing wholesale access over a cable TV infrastructure”, study for ComReg, Bad Honnef, February 2016

- Multicast support
- Bandwidth control
- Free CPE choice
- Access link state control
- Process control (related to service management)

4.2.3.2.1 Local handover

Local access, as understood by the European Commission, is one of the key characteristics for Market 3a products. It typically includes traffic handover at MDF or street cabinet level. The latter requires direct line access, which implies spectrum sharing on cable networks at an amplifier level as stated above. For this reason, local access on cable networks is economically/operationally feasible only at the MDF level, where the RF signals of radio and TV programs and data communication (from the CMTS) get assembled (combined) in order to be forwarded on the fibre to the fibre node. The CMTS in principle is the appropriate point to access a data communication connection to an end-customer within a CATV network. This is typically located on a local level[136].

The CMTS as defined in DOCSIS operates on an IP level. All of the cable operator's equipment is thus IP-based at the side connected to the core network. The IP protocol is typically used for bitstream services, so bitstream could also be offered at a local handover. As an exception outside the DOCSIS standard, Layer 2 access (as recommended by the EC for VULA environments) is also technically feasible, but only under the circumstances described in the next section.

4.2.3.2.2 Layer 2 protocol (service-agnostic transmission)

The second characteristic set out by the EC states that access has to be generic and has to provide a service-agnostic transmission capacity which is uncontended in practice. This is typically realised by Layer 2 access between the access-seekers and their customers. The aspect of uncontended bandwidth mentioned in the second characteristic is dealt with in section 4.2.3.2.4.

However, as stated in the DOCSIS standard, a CMTS only has to provide an IP-based (Layer-3) service. The CMTS hardware may optionally provide Layer 2 services on a voluntary basis, if it supports the additional Business Services over DOCSIS

136 The new VodafoneZiggo network in the Netherlands, covering approximately 90% of the homes, [✂].

(L2VPN/BSoD) standard[137]. Thus, not all CMTSs support these features[138].

[✂][139]. [✂]

According to this voluntary standard, each access-seeking provider gets its own Layer 2 Virtual Private Network (L2VPN)[140] within a DOCSIS-based network segment. Such a VPN is a network encapsulated in a more general network, which is protected against unauthorized access. All L2VPNs then represent VPN segments within the physical segment behind a fibre node on the coaxial cable segment. They only communicate in the DOCSIS data communication upstream and downstream channels and do not have access to the radio and TV frequency bands. Technically, this is either realised by an additional addressing feature called MPLS pseudowire switching (which is less well supported) or via 802.1q VLAN tagging, a well-known Layer 2 Ethernet protocol feature which is supported by a wide range of standard network equipment. The following figure shows the widely used VLAN tagging approach.

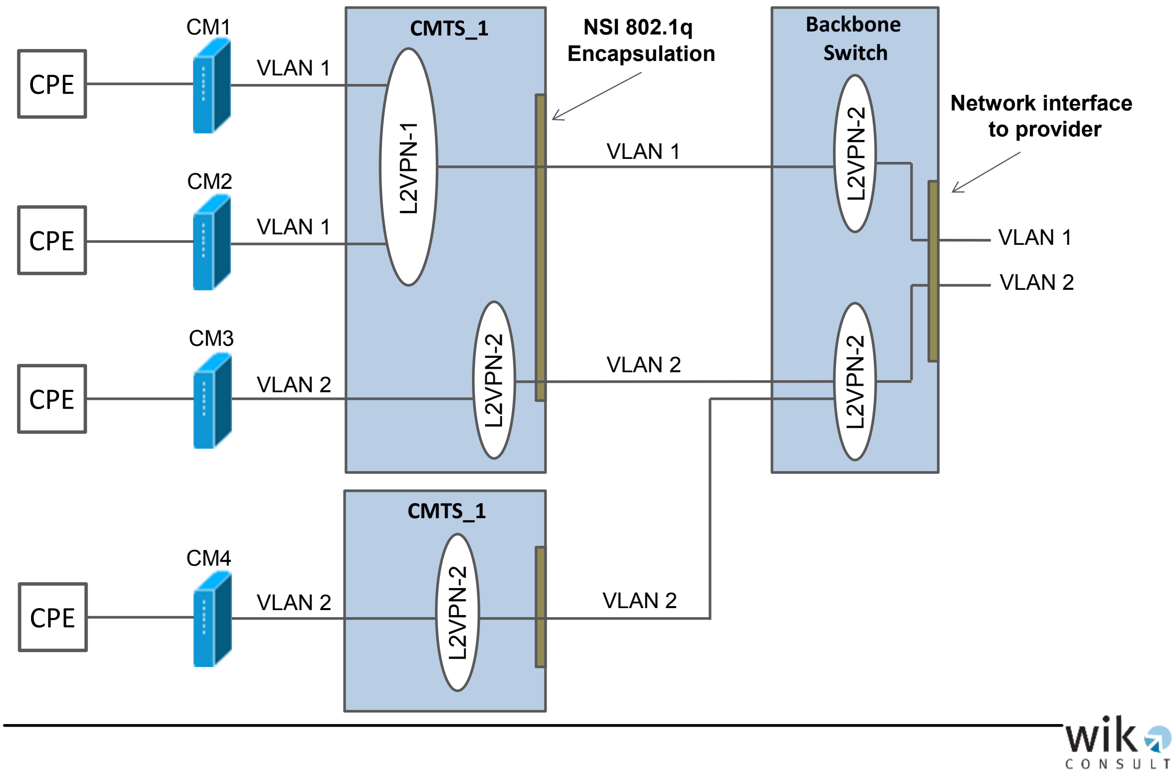
137 BSOD reserves symmetrical bandwidth per customer connected, which cannot be overbooked by other customers, and by this meets business customer demand; but it can also be used for residential customers, i.e. in a VULA-like environment. Due to the bandwidth revervation it reduces the bandwidth remaining for the other customers in an upstream or downstream path, thus could be used for only a few customers. It is neither suited for serving a mass market nor for a wholesale business product.

138 An upgade may be implemented by exchanging the CMTS software or the total CMTS, depending on its capabilities. Implementing such service would also require amending the OSS and BSS platforms of the operator. This major effort typically will not be taken by the cable-operators. One can assume that their strategy for the business market is serving the lower and medium segment of business customers (SME) by its mass market high end broadband products instead.

139 [✂]

140 L2VPN is a methodology where several user networks are transported in the same data stream but separated underneath each other by additional address information, identifying which VPN a data frame belongs to. In the Ethernet (Layer 2) protocol, “tags” are used in the standard protocol header. With multiprotocol label switching, labels are inserted between the Ethernet protocol frame and the IP header to uniquely identify each VPN. Both methods are standardised.

Figure 4-1: Different VLANs for L2VPN / BSoD



Source: BSA-Concept CATV network, NGA Forum Germany, WG Interoperability, WIK

In the example of Figure 4-1, a single provider wants to operate two different VLANs for its end-customers connected to two coaxial cable segments controlled by two CMTSs. The example therefore shows two different L2VPNs (L2VPN-1/VLAN1 and L2VPN-2/VLAN2) from the same provider spread over two CMTSs. Both CMTSs are connected to a backbone switch which provides interfaces to the different provider network gateways, thus also to the provider of the example (Figure 4-2 only shows the backbone switch interface of one provider, but several providers' interfaces can exist in parallel, all accessing separate VLAN structures such as those demonstrated here, in parallel (for simplicity, only one is drawn in the figure)). An upstream packet from cable modem CM3 arriving at CMTS 1 gets tagged with VLAN ID 2 and is then sent to the backbone switch. The backbone switch then decides based on the MAC address[141] if the packet should be forwarded to CMTS 2 (if this is allowed) or to the provider's gateway. In the downstream direction, the VLAN tagging is set by the provider before entering the backbone switch and gets removed at the CMTS level.

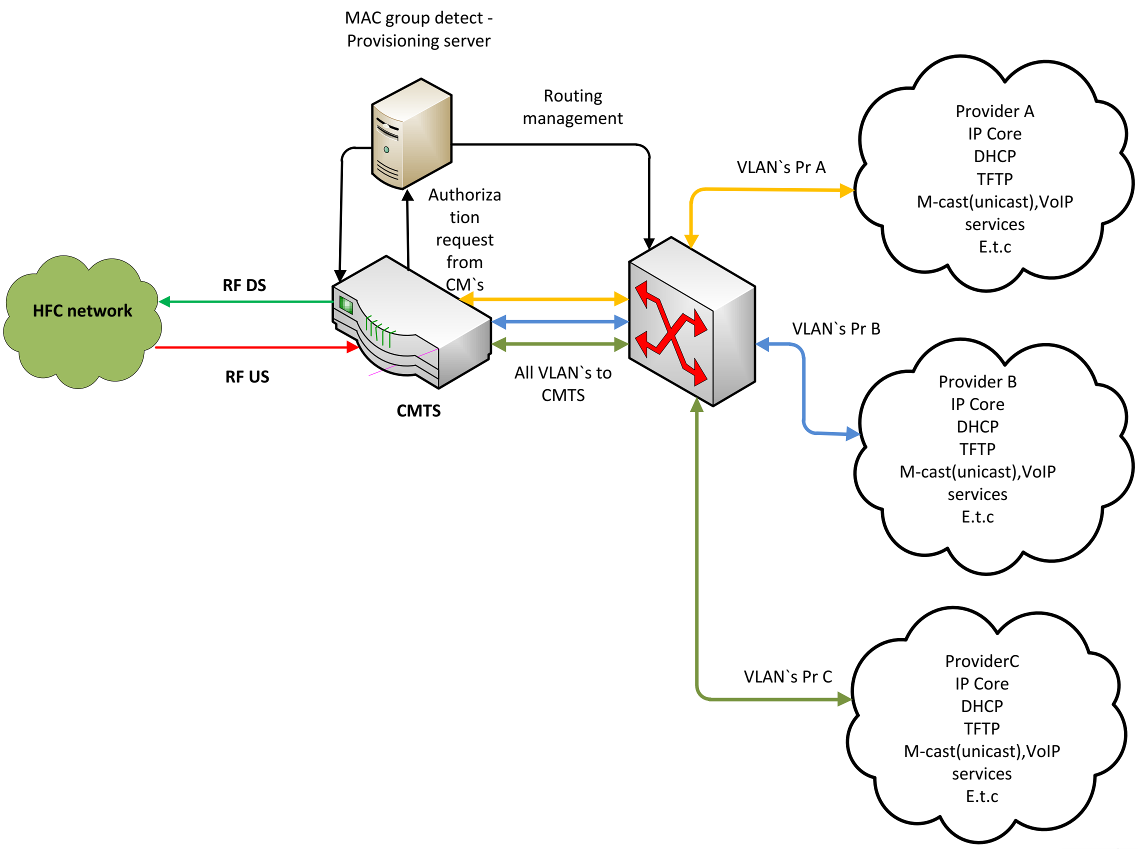
Furthermore, it is possible to connect company networks which internally use VLAN tagging within these L2VPN services. The already internally tagged packet reaching the

141 The Media Access Control (MAC) address is the Layer 2 address of the network nodes communicating in the Ethernet. It is globally unique.

CMTS gets tagged a second time. The technique is called double tagging, providing encapsulation of a customer packet (C-VLAN tag) within a service provider packet (S-VLAN tag). This double tagging allows for private customer (typically business customer) VLANs inside each of the provider's VLANs, thus supporting protocol transparency.

In normal (non-company) setups, all customer modems belonging to a single provider are assigned to a corresponding L2VPN, which consists of a logical group of one or more frequency channels within the RF spectrum called MAC Domain. One could imagine such a group as one big communication channel spread across all network segments. The wholesale network operator provides this provisioning procedure as a service for the access-seekers. A core switch/router behind the CMTS distributes the traffic coming from the different virtual network segments to the assigned provider gateways and vice versa. Figure 4-2 shows an example L2VPN setup.

Figure 4-2: L2VPN switching



Source: ContaQ

The example above demonstrates the main disadvantage of the BSoD/L2VPN solution. Each provider's MAC domain (consisting of one or more L2VPNs) is built on a unique set of frequency channels splitting the downstream and especially the more scarce upstream bandwidth into fixed slices. If one assumes an equal distribution of the channel capacity for three operators on the network, each provider gets 120 Mbps/ 3 = 40 Mbps upstream bandwidth in the DOCSIS 3.0 example of Figure 3-12 above, which is insufficient capacity to run three network operator businesses in a competitive environment.[142] Not only is the transmission volume restricted, but the peak bandwidth is too. Other capacity distributions can be realised, but they cannot overcome the restriction that the sum of all upstream bandwidth is limited to 120 (max. 240) Mbps.

For DOCSIS 3.1 this problem continues to exist in an analogue manner, but on the larger up- and downstream capacities. Since capacity upgrades typically are implemented along the end-customer demand one can assume that there will not exist sufficient spare capacity on a regional or national scope for a wholesale business at all. If an operator would decide for expanding its network capacity and OSS and BSS systems for a wholesale offer, one can assume that it would first of all cover a less complicated WCA service before it would go down to a VULA service with guaranteed bandwidth in order to approach the product definition freedom of an LLU-like service in a volunteer manner.

IP instead of L2 interface?

The discussion above shows that DOCSIS typically operates on the IP-Protocol layer, while the Protocol agnostic VULA requirement results in a layer 2 protocoll, the Ethernet protocoll. One could wonder, why Ethernet is preferred against IP?

The tasks for communicating between electronic systems are complex. The procedures and signals used are called communication protocol. In order to enable the combination of different technologies, technological improvements and usability for a wide range of applications within one connecting network the protocols are structured into layers of dedicated functions, which complement each other. Some decades ago the International Standards Organisation (ISO) defined a communication protocol reference model for Open System Interconnection (OSI) which still is valid and used today. It includes seven layers and the infrastructure (Figure 4-3).

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142 Even with the theoretical maximum of eight channels of 30 Mbps each (see footnote 62), 80 Mbps per operator would remain, meaning the capacity and peak bandwidth are still constrained, making the system poor for capacity-guaranteed bandwidth for several customers at a time.

Figure 4-3: OSI seven layer reference model of communication protocols

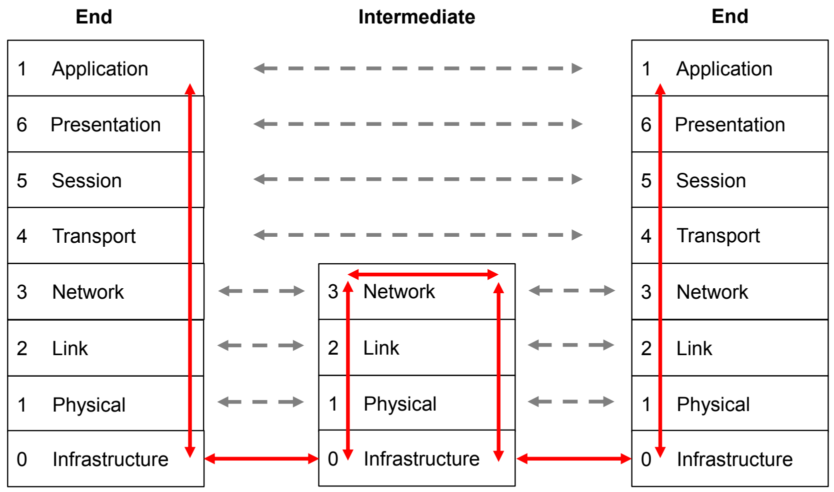
End-System

1 Application:	The software to be used by end users
6 Presentation:	Agrees and operates how to stucture data during exchange
5 Session:	Controls the exchange of data between Applications
4 Transport:	Controls the exchange of data between end-systems, loss of data
3 Network:	Transports and switches data over intermediate systems to end nodes
2 Link:	Logical control of data flow and media access between neighboring nodes
1 Physical:	determines electrical and/ or optical signal access to the transmission medium
0 Infrastructure:	Passive physical infrastructure (copper/ fibre strand, cable, duct, trench)

Source: WIK

One important layer is the network layer, numbered as layer 3. Almost all of today's networks have been migrated towards IP (Internet Protocol). The network protocol organises the end-to-end communication in the wide area network (WAN) over many network nodes – not only within a country but also internationally (Figure 4-4). Due to its mass market acceptance the layer below (Layer 2) is implemented today almost everywhere as the Ethernet Protocol. Ethernet protocol was originally been designed for Local Area Networks (LAN). However, its application was later expanded to become a general link layer protocol. It is the last layer above the link specific and technology dependant transmission protocols and electro-physical line signal protocol level (Layer 1). The different infrastructures were not included in the original ISO model, but we show them below under the title layer 0.

Figure 4-4: OSI communication interworking, layer per layer or peer-to-peer



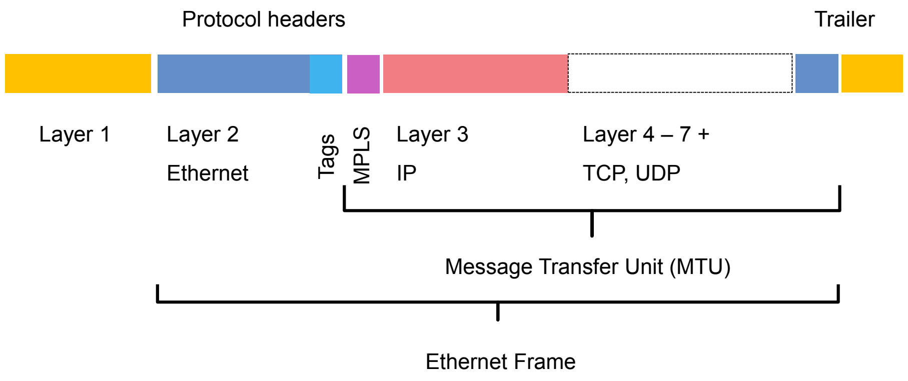
Source: WIK

Each layer could be considered to be like an envelope which contains information which can only be interpreted through the protocol layer software to which it belongs. These envelopes are also called packets (layer 3) or frames (layer 2). The telecommunication protocols work in a hierarchical manner. The envelope (frame) for the Ethernet protocol (Layer 2) is enclosed by layer 1 and itself encloses layer 3, which also includes the upper layer envelopes.

In principle nobody is looking into the other layer envelopes. Sometimes, there is a need to include additional information on how to handle frames or packets in the protocol. This is the case when an operator wishes to establish and 'address' (apply tags to) additional virtual LAN (VLAN) and when offering MPLS[143] (Figure 4-5). Because such additional information should not reduce the transport space for higher level information (i.e. should not reduce the size of the envelope, or cause significant changes in the software and systems of the layer above) larger Ethernet frames are required.

143 MultiProtocol Label Switching, a methodology for predefining network pathes in a WAN by adding address labels for the pathes in front of the frames or packets.

Figure 4-5: Protocol enveloping of Layer1 – 3 and additional Layer 2/3 address functions (VLAN tagging and MPLS)

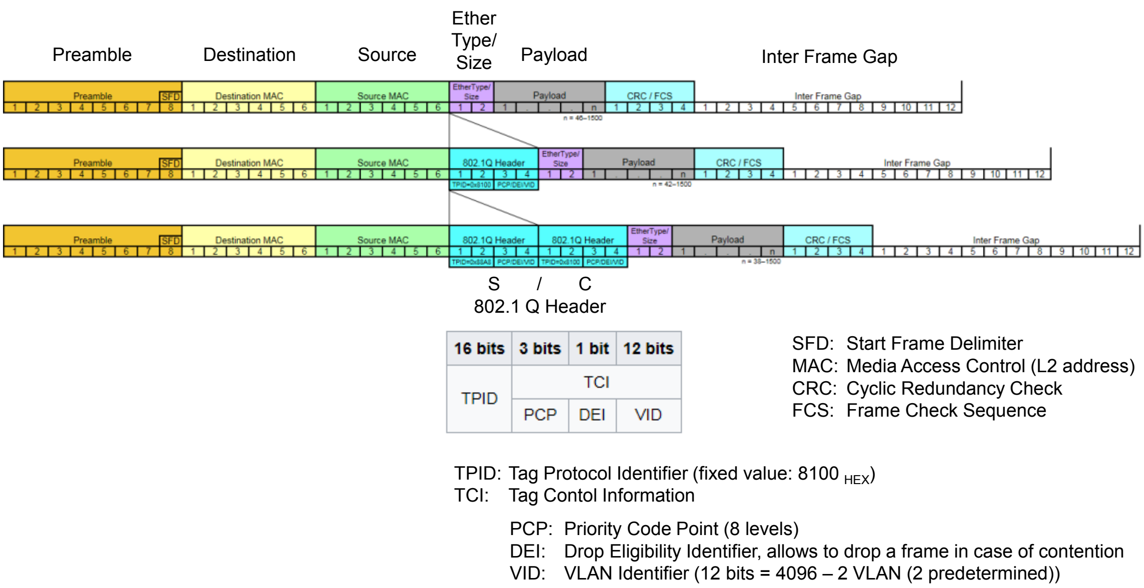


Source: WIK

Figure 4-6 describes the double tagged Ethernet frame as it is demanded for in the VULA environment. It offers two address spaces for VLAN, each of 12 bits. The outer (first) one is called S-tag, the inner C-tag. In case of wholesale access typically the outer is used by the access provider, the inner by the access seeker. Because both parties operate on layer 2 they in principle could agree upon a different use of the address space. While the standardized MTU size of Ethernet is 1500 bytes, the option of using a larger size gives additional flexibility to design the communication product on a layer 2 level. Common predefined uses include double VLAN tagging and MPLS VPN (Virtual Private Networks – used for secure links for business). Additional address space would leave room for future creativity, i.e. for MPLS extensions, larger labels or stacked labels, additional L2 VLAN tags for business customer products or new residential end-customer products, etc.. While, in an LLU environment each operator could decide itself on the setting the MTU size, subject only to the limitations of its equipment, this parameter is controlled by the access provider in the case of active access products such as VULA.

The protocol header in Figure 4-6 describes also the tool for immediate quality control in the protocol header, the PCP. So the layer 2 protocol ist the protocol which immediately influences the link transmission. It is the first “envelope” independant from the link technology. This reasons why the layer 2 protocol is ideally suited for wholesale access over a link, while IP is the more distant protocol with a wider international address space and well suited for central handover. An overview over the different characteristics with regard to wholesale and the capability to control the transmission quality by the wholesale seeker is given in Table 4-1.

Figure 4-6: Double-tagged Ethernet frame structure



Source: Wikipedia, WIK

Table 4-1: Ethernet or IP handover protocol

Protocol / Criterion	Ethernet (Layer 2)	IP (Layer 3)
Quality control	direct	less direct
Transmission quality (delay, jitter, loss)	good	less good
Wholesale operator stack in stack VLAN tagging	direct	less direct
Larger protocol header	yes	no
Protocol overhead	lower	larger
Adress space	limited (VLAN)	internationally unique
Product definition freedom	higher	lower

Source: WIK

4.2.3.2.3 Multicast support

Streaming digital audio and video content is one of the major tasks for provider networks. A huge part of the downstream bandwidth and an increasing part of the upstream bandwidth gets consumed by all kinds of streamed media content.

That said, today's cable networks deliver a range of media streams (TV, radio, VoD[144], etc.) over different types of access technologies. Besides classic analogue TV, digital TV and VoD streams, which are delivered via DVB-C channels (Digital Video Broadcasting – Cable, outside the DOCSIS frequency spectrum), a rapidly increasing part of the media stream is IP-based and thus gets transported inside the DOCSIS spectrum.

While some of these streams are completely asynchronous from others (e.g. individually downloaded on demand like VoD or time-shift viewing), most of them still belong to the linear TV/radio category, so one stream serves all customers at the same time. This special form of (synchronous) streaming is called Broadcast, or if restricted to a subset of all end-customers connected it is called Multicast. Multicast saves transmission capacity compared to individually streaming the TV-channels down to any customer in parallel[145]. The increasing demand for asynchronous streams causes capacity problems: if no further action is taken, a huge amount of individual copies streamed at the same time will consume a big share of the available bandwidth on their way downstream to the customer. To avoid this waste of bandwidth, cable networks support different types of multicast functionality.

Considering classic linear TV and radio services, a simple but effective multicast mechanism has been included in the CATV networks since the beginning: the standard channel bouquet. These channels could be provided by the access provider on a reselling basis.[146] Today, the standard channel bouquet is extended by IP Over The Top (OTT) services consuming bandwidth inside the DOCSIS (IP) spectrum. To address this increasing bandwidth consumption, some efficiency-improving multicast functionality was added to the DOCSIS standard. Internet Group Management Protocol

144 Video on Demand (VoD)

145 Streaming is a general name for transmitting a continuous datat stream over a longer period of time, like video and audio signals. It could be bidirectional, i.e. for bilateral conferences. A subset of streaming ist broadcasting or multicasting. Broadcast transmits an information to all customers connected to a network, multicast restricts it to a subset of customers. A well known example is the free TV radio emission. Applying set-top boxes for the reception reduces the broadcast to a multicast. Under Linear-TV one understands the broadcasting or multicasting of TV in realtime without intermediate recorders, typically also without more complex interaction.

146 The access provider could also add some individual downstream radio/TV channels for operators' individual offers, besides the standard program bundle (bouquet). Including all TV channels in the IP downstream link at a fast speed would exceed its capacity (i.e. 150 SD channels with 3 Mbps each equals 450 Mbps, exceeding 400 Mbps downstream capacity of today's typical DOCSIS 3.0 implementations. For DOCSIS 3.1 one cannot expect the same constraints, but even there assuming an increase in TV-channels and the existence of several wholesale operators the downstream capacity may become scarce).

(IGMP) v2 snooping was the first feature introduced in DOCSIS 1.1. This has been extended by the DOCSIS 3.0 Multicast DSID (Data Set Identification) forwarding feature which supports several IPv4 and IPv6 multicast protocols (IGMPv2, IGMPv3, MLDv1 (Multicast Listener Discovery), MLDv2). All these protocols allow optimisation and restriction of the multicast downstream transmission capacity to only those channels being requested by the IPTV end-customers at a time. The other (not requested) channels are not transmitted, but will be included in the stream, when selected. Additionally, multicast Quality of Service (QoS) features have been added to ensure that video streams achieve the desired quality.

Thus, besides the option to resell the standard program bouquet, additional programs can be provided in the DOCSIS data channels, optimising the capacity consumption using dedicated protocols restricting the downstream to those requested channels. An efficient IPTV wholesale business is therefore a combination of standard program resale and special program wholesale bitstream.

According to the DOCSIS standard, these features are only available via the IPv4 and IPv6 forwarding engine. Packets routed through the L2VPN forwarding engine do not benefit from these features. To support multicast features on the Layer 2 level, access-seekers have to manage multicast traffic inside their virtual network for themselves or they have to separate their multicast traffic from their virtual network and deliver it via a downstream service flow shared between the wholesale provider and the access-seeker(s), i.e. as shown with the standard channel bouquet above.

Thus, there is no option for Layer 2 VULA multicast support within a CATV network infrastructure today or in the foreseeable future (with DOCSIS 3.0 and 3.1).

Typically Multicast support (Multicast frame replication) is the more important for efficient wholesale network operation the more wholesale customers are aggregated beyond the wholesale access point. Multicast frame replication allows to send a TV-channel once over the handover interface and it is replicated to all customers who want to watch it. This saves bandwidth on the handover interface and the downstream channel. The effect gets the larger, the larger the number of customers watching the same channel in parallel. If not supported each end customer would require an individual stream, at the same time and with the same content. Considering the CMTS location and the number of customers aggregated the support of Multicast should be relevant, but a significant bandwidth saving effect may already be achievable with a resale approach for the standard channel bouquet. In fact Multicast even for the additional channels cannot be supported by L2VPN, so at least in a formal manner is not completely in line with the VULA expectations, independent from the DOCSIS release.

4.2.3.2.4 Bandwidth control

Having sufficient control over the bandwidth within the cable spectrum is one of the key criteria set out by the EC for VULA-type products to be included in Market 3a. It needs to be uncontended in practice and provide guaranteed bandwidth.

DOCSIS historically started as a best-effort service using a data request-grant methodology (fixed bandwidth capacity allocation per user in the upstream). This concept changed with the introduction of service flows in DOCSIS 1.1, giving access to upstream capacity for the end-customers:

- Unsolicited Grant Service (UGS)
  A fixed number of timeslots is periodically reserved for a single modem
- Real-Time Polling Service (rtPS)
  Similar to UGS, but the modem must ask for the reservation, otherwise the timeslot is free to use for other modems
- Unsolicited Grant Service with Activity Detection (UGS-AD)
  A combination of UGS and rtPS, switching from UGS to rtPS and back due to missing activity/reactivation
- Non-Real-Time Polling Service (nrtPS)
  Guarantees a transmission even if the network is congested
- Best-Effort Service (BE)
  Modem and CMTS simply do their best to send the data when possible

Most of the methods (access protocols) were designed with VoIP as the use case in mind, providing a fixed number of timeslots for sending data upstream and thus guaranteeing a constant bit rate and capacity (relevant for voice transmission at a dedicated quality).

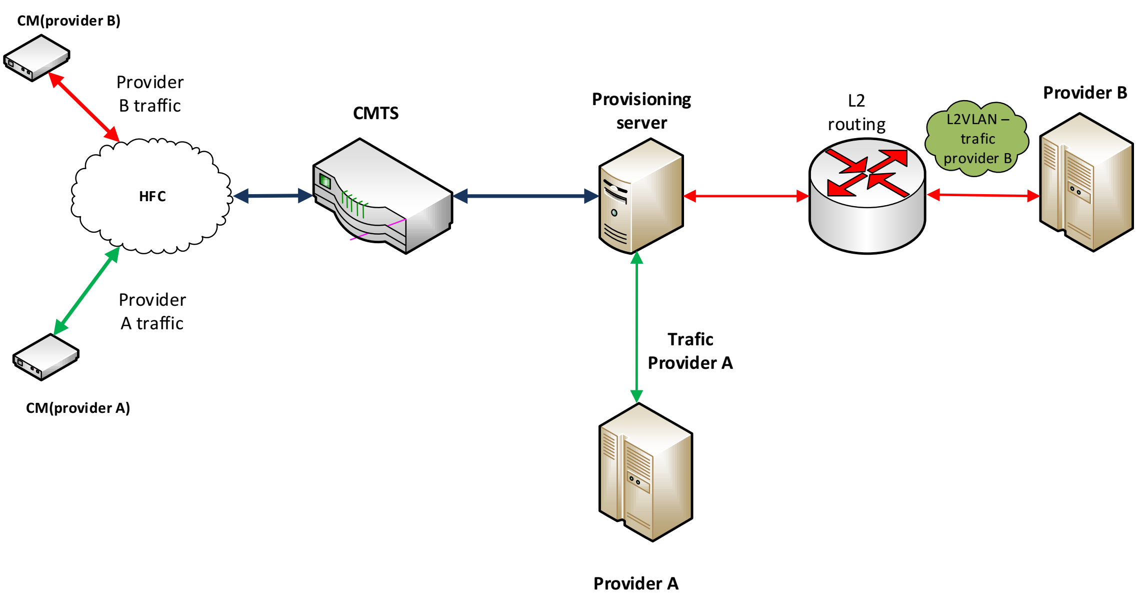
With the concept of service flows, one is able to get a guaranteed bandwidth for different types of traffic. However, this does not necessarily include a multi-tenant separation of provider networks. To achieve service-agnostic transmission capacity, the “collision domains” of the different providers have to be separated from each other. This could be achieved using the concept of MAC Domains[147] for the upstream and downstream direction, which is supported in DOCSIS 3.0 and 3.1. Each provider (wholesale provider and access-seeker) gets its own MAC Domain for each fibre node. All upstream and downstream channels exclusively assigned to such a MAC Domain then provide a guaranteed per provider bandwidth within the network segment.

147 A DOCSIS MAC Domain is a logical unit managing a set of upstream and downstream channels. A CM is registered to only a single MAC Domain. Technically these MAC Domains are represented by MAC Domain CM service groups for the different fibre nodes. See DOCSIS 3.0 section 5.2.7, CM-SP-MULPIv3.0-I29-151210 for further details.

For the access-seeking providers, the backbone switch and the provisioning system of the wholesale provider represent the “interface” to their customers behind the CMTS. The switch hosts the PoI (Point of Interconnection) ports where the traffic is transferred between the networks, and the provisioning system hosts the interface to the intercarrier process gateway. Although these interfaces could be seen as a service-agnostic wholesale access solution, it is restricted to IP-based traffic and do not support Layer 2 services, as demanded by the EC VULA definition. (Layer 2 services are not guaranteed by the DOCSIS standard).

A virtual wholesale access product providing a generic solution, as demanded by the EC, is typically understood as Layer 2 access for the access-seekers. Thus, the concept of MAC domain service groups is clearly outperformed by the L2VPN/BSoD solution regarding the completeness of the feature set. The following figure shows an example setup.

Figure 4-7: Multiprovider solution



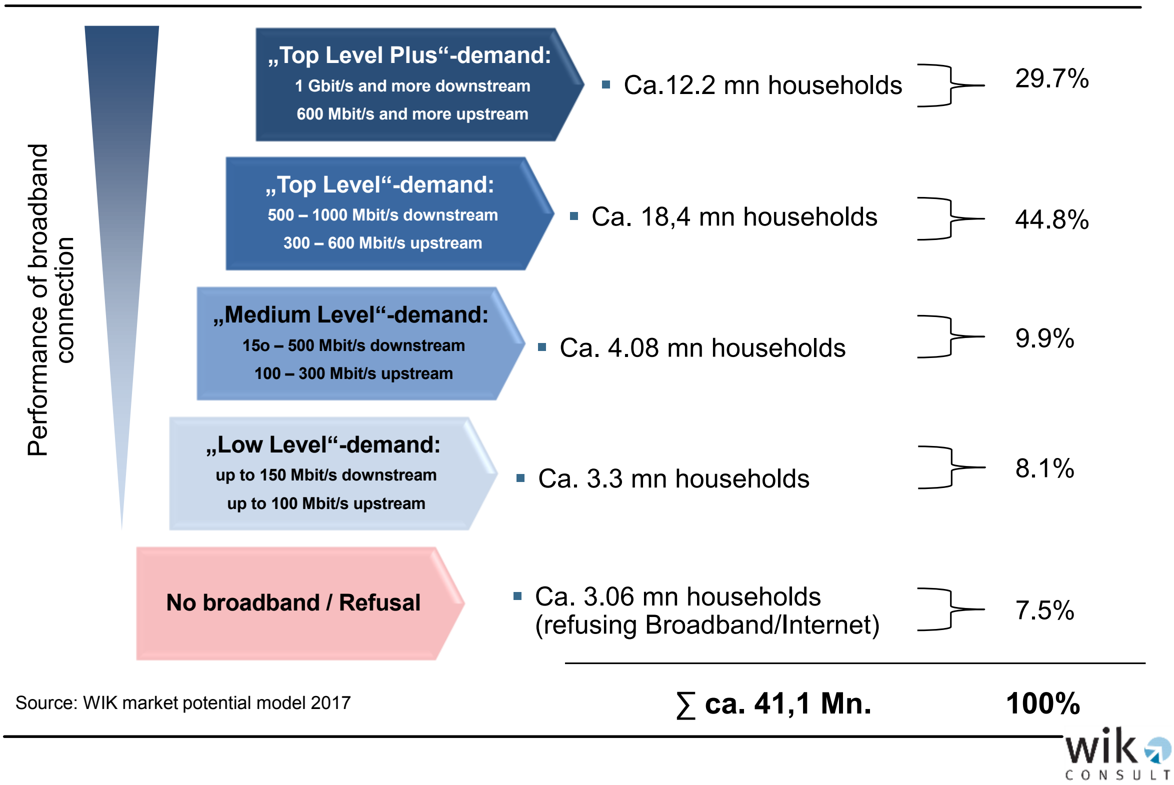
Source: ContaQ

In this setup, the wholesale provider (Provider A) is able to directly connect its hardware whereas the access-seeking provider (Provider B) is connected via an intermediate L2 switch.

The bottleneck in the upstream channel will soon be totally consumed by both of these methods if uncontended upstream capacity is provided. A demand of nine symmetrical connections of 10 Mbps uncontended already exceeds the upstream capacity typically available in DOCSIS 3.0. But even in DOCSIS 3.1 scarcity occurs with 10 x 100 Mbps uncontended access channels, and even in the Full Duplex Environment the CMTS nodes should not serve several 1 Gbps upstream channels for customers[148].

Figure 4-8 summarizes the results of a study WIK recently conducted/ updated for the demand in Germany for the year 2025[149]. This is based on the assumption that there are no real bandwidth constraints in the network access. One can assume that the situation in the Netherlands will be similar, whereas the available infrastructure in the Netherlands (FTTH 30%, cable-TV close to 100%) offers significantly higher performance (which is not relevant for the demand forecast approach chosen).

Figure 4-8: Demand forecast for Germany in 2025



Source: see footnote 148

WIK expects that the bandwidth scarcity for DOCSIS even with release 3.1 and Full Duplex in case of wholesale business besides serving the own retail customers will hold on for the years coming (2025 and beyond).

148 One can expect bandwidth demand increase within the coming years, and all such considerations depend on such forecasts. For a bandwidth demand prognosis see S. Strube Martins, C. Wernick, T. Plückebaum, I. Henseler-Unger, "Die Privatkundennachfrage nach hochbitratigem Breitbandinternet im Jahr 2025", Bad Honnef, März 2017, http://www.wik.org/fileadmin/Studien/2017/Die_Privatkundennachfrage_nach_hochbitratigem_Breitbandinternet_im_Jahr_2025_FINAL.pdf

149 See footnote 148

4.2.3.2.5 Free CPE choice

Although cable networks are built on a bundle of different technologies, each of them is well documented and standardised. TV, radio and VoD channels are built on the DVB-C (or DVB-T) standard and internet-based services as well as VoIP services are based on DOCSIS. In such an environment, all providers (the wholesale provider as well as the access-seekers) are able to use the standard equipment they want to offer on the customer side (tested cable modems and CPE), and to take effective control over the network in a way that allows product differentiation. Thus, the CPE may be freely chosen among all systems offered and meets the appropriate DOCSIS standard, and the cable modem typically is the operator's network endpoint and determined by them.

4.2.3.2.6 Access link state control

To be able to manage their own virtual network in case of an incident, an access-seeker needs to get sufficient control of the link state of his customer's cable modem. By this, the access-seeker may control the modulation on the access line (connection, link) used by the modem, change it or other access link parameters, and read transmission failure messages and statistics etc. According to the DOCSIS 3.0 standard, each CMTS must implement the CMTS CM Registration Status Service Definition (CMTS-CM-REG-STATUS-TYPE) which could be read out via several protocols (see next section) along with other information useful for debugging and incident analysis. The wholesale provider could offer this information via a service interface to the access-seeker. From a technical point of view, a wholesale-seeker could control its access lines within the wholesale provider's network. However, access to the cable modems by several operators would require an additional multi-tenant facility,[150] mutually protecting the other operators' access lines from unauthorised access, a feature not available yet as an integrated on-the-shelf characteristic of the currently installed OSS/BSS of CATV network operators.

4.2.3.2.7 Process control (related to service management)

Each access-seeker must also be capable of controlling its (virtual) part of the equipment (the systems providing and operating the end-customer connections) without gaining direct access to the equipment and the wholesale provider's customers. These

150 A multi-tenant facility allows the virtual separation of software processes operating in the same environment and on the same set of resources in a manner such that each of the processes does not affect the resources of the other processes. Multi-tenancy is a prerequisite for multi-operator access to a wholesale provider's OSS.

features build a superset of the previously mentioned multi-tenant access link state control principle[151].

Technically such a feature set includes configuration and fault management as well as performance and account management. Each access-seeking provider therefore must be able to set configuration parameters and receive fault messages for the CMTS and the cable modems as long as the information is associated with their customers. An interface system offered by the wholesale provider filters the incoming requests from the access-seekers and translates authorised requests into machine-specific requests and vice versa.

In case of DOCSIS hardware (CMTS and CM), these requests and fault messages are part of the DOCSIS specification.[152] The interface system itself communicates with the CMTS directly via SNMP (v1, v2c) or IPDR, (Internet Protocol Detail Record) which are both mandatory. So the basic features for remote control exist, but it remains unclear how to restrict the access of each provider to its own end-customers only and how to guarantee that the other providers' customers may not be harmed, intentionally or unintentionally. The requests and fault messages could only be performed by multi-tenant add-ons for the network operating system, which are not available as a standard feature, if at all.

4.2.3.2.8 DOCSIS and VULA summary

The options for wholesale VULA offers are constrained by insufficient Layer 2 protocol support (service-agnostic transmission), which is not mandatory in the DOCSIS standard for now and the future. Regarding the support of multicast services, the DOCSIS standard is based on IP and thus supports IP-multicast protocols only. Using these IP-multicast protocols in a shared IP downstream communication channel consumes a high bandwidth share of the total capacity and thus is inappropriate for a complete channel bouquet, thus should be restricted to some special offers (see section 4.2.3.2.3). The more efficient solution would be a resale of the transmitted TV channels. The multicast bandwidth control features of DOCSIS are based on the IP, but are not available in the DOCSIS releases 3.0 and 3.1 for the Layer 2 protocol.

Free support of CPE may be supported by DOCSIS, but also depends on the operators and their coaxial frequency alignment. Also, link state and further process control functions exist within DOCSIS 3.0 and above, but the use of these features by wholesale-seekers requires multi-tenant capabilities of the network operating systems. Such multi-tenancy is – according to WIK's knowledge – not a standard feature of any

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151 For details of process control see: T. Plückebaum, H. Kohl, M. Muckhoff, „Technical feasibility of providing wholesale access over a cable TV infrastructure", study for ComReg, Bad Honnef, February 2016

152 See Operations Support System Interface Specification (CM-SP-OSSIv3.0-I27-150827).

network operating system, but has to be developed on demand and at the operators expense.

The capacity of DOCSIS 3.0 in the upstream direction is greatly restricted (10% from downstream). Offering wholesale uncontended VULA bandwidth would reduce the capacity for the remaining wholesale providers' own customers significantly and would prevent future developments in achieving more symmetry in upstream and downstream traffic. Furthermore, uncontended and symmetrical bandwidth could only be provided to a very limited extent and to the detriment of the remaining users[153]. Mandating VULA in DOCSIS 3.0 with uncontended upstream bandwidth would require the operator to upgrade its network, if the wholesale product is demanded.

The bandwidth improvements of DOCSIS 3.1 cover upstream and downstream at the same scale, so do not improve the traffic asymmetry characteristic. If the upgrades are performed on the existing customer capacity demand evolution, the upgrade to DOCSIS 3.1 will not improve the operator's openness to enter a wholesale business. In case of Full Duplex availability the asymmetry between up- and downstream disappears and the bandwidth scarcity for symmetrical services with uncontended bandwidth is relaxed. But also in this case the bandwidth demand will follow the capabilities and increase (Figure 4-8) in such a way that we do not expect existing cable-TV network operators with a customer base like the one of VodafoneZiggo experience an economic need to fill the network by additional wholesale customers, increasing bandwidth scarcity to the existing customer base. This might be different for new market entrants having constructed a competing parallel infrastructure which cannot be filled by own retail customers alone[154]. In case of a wholesale obligation for a cable-TV network operator it would have to enhance the capacity of its whole network accordingly – and to expand its OSS and BSS systems for serving wholesale customers, including expanding it by a multi-tenant capability.

In addition one has to keep in mind that Full duplex DOCSIS 3.1 in addition to the system upgrades to release 3.1 and the exchange of all cable modems requires full duplex amplifiers in the field, at least a deep fibre roll out, if not better RFoG, and the introduction of the echo cancelation boxes. Thus there is significant investment required for the additional electronics and civil construction work[155].

153 In contrast to cable-TV networks the access line of a xDSL-network is not shared. Adding a wholesale customer has no impact on the bandwidth of the neigbouring customers. A symmetric service can be provided on the basis of the upstream channel's bandwidth without affecting any neighboring end-customer. Overbooking/ contention in xDSL networks can be prevented by dimensioning the upstream capacity beyond the DSLAM/MSAN accordingly, individually and on demand.

154 [✂]

155 The closer the fibre to the homes, the more the investment per home increases. WIK estimates at least fourfold the investment so far made for the civil fibre infrastructure. This will depend also on ducts already available (for coax use or in a sharing approach).

In Denmark, where TDC (the national incumbent telecommunications operator) is obliged to offer wholesale on its Cable-TV network and where the upgrade towards DOCSIS 3.1 has already started and TDC is rearranging its frequency spaces for Radio/ TV and data communications there only is obliged an IP-Bitstream service with TV-channel resale (see section 2.3).

WIK does not envisage a general network infrastructure system that supports VULA[156] as a mandatory or voluntary offer in DOCSIS 3.0 or 3.1 systems within the next five to seven years (up to 2025), unless it would be obliged for regulatory reasons.

4.2.3.3 Wholesale bitstream access (WBA/ WCA)

In contrast to the wholesale local access (Market 3a), the wholesale central access market 3b provides central traffic handover at core sites at the national or regional level next to the backbone connections of the wholesale provider. The traffic is then routed through the wholesale provider's network down to the end-customers on a best-effort basis with no guarantees for bandwidth, latency, etc.

Such access only provides the transport of IP-based services with no or at most limited control over the transport network by the access-seeker and thus only allows bitstream-based products with reduced capabilities for access-seekers to differentiate their offers.

Regarding cable networks, the traffic handover can take place starting at the CMTS locations (comparable to MDF site level) and at any IP node level upwards in the network. According to the DOCSIS standard, all CMTSs are Layer 3/IP-based network units and therefore the support for bitstream-based products is assured.

Such network infrastructure equipment has already been available for a longer while,[157] already with any DOCSIS 2.0 equipment, and all the subsequent releases support such features. WIK assumes that the reason why only a few CATV network operators offer such wholesale services is that the other operators have sold a large share of the upstream network capacity to its retail customers already and have no need to offer wholesale products, enabling competitors to enter the retail market by limiting its own scarce upstream growth capacity.

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156 As described in section 4.1.2 and discussed above – there may come up new VULA definitions, which are beyond the scope of this expert opinion.

157 DOCSIS 2.0: CM-SP-RFIv2.0-C02-090422, Section 5 (p. 29), http://www.cablelabs.com/wp-content/uploads/specdocs/CM-SP-RFIv2.0-C02-090422.pdf. This document was actively worked on between December 2001 and April 2009.

4.3 Overview over the applicability of wholesale access over the different technologies

While copper has been the existing and for a long time of the past demand meeting telecommunications access infrastructure it now runs out of date for the increasing bandwidth demand. This has impact on the options of wholesale access as defined so far by the European Commission. The overview given in Table 4-2 reflects the situation for the technical capabilities of wholesale access in an NGA demand environment of at least 30 Mbps downstream in an asymmetric distribution, for VULA also a symmetric traffic option shall be possible. The table does not reflect the willingness of operators to offer such services, nor does it reflect the interest of possible wholesale access seekers to buy them.

Table 4-2: Overview wholesale access (NGA) depending on technologies

Technology	ULL	VULA	WCA
Copper	-	✓	✓
Fibre PtP	✓	✓	✓
Fibre PtMP*		✓	✓
Coax 3.0			✓
Coax 3.1			✓
Coax 3.1 FD		✓	✓

FD: Full Duplex, * in NL not relevant today

4.4 Competition between the major players of copper/ fibre and coax networks

The largest coax-network operator in the Netherlands is a result of the merger of UPC and Ziggo to a new Ziggo operator covering almost 90% of the households in 2016. Further 6% of the households are served by smaller local cable-TV network operators[158]. Just recently the mobile and to some extent fixed network operator Vodafone merged with the new Ziggo to VodafoneZiggo starting January 2017. The old Vodafone fixed network business mainly based on FTTH unbundling has been split of and sold to T-Mobile. The merger of the two cable-TV network operators now requires to harmonize the fixed network products, the platforms and the operating and monitoring systems (OSS) and organisations but also the sales and order processes and business supporting systems (BSS) and the organisation from the service subscription and order entry (and change and cancelation) down to providing and implementing the services for the customers by the network components. This will require large efforts and cost for training and software development.

158 Keetelaar, J.: Commercial Wholesale Agreements in the Netherlands, WIK Investment Workshop, 7. March 2017, Brussels

By implementing the merger with the mobile business towards quadruple play products and by splitting off the existing fixed network customers of Vodafone adds significant complexity. This will make the young and growing together organisation not very keen to approach new challenges like migration to new technologies, starting new (wholesale) business or spending big investments for capacity enhancements in the near future. Planning for entering the wholesale access market (as a second player) on a volunteer basis is the least urgent task compared to the other challenges ahead. Typically, and as proven in the past in the Netherlands, the cable network operators have been pushing and driving the competition for higher bandwidth services. [✂][159] [✂]. So they are busy in keeping pace with the customer bandwidth demand and have no need to drive it, unless the market and the large fixed network competitor KPN would be forcing to do so. Natural next steps in upgrading could be the classical tools of cable-TV network operators, fibre node splitting, making use of the digital dividend and migration to DOCSIS 3.1 in those areas with pressing demand first.

The large incumbent fixed network operator KPN just finished the second step of the Reggefiber take-over, which today allows to serve approximately 30% of the Dutch market by FTTH. Typically integration of such merger will require a couple of years. Unfortunately, the node locations (star points) for the copper and fibre access lines are dislocated, which makes regional field service more complex and expensive. [✂][160]. [✂]. KPN stated that customer bandwidth demand results in a rather poor fibre take-up. In order to keep pace with the customer demand KPN therefore uses its existing copper network by amending its FTTC footprint, using vectoring and migrating to VDSL2 profile 35b (Vplus) with its approximately 300 Mbps. [✂].

Both operators would have to significantly invest into additional FTTH investment, respectively investment into fibre to the Last Amplifier (FTTLA) in case of full duplex DOCSIS in order to significantly increase its infrastructure to 1 Gbps and to more symmetric capacity. The view of both operators seems to be that the bandwidth demand requested by the end customers can be met by the capacity tool set the operators have today, without requiring significant additional fibre investment.

159 Interview with VodafoneZiggo in the context of this study
160 Interview with KPN in the context of this study

So we observe a situation where the incumbent fixed network operator already owning a larger FTTH PtP infrastructure is not willing to invest into fibre infrastructure in the next years. And if KPN does not, VodafoneZiggo has no need either.

VodafoneZiggo can use time to consolidate their systems and tools before migrating to DOCSIS 3.1 and later may be to full duplex DOCSIS 3.1. We assume wherever network components have to be exchanged or upgraded they will do it by considering future bandwidth needs (i.e. higher DOCSIS 3.1 frequency range, full frequency range bidirectional transmission, support of the DOCSIS 3.1 transmission procedures), taking advantage from the fact that DOCSIS 3.1 is downwards compatible with 3.0, and by this step by step prepare for the upgrade to DOCSIS 3.1 over a longer time period. According to today's knowledge (technical standards are not agreed upon yet) full duplex DOCSIS will require a FTTLA fibre infrastructure; and if this infrastructure is not provided in an unbundled manner by the incumbent KPN, they will have to install it by their own by a significant investment. As long as VodafoneZiggo does not deploy significant spare capacity which has to be filled by third party customers in order to recover the investment we do not expect them to start a wholesale business on a volunteer basis. In addition, a wholesale business only makes sense in larger areas at least. And it would require to overcome the typical upstream bottlenecs of DOCSIS, so full duplex support would be ideal. But deploying FTTLA to all of their last amplifiers (90% coverage) may require a decade of construction work. So we see no volunteer wholesale offer based on VodafoneZiggo's coax network infrastructure for the time up to 2025.

[✂][161]. A technical platform operating PtMP fibre topologies and with characteristics comparable to DOCSIS 3.1 full duplex could be implemented with 10G symmetrical PON systems too. Such systems can be also unbundled on a wavelength level (see section 3.2.2). But they would not enable a use like a transparent unbundled fibre so that VodafoneZiggo could use it in a wholesale manner for FTTLA. Such problem could be avoided by constructing the fibre access network in a shared manner.

4.5 Assessment of the economic effects on entrants

A new market entrant has to decide which market position it wants to take – a high quality provider with products differing from those in the market regarding bandwidth and delay at a reasonable, not necessarily low price, addressing its services to a restricted market segment of residential customers, or a mass market low price aggressive competitor. Furthermore, the entrant has to decide what is the market size

161 Indicated in the interviews with KPN and T-Mobile for this study to be addressed, local or regional or national, including high end business customers also or not. Since many operators offer TV also, one can assume that a market entrant should do that also.

There is a wider choice of wholesale access products in the Netherlands:

- Copper ULL
- VULA (on copper)
- FTTH ULL
- WBA on copper
- WBA on fibre

Based on KPN's network (100% homes passed by copper, 30% homes passed by fibre). For the future we hypothetically assume[162] that there will come up

- VULA (on Coax)
- WBA on Coax (IP)

Based on VodafoneZiggo's network (90% homes passed).

4.5.1 National market new entrant based on bitstream first

It is quite easy and only requires low initial investment for a new entrant to immediately address the national market by best effort products based on the incumbents national bitstream offer. The entrant only will have to connect itself to one national handover point, and for resilience reasons also a second may be chosen. It could then step by step climb up the ladder of investment by collocating at the metro-core locations. This only makes sense if this change is combined with a higher quality of the wholesale access products, by changing from WCA to VULA, allowing for a higher degree of product differentiation than WCA. If there is no intention to improve the products, there is no need migrating to the metro-core locations, because higher access speeds are already available with WCA (accessing the end-customers by bitstream over fibre or FTTC access lines). If there is a price difference between central and regional (metro-core) handover of bitstream it simply is an economic decision from which market share onwards a collocation at the lower level (metro-core) is beneficial. Migrating even deeper into the access network follows the same rules. According to KPN's access network structure the next step only could be directly accessing the FTTH ODF locations at the metro-core or city PoP locations, now here, but only here at the FTTH unbundling locations being able for full product differentiation. A further migration

162 Despite the fact that WIK does not see reasons for a volunteer wholesale offer of the largest national cable-TV operator it can make sense to hypothetically model such case, assuming that the market development will deviate from the prognosis.

towards the copper LLU MDF locations makes no sense, because of the poor bandwidth offers which can be realized there (based on ADSL 2+).

4.5.2 Regional market new entrant based on FTTH

Another, high quality related approach might be taken starting regionally and address the end-customers in the densest populated areas covered by FTTH first. This areas might be completed by a bitstream based offer in the other FTTH served areas, there migrating to FTTH unbundling if a market share has been achieved allowing for a profitable step up on the ladder of investment, by changing from bitstream to physical unbundling. This offer may then be completed by a VULA based offer of higher quality for the metro-core locations not yet served, starting either according to size from a larger number of end-customers served to lower figures or by completing areas first before migrating to more remote areas. Also a combination of both could be possible. This may depend on the local strength of the brand. A strict economic approach would be driven by the size, following it in a decreasing order. In order to speed up with a national coverage the not yet VULA served areas could at first be addressed by bitstream – but bitstream offers may harm the quality brand the entrant started with.

Of course there are many different combinations possible. One has to keep in mind that deploying an own network for accessing the handover points and collocating there causes fixed cost, which are better justified when the amount of traffic taken over there justifies this under the product approach and position taken. Physical unbundling for a few lines will not justify the MDF/ODF collocation cost and location backhaul investment. On a wider scale this can be transferred to the handover locations of bitstream respectively VULA. All wholesale seekers WIK has interviewed during the study explicitly stated that the goals of the business cases and the economic viability have to be met.

4.5.3 Existing wholesale unbundling based operator on its migration to FTTH

A wholesale operator having started the wholesale access business with copper LLU who now has to migrate to higher access line bandwidth than technically feasible by ADSL2+ can change to VULA at the metro-core locations, observing its copper LLU investment getting stranded over time and to a wider extent. A migration to FTTH unbundling would require another significant investment because the fibre ODF do not coincide with the copper MDF. Thus stepping back to VULA and perhaps later on stepping one step forward the ladder of investment once again towards FTTH unbundling seems to be a more careful path of strategy development, allowing for breakpoints rethinking if the path chosen is successful. However, such migration considerations are out of scope of the economic analysis of this study, which will deal with the view of a market entrant only.

4.5.4 New market entrant using a coax-cable based platform

If there would come up a coax-infrastructure based operator with a more or less national coverage on DOCSIS 3.0, migrating to DOCSIS 3.1 and then to Full Duplex 3.1, offering Wholesale Central Access with national handover and a VULA-like product handed over at the CMTS locations, one could imagine that such a platform could compete with the incumbent operator based access platform described before. Of course, the handover points to access the wholesale access services are completely disperse from those of the incumbent operator. But for a new entrant it typically does not care much where the national handover is located. Stepping one step up on the ladder of investment towards VULA there are significantly more colocation points (approximately [✂] CMTS locations compared to 161 metro-core locations). Hence such step has to be decided handover point by handover point in a business case analysis comparing the additional network cost with a lower price for the VULA access line and/or the higher income achievable due to the higher quality of the access line.

When the new entrant has decided to go for the coax based VULA, there is in fact no way back, since the VULA colocation points do not coincide.

From today’s point of view there will not be any further migration option towards FTTH, since the fibre installed for Full Duplex DOCSIS 3.1 will stop at the last amplifier in front of the buildings or in the basement, but not all homes. A migration to the incumbent’s FTTH access platform is theoretically imaginable, but the access areas of a CMTS and an ODF are not congruent, so that gaps will come up, which at least for a transient period of time would require either a duplicated old and new overlapping infrastructure or a loss of customers in the gaps.

4.5.5 Change of wholesale provider

As a new entrant one can easily benefit from different wholesale offers at the time entering the market – and competition will have an influence on the market prices. A change between the different central wholesale bitstream offers is relatively easy performed and at rather low cost. When starting climbing up the ladder of investment the wholesale seeker is more stuck with his wholesale supplier because of the infrastructure investment taken. Because of the larger number of CMTS locations this effect will be stronger when opting for the coax based operator in the Netherlands than for the incumbent. A migration towards FTTH unbundling only one supplier can offer. This seems to become a competitive disadvantage for the coax-based supplier, at least for the (small) market segment of high quality access operators entering the market.

This competitive disadvantage may to some extent demotivate a coax-cable based operator to decide entering the wholesale market at all.

4.5.6 Used assumptions for the modelled new entrant

In the model we apply an hypothetical entrant which is considered to be an alternative operator which focusses on providing services to residents and small business. This is due to the focus of the market analysis on Markets 3a and 3b.

The offered retail services will be best effort products based on standard SLA of the wholesale access products. This is due to the low share of wholesale access services bought currently with premium SLA features (less than 10%) and the additional model complexity this would bring.

The entrant's retail services are built on available wholesale access products of KPN. As there are no reference offers available for wholesale services over coax from VodafoneZiggo, the KPN prices serve as approximation for the likely costs of WCA and VULA over coax. The KPN cost have been adapted on coax where required (no volume discount on connection charges and EVC as only applicable on copper based services and no symmetric components as coax is assymmetric). As wholesale costs make up to 60% of the total costs (for WCA) this gives already an impression what would happen if the same costs structure and level would be applied for the different (coax) network as is currently used by KPN for its copper and fibre network.

The current costs of wholesale access services have been used to calibrate the models until 2025 as we do not expect significant changes in the underlying networks. [✂]. However, it could be that the costs of producing wholesale services over coax is cheaper compared to copper and fibre. In that case, the sensitivity parameters can be used to consider the impact of a lower costbase. For each scenario this is mentioned. For example lowering the wholesale costs with 10% would improve the resulting business case margin with x%.

For the demand modelling of the retail services, following aspects have been considered:

- The demand calculation are based on homes passed. Based on CBS data we have derived that until 2025 this number will grow with an estimated 5%
- For the average revenue per potential customer, we have looked at the latest available market data in the ACM Telecom monitor of Q3 2016 and combined these with assumptions of a possible distribution of the line speeds. We have assumed that the current available lines speeds will be sufficient to cater the requirements until 2025. In case this will change in the coming years due to different end user behaviour (application usage), the ARPU figures can be amended directly in the model or the sensitivity figure per scenario can be used to see the impact on the end result.

- As reference for the entrant's retail pricing, we have observed the current market prices of KPN and VodafoneZiggo for their retail services. For the calculated revenues, we have assumed that the entrant needs to set his retail pricing 10% below the reference prices of KPN and VodafoneZiggo in order to attract customers to migrate from their existing providers. The 10% mark-down is based on observations in the current pricing of alternative operators of services with comparable packages and line speed.

In regards to market positioning, we have assumed the following:

- The entrant offers best effort quality products for reasonable price and positions itself as a customer friendly company. This translates into a bit higher retail costs (customer service, billing etc.) to achieve and hold its market position. We do not expect entrants with a low quality service to be able to survive in the Dutch market on the medium and long term.
- Ramp-up costs are not considered as we consider a steady state approach; the entrant has reached a certain market position and share and efficiently uses its network and purchased wholesale access. It is clear that when considering these ramp-up costs, an entrant would have a higher cost level in the begin years as network and wholesale capacity would not be utilised as efficiently as it is modelled. Therefore these business cases reflect a conservative estimation. When the calculated margin in the models is already critical, considering ramp-up costs would worsen the case.

5 Business case modelling

The aim of the business case modelling is to assess the economic viability of technically feasible entry options in the foreseeable future (up to 2025). The entry shall be based on wholesale products granting access to alternative operators, based on the copper and fiber network of KPN and the coax network of VodafoneZiggo (both will be referred to as incumbent firms). The goal is to get insight into the conditions under which entry would take place, if the access options were available.

Therefore we will review entry for each separate access option in the modelling. It would also be possible to enter the market using combinations of access options, but this would blur the single effects and would be of less help in the market review.

Economic viability will be measured by the opportunity to generate profits from the roll-out in the long run. The built models follow a steady state approach, where the roll-out-plans of the alternative operator are finished and materialised, neglecting ramp-up costs.[163] This means that if we find an access option not to be viable (hence in the long run), for sure it would not be viable considering additional ramp-up costs.

5.1 Modelling approach

The modelling represents a business case, where for a wholesale based entrant the costs of his roll-out are compared with the weighted revenues of the products he can sell, based on the wholesale product available. The entrant in the model is assumed to have a core network already in place, to which it is able to connect the access nodes addressed in its roll-out plan via backhaul connections.[164]

Access to end customers by the entrant is realised via interconnection with the access nodes in the incumbent network. The addressable number of customers per access node basically determines the possible revenues and costs of the entrant's roll-out plan. In the modelling we have considered the capture of the actual addressable customer base per access node in the respective incumbent network.

The modelling comprises the access options of national WBA (WCA) based on copper, fiber and coax infrastructure, (regional) VULA based on copper and coax infrastructure and LLU based on fiber infrastructure.[165].

163 These costs typically arise due to underutilisation of the equipment during the entrant's start-up phase, where investments have to be made before the envisioned number of customers can be attracted and gained.

164 This assumption helps to free the analysis from the need to build a full fletched bottom-up model for the entrant, which is out of scope of this study.

165 Copper LLU and fiber VULA were excluded as access options in the analysis as they have no relevance in the Dutch market due to the substitution by copper VULA and the presence of fiber LLU

The modelling task is realised with the help of three excel spreadsheet tools. Based on the available network information of the Dutch copper, fibre and coax networks, it was observed that for certain access options the access nodes overlapped (KPN's copper and fibre network) and for other they were separate. This impacted the split in the following models:

- Coax (HFC) model with
  - [✂] access nodes (CMTS locations) of VodafoneZiggo network as handover points for VULA
  - 2 access nodes (national handover points) for WCA.
- Fiber ODF access model with
  - [✂] access nodes (City Point of Presence (PoP) and Metro Core (MC) locations) of KPN/Reggefiber network. The MC locations act as handover points, aggregating the Area PoP and City PoP's where City PoP demand is too low (< 10.000 customers).
- Copper and fiber based model for VULA and WCA
  - 161 access nodes (Metro Core locations) of KPN's copper network as handover points for VULA
  - 2 national handover points for WCA related to KPN's copper and fibre network.

The customer base of the entrant is derived as a percentage (called market share in the model) of the addressable customers at the connected handover nodes. The roll-out plan of the entrant is represented by the number of handover nodes he will be connected to, assuming that the nodes with the highest customer potential are connected first. The customer potential per node is always represented by the number of homes passed in the incumbent network. This is important to keep in mind when setting and interpreting the market share parameter of the entrant. Table 5-1 shows the sum of the number of homes passed in the networks of KPN and VodafoneZiggo supplied by the incumbent firms upon request. The data of KPN includes households and business homes. For VodafoneZiggo we interprete that the data also include households and business homes.[166]

respectively. However, the option of fiber VULA is foreseen in the model for future use if relevant. Furthermore, coax based LLU was excluded as it is technically not feasible.

166 The household statistic for the Netherlands reports 7,720,787 households for 2016. Assuming a 90% household coverage in the coax network, the reported number of homes passed overruns the covered 90 % of households by 3.2%. So we assume that business homes are included in the data delivered.

Table 5-1: Total number of homes passed in the incumbent networks

	Homes passed
KPN	
Copper network	8,415,123
Fiber network	2,246,320
VodafoneZiggo	
Coax network	7,177,197

We use homes passed (HP) by a given infrastructure as the addressable customer base, since an entrant can in principle reach any passed home by connecting to the incumbent network. For an activated customer this is obvious, for a connected but not activated customer only activation by the incumbent firm is needed. In case that the home is passed but not connected, a drop line can be installed to connect the respective customer at limited costs. The number of homes passed could be roughly twice the amount of homes activated in the Netherlands due to overlapping networks of coax and copper for example. Hence, a market share of 2% (of homes passed) in the model could relate to 4% market share in terms of homes activated.

In case of WCA, modelling a nation-wide coverage (all homes passed by the respective infrastructure) is accessible to the entrant by connecting to a single handover node with a second one for redundancy. The costs for this redundancy is covered by calculating additional collocation cost, additional uplink costs and additional access node equipment costs.

5.1.1 Defining the reviewed base case and relevant scenario parameters for the modelling

For the business case it is important to develop a realistic base case scenario that reflects the market conditions in the Netherlands and the characteristics of an efficient entrant. These parameters are kept constant in the models. In addition to these 'base case parameters', there are 'scenario parameters' which change per reviewed entry scenario (see 6.1 for a description of the tested scenarios).

The 'base case parameters' concern the expected average revenue per end customer (ARPU), cost characteristics but also the approach of focussing at the largest access nodes when reviewing a regionally operating entrant. Furthermore, it is assumed that the entrant focusses on mass market retail products including small office and home office customers. Also we assume that the entrant offers quality products (impacting network dimensioning) and a good customer service (impacting retail and other costs like billing).

The ARPU of incumbent KPN is considered for the copper and fibre models and the ARPU of cable operator VodafoneZiggo for the coax model. The entrant is considered to set its retail price level below KPN's and VodafoneZiggo's retail prices in order to attract its customers. For the base case scenario, it is defined that the entrant offers its retail services 10 % below the retail prices of KPN and VodafoneZiggo in the respective models.[167]

The entrant offers best effort quality products for reasonable price and positions itself as a customer friendly company. This translates into a bit higher retail costs (customer service, billing etc.) compared to an established firm, to achieve and hold its market position. Therefore, in the base case, the total retail costs are set at 13,5 % of the revenues. This is roughly 3 % higher than WIK benchmark data for already established firms would suggest. The extra mark-up of 3 % is an assumption by WIK.

The 'scenario parameters' in combination with the different models, reflect the reviewed scenarios for an entrant to operate on a certain access product, geographical coverage and market share.

The possible access products are; copper and fibre WCA, copper and coax VULA, Coax WCA and Fibre LLU. The market coverage can be national or regional coverage, which reflects the geographical roll-out of the entrant. In case of WCA, there is national coverage and the entrant connects to 2 national handover nodes (one would be sufficient, however the second is assumed for resilience reasons). In case of VULA and LLU there are two possible scenarios; connecting all available access nodes for national coverage or focussing on the most attractive ones, which we call a regional coverage. Most attractive is defined as those access nodes, where addition in the business case still increases the absolute net margin for the entrant. The model automatically selects the largest access nodes first (i.e. with the highest number of homes passed connected to it).[168] The more access nodes are connected, the higher the connection charges based on dark fibre become. At a certain point the additional connection costs will be higher than the revenue from the additional customers. This is where the 'regional scenario' stops.

Market share is a scenario parameter which impacts the percentage of homes passed the entrant is able to capture and turn into active customers. As noted before, market share is the % of homes passed, which is a much larger base than the number of active broadband connections (roughly twice). Hence, when comparing the value of the

167 The focus of the model is on best effort products without premium services. The entrant offers products that are as good as those of the incumbent. According to our experience the entrant has to reduce its price to gain customers. A price-aggressive low cost (low quality) entrant would need a higher markdown of prices. Added value in form of additional product packages is taken out of the ARPU anyway and better performance is hard to capture in the model. Performance in the sense of treatment of customers is considerd by higher retail costs (customer care).

168 The ranking of the nodes according to size is performed separately for each infrastructure type since the handover points differ per infrastructure.

‘market share’ parameter in the models, one needs to realise that this corresponds with a market share of active broadband connections which is twice as large.

Other cost components are more related to size of the entry, which is determined by the market share and the roll-out plan. The modelled entrant is assumed to have a core network already in place, to which it is able to connect the access nodes addressed in its roll-out plan via backhaul connections. The costs for the core network are modelled as costs per Mbps of the busy hour traffic. These costs may vary strongly with the size of the entrant in terms of traffic throughput. Since the core network costs form only a small part of the total network costs, we use a conservative estimate of 2€ per Mbps per month, based on WIK’s modelling experience.

5.1.2 Demand modelling approach

As described above, the reviewed scenarios are based on access options and different geographic roll-out of the entrant. Demand is therefore derived from the potential market size accessible via connected access nodes and the estimated market share of the entrant.

The demand potential is derived from input figures concerning the number of subscribers served by the distribution areas of relevant access nodes of the network operator. The latest available data have been used in the models, hence data from KPN/Reggefiber network for the copper and fiber based infrastructure and from VodafoneZiggo network for the coax cable infrastructure.

Received data consisted of the number of homes passed per MDF area for KPN’s copper network and per Area PoP and City PoP for KPN’s fiber network. For VodafoneZiggo’s coax network, applied data regarded the number of homes passed and the number of homes activated per CMTS area. We also asked for the assignment of the nodes to the higher network levels respectively for each infrastructure, to perform the aggregation of the customer potential to the handover nodes in case of LLU and VULA.

For WCA the national coverage (total sum for all areas) of the infrastructure applies. For VULA in the copper network 161 Metro Core Locations (MC) are defined as interconnection nodes. The copper demand per MDF area has been aggregated to these 161 access nodes, so that the model can use the precise number of homes passed per MC location as basic demand input. The total number of homes passed for the copper network amounts to [✂] accessible via 161 MC nodes. For the fiber network KPN supplied the latest available numbers of homes passed per service area (Area PoP / City PoP) together with an indication of which Area PoP aggregates to which City PoP and also how the City PoPs and Area PoPs relate to the 161 Metro core locations in the KPN network. In total the reported number of homes passed in the

KPN/Reggefiber network amounts [✂]. For the demand modelling of the fiber LLU access we derived [✂] access points.

We assumed that an entrant would always seek access at that level where the highest number of customers are accessible. Fiber can be accessed at Area PoPs or City PoPs using a backhaul service of KPN. Since the City PoP forms the higher level node in the fibre network, one or several Area POPs aggregate to its assigned City PoP. The number of customers addressable at the City PoP is always higher or at least equal to the number of customers accessable at the Area PoP. Therefore we assumed access at the City PoP level. Furthermore, KPN is obliged to grant fiber access at the MC location level, when the accessible number of customers at a City PoP is less than 10.000, together with a backhaul service from the City PoP to the MC location.[169] Therefore we aggregated the number of customers to the MC location level when the number of customers at the City PoP level were below 10.000 homes passed. This procedure resulted in [✂] handover points at the City PoP level and [✂] handover points at the MC level. The number of homes passed for these [✂] handover points form the basis of the demand estimation.

For the coax network of VodafoneZiggo/UPC we assume the CMTS locations as interconnection points for VULA access and 2 national interconnection points for WBA access. From the VodafoneZiggo network data we derived [✂] handover nodes with the number of homes passed per node as demand potential. In total VodafoneZiggo reported on [✂] homes passed in its network.

For each infrastructure, the number of homes passed is inflated by a growth factor to reflect household growth in the Netherlands for the envisaged time period. We use a growth factor of 5% of homes passed covering the household growth in the timeframe until 2025.[170] In principle with this parameter other projections of growing, shrinking or shifting demand potential can be introduced.

With the help of a predefined market share of the entrant under consideration the number of customers per access node is derived. In case of a sub-national roll-out we have assumed that the nodes with the highest customer potential are rolled out first. We have considered this by ranking the service nodes according to customer potential and applying the market share to the first *n* nodes (parameter in the model) that shall be connected according to the roll out plan.

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169 According to ACM these are obligations introduced during the last market 3a review in art. 271 – 281).

170 The figure is an educated guess based on household statistics from Netherlands CBS. The yearly household growth according to the latest figures between 2015 and 2016 was about 0.725%. The mean yearly growth rate between 2005 and 2016 amounts to 0.777%. Considering the timeframe up to 2025 the household growth from 2016 to 2025 will lie between 6.5% and 6.99% and between 2017 to 2025 between 5.8% and 6.21%. Since the mean yearly growth rate is declining over the years we have applied 5% as a conservative estimate of the household growth for the envisaged timespan.

5.1.3 Modelling revenues

Revenues are modelled using an average revenue per user (ARPU) which is multiplied with the number of users derived from the demand model. In the model we consider the ARPU of the incumbent (KPN, VodafoneZiggo) and compute the ARPU of the entrant relative to the incumbent by considering a markdown according to the entrant's strategy (high quality entrant with reasonable discount or low quality offer with aggressive price strategy). For the time-span of the foreseeable future we expect stable prices in the market, including quality upgrades without extra costs for the customers.

Figure 3-1 shows the example of the derivation of VodafoneZiggo's blended ARPU for the VULA computations. The ARPU is derived from the prices of the targeted retail market services, the most important product bundles and assumptions about the share of customers of the incumbent that order these products. The table relates the bundles (single, double and triple play products) to the marketed line speed. Prices for the bundles were taken from the VodafoneZiggo website.[171] Prices of bundles containing services not considered at the cost side of the calculations like mobile services, content related services like Netflix or cloud services are corrected by the estimated value of that service. Discounts and promotions are also considered. From this information the ARPUs shown in the Figure 5-1 were derived. The customer shares of the products were estimated from Telekom Monitor Q3 2016 information. The shares form the weighting matrix to derive a blended ARPU for VodafoneZiggo of 53.10 €.

Figure 5-1: COAX based blended ARPU derivation for VodafoneZiggo using customer shares per line speed as weights

COAX VULA ARPU					
Customer shares according to bundles and line speed					
	50Mbps	**150Mbps**	**300Mbps**	**500Mbps**	**1Gbps**
Single play (internet)	4.4%	5.5%	1.1%	0.0%	0.0%
Double play (internet + voice)	8.8%	11.0%	2.2%	0.0%	0.0%
Triple play (internet+ voice+ TV)	26.8%	33.5%	6.7%	0.0%	0.0%
ARPUS per proposition, ex. discounts & promos					
Single play (internet)	€39.50	€48.00	€56.00		
Double play (internet + voice)	€53.00	€57.00	€65.00		
Triple play (internet+ voice+ TV)	€44.00	€57.00	€72.50		
Blended ARPU ex. discounts & promos coax VULA	€53.10				

171 This is true for the coax network based ARPU data in this example, for the copper and fiber based infrastructures the corresponding ARPU data is derived from KPN retail data.

The model allows to use a blended ARPU for each of the access options WCA, VULA and fiber LLU.

The derivation of the entrant's ARPU is established by applying of a certain price discount relative to the incumbent's ARPU reflecting the entrant's strategy to gain customers. Figure 5-2 shows the derivation for our base case, where we assume a 10% discount, based on observations in the current pricing of alternative operators of services with comparable packages and line speed. This computation results in a blended ARPU of 47.79€ for the entrant. The price discount of 10 % relative to the incumbent is considered to be a minimum requirement for an entrant to attract customers from the incumbent or other competitors.

Figure 5-2: COAX based blended ARPU derivation for the entrant

Entrant ARPU development	Reduction factor
VULA ARPU price discount relative to VodafoneZiggo	10%
Entrant ARPU	
VULA ARPU	47.79

The model also considers revenues from voice termination. These are computed by application of the current fixed line termination charges in the Netherlands to the estimated minutes of inbound traffic. Revenues from CPE-equipment are assumed to be already included in the retail price.

5.1.4 Modelling costs

The costs to consider are incremental costs incurred by the entrant for the provision of the services to its customers. These comprise the entrant's own network and equipment costs, wholesale costs, retail and other costs and common costs. Own network and equipment costs and wholesale costs directly depend on the access option used to connect to the customers and they are also directly linked to the network roll-out and the implied number of customers.

<u>Wholesale costs</u>

Wholesale costs are directly linked to the access option implied by the entrant's roll out strategy. They typically consist of one-off connection or setup-costs, and a recurring rental fee with or without capacity based charges. Also auxiliary services like co-location and handover costs have to be considered. Since wholesale costs make up for the major amount of costs for an entrant, we have paid special attention to a good estimation of these costs.

For copper VULA and WCA we have used the existing KPN commercial wholesale price offer, checked and approved by ACM, to estimate the wholesale costs for the entrant.[172] For coax based services no such offers exist. We therefore applied the commercial KPN offer to model the prices for VULA and WCA in the coax case. To model the wholesale costs for fiber LLU we used the current (2017) Reggefiber ODF access tariff[173] together with the KPN tariff for ODF backhaul FTTH (from 2016)[174].

To estimate the costs for co-location we used the co-location tariff schedule for MDF Access[175] for copper and fiber WCA access and for fiber LLU in case of Metro Core handover and also to estimate the cost for co-location for coax based VULA and WCA. For copper based VULA a co-location tariff is included in the VULA tariff. For fiber LLU with handover at the City Pop a co-location tariff is included in the ODF access tariff schedule.

Own network equipment cost

Own network and equipment costs consist of core network costs, backhaul connection costs to connect the access nodes with the entrant's core network and costs for equipment at the access nodes and the customers' premises. The equipment needed depends on the technology applied, the number of customers per access node and the customer's line speed (busy hour capacity demand), which has to be dimensioned accordingly.

Figure 5-3 shows the derivation of the weighted busy hour traffic per user which is applied for the derivation of the busy hour traffic in the entrant's network, by multiplication with the number of customers. We use a traffic estimate for each combination of product bundle and line speed and form a weighted average with the weighting matrix of customer shares according to bundles and line speed, already applied for the ARPU calculation. The kbit/s per bundle and line speed is based on an estimation by WIK, where we assume a rising busy hour traffic value with higher line speed. According to our experience customers demanding higher line speeds have a higher usage rate. We expect customers to select into the typically more expensive tariffs if they have a higher consumption need.

The busy hour traffic per user derived (471 kbit/s in the example) is used for the dimensioning of the node equipment (switches, port demand, uplink ports), backhaul dimensioning and for the traffic based cost components especially the core network costs. It is also used to compute traffic based cost components in the wholesale tariffs.

172 For WBA we used 20170224_WBA Annex4; V1.2; for VULA we used Annex 4 VULA v1.4.
173 For fiber LLU we used Annex Tarieven bij ODF overeenkoomst v3.1.0.
174 We used Prijslijst ODF Backhaul FTTH Versie 1.0.
175 We used Collocatie tbv MDF Access Tariff Schedule Versie 8.0.

Figure 5-3: Derivation of busy hour traffic per user for the COAX based entrant

VULA busy hour traffic					
Customer shares according to bundles and line speed					
	50Mbps	**150Mbps**	**300Mbps**	**500Mbps**	**1Gbps**
Single play (internet)	4.4%	5.5%	1.1%	0.0%	0.0%
Double play (internet + voice)	8.8%	11.0%	2.2%	0.0%	0.0%
Triple play (internet+ voice+ TV)	26.8%	33.5%	6.7%	0.0%	0.0%
busy hour kbit/s per proposition					
Single play (internet)	[✂]	[✂]	[✂]	-	-
Double play (internet + voice)	[✂]	[✂]	[✂]	-	-
Triple play (internet+ voice+ TV)	[✂]	[✂]	[✂]	-	-
Weighted busy hour kbit/s per port speed per user	[✂]	[✂]	[✂]	0	0
Weighted busy hour kbit/s per user	471.00				

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The costs for backhaul (which are not part of the wholesale tariff) were estimated by wholesale dark fiber prices from Eurofiber.[176]

Other costs incurred concern costs enabling TV services (IP-TV servers, cable TV servers, multicast equipment, licenses), Video on demand services (VoD servers, licenses) and voice services (media Gateways and VoIP server, voice interconnection) and of course Internet services (internet connectivity).

Retail costs (customer acquisition, customer care, marketing, billing etc.) are considered by mark-ups on revenues. Other costs like TV content costs, and OS integration costs can probably be considered per customer or another known cost driver.

176 The used price schedule was provided by ACM.

6 Scenario analyses and discussion

6.1 Tested scenarios

As described in paragraph 4.5, there are different scenarios possible for the business case of a new entrant based on the intended roll-out of the new entrant and/or the usage of the different wholesale access services.

The focus is on an entrant operator selling mass market retail services covering residential end users and small businesses using residential products. Each wholesale access product will be tested separately in order to review the economic viability. Therefore, scenarios with combinations of wholesale access services are outside the scope. The same applies for migration scenarios of existing copper LLU based operators to copper VULA and FttH LLU.

Due to the different geopgraphical coverage between the copper, coax and fibre networks in the Netherlands, different names have been used two distinguish a broad geographical coverage and a focused geographical scenario on a certain area or areas. For the almost nationwide copper and coax networks, we have called these two options 'national and regional coverage'. For the much smaller fibre network (30% of households covered), the two tested scenario's are called 'complete and partial network coverage'.

The following scenarios have been tested based on the developed copper, fibre and coax models:

KPN Copper – Fibre model

1) Entrant operator with national coverage providing best effort retail services based on WBA for copper and fibre (wholesale service WBA NWAP). There will be 2 handover points for resilience.
2) Entrant operator with national coverage providing best effort retail services based on VULA for copper (wholesale service WBA Annex 4 VULA). There will be 161 handover points.
3) Entrant operator with regional coverage providing best effort retail services based on VULA for copper and focussing on the attractive areas only with handover points at the relevant access points.

KPN fibre model

4) Entrant operator with complete fibre network coverage providing best effort retail services based on fibre LLU (wholesale service ODF Access). There will be [✂] handover points.

5) Entrant operator with partial fibre network coverage providing best effort retail services based on fibre LLU and focussing on the attractive areas only with handover points at the relevant access points.

VodafoneZiggo coax model

6) Entrant operator with national coverage providing best effort retail services based on WBA for coax and 2 national handover points for resilience.

7) Entrant operator with national coverage providing best effort retail services based on VULA for coax and handover points at the [✂] CMTS locations.

8) Entrant operator with regional coverage providing best effort retail services based on VULA for coax and focussing on the attractive areas only with handover points at the relevant CMTS locations.

The model set-up and related assumptions are described in chapter 5. The models are populated with available data from the Dutch market complemented with benchmark data and estimates from WIK in line with the envisaged new entrant. Furthermore, the different scenarios require different parameter setting in the models, which will be discussed in this chapter.

Regarding the required profitability to label a certain access scenario economically viable, we remark that although there is a WACC applied in the models, it is applied only to annualise those components where capital investments related to cost components have been considered (equipment at the aggregation and metro core sites, CPE and one time charge components). For the other cost components, where an average linear relation is used (for example for core network costs or IP transit), the WACC is not considered although in reality these costs components would have a capital expense as well. Hence, we consider a model break-even when the margin is above 0%, however in reality an entrant would most likely need a minimal margin around 4.5% , which is the WACC set for KPN's copper network[177]. For KPN's FTTH network an even higher WACC of around 6.5% was set due to higher systematical risk. For the KPN copper fibre model and the VodafoneZiggo coax model, we have used the 4.5% WACC as the majority of the network is either copper or coax. For the KPN fibre model the 6.5% WACC is applied.

177 See https://www.acm.nl/nl/publicaties/publicatie/14469/Onderzoek-naar-de-vermogenskostenvoet-WACC-van-KPN/

6.2 Analysis

First we will discuss the results of each scenario, when it becomes profitable, what the main cost structure is and what are the most important components of each model. Thereafter we will check whether the regional scenario of focussing on the largest network nodes is realistic by checking if these are geographically spread across the Netherlands or close to each other enabling a pragmatic business case. For marketing and logistic purposes an entrant would focus on certain complete geographical areas containing larger but also smaller access points. Lastly, it has been checked when it is economically attractive for an access seeker to switch from WCA to VULA and LLU services per network.

The tested scenarios are displayed in the tables and graphs in the report. Furthermore, they are stored in each model in a separate tab called 'Scenario analyses WCA/VULA/LLU'. The tables start with a green marked column which displays the break-even scenario, thereafter everytime the same marketshare points are tested (0.5, 1,2,3,5 and 10%, marked in light blue). For the regional scenarios where the combination of marketshare and number of connected handover points impact the resulting margin, there are multiple tables (one for each number of connected handover points). These are not all included in the report but displayed in an overview graph. Furthermore, the tables related to the regional scenarios have a last red marked column, which indicates the limit to a profitable roll-out for the entrant. This is the point where adding an additional handover point creates more additional (connection) costs versus additional profit from new customers connected to this handover point.

6.2.1 Scenario 1 – Entrant with national coverage based on WCA for KPN's copper and fibre network

For testing this scenario, the KPN copper & fibre model is used, whereby both KPN's fibre and copper network is considered (as Wholesale Central Access (WCA) is available over both). In this scenario, the new entrant connects its core network with two handover points of KPN to reach all available customers on KPN's copper and fibre network. The KPN wholesale service WBA with national handover is used to build its mass market retail services for residential and small business customers in the Netherlands. A retail service with good quality is offered at a price point which is 10% cheaper compared to KPN's retail service (applies to all other models as well). See Table 6-1 for an overview of the tested (sub) scenarios.

Table 6-1: Results of the business case for scenario 1 – Entrant with national coverage based on WCA for KPN's copper and fibre network

Scenario 1 – Entrant with national coverage based on WCA for KPN's copper and fibre network (KPN copper & fibre model)							
Marketshare (% of available homes passed on KPN's copper & fibre network [✂])	**0.04%**	**0.5%**	**1%**	**2%**	**3%**	**5%**	**10%**
Resulting number of customers for the entrant	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**
Resulting overall margin for the entrant's business case	**0.2%**	**15.8%**	**16.5%**	**16.8%**	**16.9%**	**17.0%**	**17.0%**

From a very small market share onwards ([✂] customers), the business case becomes positive. This is due to the low amount of fixed costs as the entrant only has to connect 2 handover points (only co-location costs and port costs contributing to one time costs).

Most of the other costs are increasing linearly with increasing number of customers. This also applies for the wholesale costs, which determine almost 60% of all costs in the business case. This also explains why the the margin quickly arrives between 16 and 17% but remains at that level despite a growing number of customers for the entrant. Even a hypothetical market share of 10% results in 17% net margin.

One of the cost differences between the KPN wholesale access service WBA with national handover and WBA VULA and the other wholesale access services, is that WBA with national handoverhas a volume discount based on the connection and virtual circuit fees. This discount is up to 15% on the total monthly amount for connection and Ethernet Virtual Circuits (EVC's). This discount explains the higher margin for the scenarios tested based on WBA with national handover in the KPN's copper and fibre model compared to scenarios tested in the VodafoneZiggo coax model (based on WCA over coax).

Sensitive parameters of the model are wholesale costs and average revenue per customer (ARPU). If wholesale costs vary with +/-10% this respectively decreases and increases the margin of the business case with around 5%. If the ARPU would increase with 10%, the margin of the business case improves with 7.6%. On the other hand, if the ARPU would decrease with 10%, the business case margin decreases with 9.3%

Taking into account our earlier remark on a minimum margin of the business case around 4.5% and considering the scenario results, we consider entrant business cases based on the KPN wholesale service WBA with national handover economically viable.

6.2.2 Scenario 2 – Entrant with national coverage based on WBA VULA for KPN's copper network

For testing this scenario, the KPN copper & fibre model is used, whereby only the copper network is considered (as WBA VULA is only available for the KPN copper network). In this scenario, the new entrant connects its core network with all 161 handover points (the metro core locations) for VULA in KPN's copper network. The wholesale service copper VULA (WBA VULA) is used to build its mass market retail services for residential and small business customers in the Netherlands. See Table 6-2 for an overview of the tested (sub) scenarios.

Table 6-2: Results of the business case for scenario 2 – Entrant with national coverage based on VULA for KPN's copper network

Scenario 2 – Entrant with national coverage based on VULA for KPN's copper network							
Marketshare (% of available homes passed on KPN's copper network [✂])	**1.4%**	**0.5%**	**1%**	**2%**	**3%**	**5%**	**10%**
Resulting number of customers for the entrant	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**
Resulting overall margin for the entrant's business case	**0.9%**	**-70.2%**	**-14.9%**	**12.8%**	**21.9%**	**29.3%**	**34.8%**

From [✂] customers (1.4% market share of homes passed) onward, the business case for an entrant connecting all copper VULA handover points becomes positive. Scenarios with lower market share are strongly negative. This is related to the large block of one time costs for WBA VULA; 2.5 million upfront payment and 4.5 million for connecting to all handover locations. The other components of the VULA wholesale costs are mostly linear. Therefore, the model shows that with growing number of customers for the entrant (and distribution of these one time costs), the resulting average margin continues to rise.

The wholesale costs for WBA VULA, expressed as % of the total costs in the business case are around 50%. Compared to WCA this is roughly 10% lower. This is logical as less parts of KPN's network are used by the entrant due to handover points lower in the network hierarchy. If wholesale costs vary with +/-10% this respectively decreases and increases the margin of the business case with 4.7%.

Another sensitive parameter of the model is average revenue per customer (ARPU). If the ARPU would increase with 10%, the margin of the business case improves with 7.9%. On the other hand, if the ARPU would decrease with 10%, the business case margin decreases with 9.7%

Considering that the current market share of alternative operators between 5 and 10% of homes active (roughly comparable with 2.5 to 5% of homes passed in the model), this scenario seems economically viable for a larger entrant.

6.2.3 Scenario 3 – Entrant with regional coverage based on VULA for KPN's copper network

For testing this scenario, the KPN copper & fibre model is used, whereby only the copper network is considered (as WBA VULA is only available for the KPN copper network). In this scenario, the new entrant connects its core network with KPN's copper network via WBA VULA while focussing on the attractive areas only. The model ranks the access points automatically according the number of available homes passed. This ensures that the largest nodes are first connected as would be done in reality.

In comparison to the previous scenarios, variation is not only possible in market share but also in the number of connected access points (read how far the entrant rolls out its own network). Therefore, there are multiple tables available, which are aggregated in a graphic and the most likely market share scenario of 2% is included in the text for comparison to the other scenarios.

The table related to this scenario has an additional red marked column at the end. This column shows until which number of connected handover points it makes sense for the entrant to rol-out its network. This is the point where adding an additional handover point creates more additional (connection) costs versus additional profit from new customers connected to this handover point, hence where the absolute margin of the business case is optimised.

See Table 6-3 for an overview of the tested base case scenario of 2% of homes passed (roughly 4% market share of homes activated).

Table 6-3: Results of the business case for scenario 3 – Entrant with regional coverage based on VULA for KPN's copper network

Scenario 3 – Entrant with regional coverage based on VULA for KPN's copper network							
Marketshare (% of available homes passed on KPN's copper network (depending on connected access points max [✂]))	**2%**						
Number of largest access points connected (max 161)	**3**	**2**	**5**	**10**	**50**	**100**	**114**
Resulting number of customers for the entrant	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**
Resulting overall margin for the entrant's business case	**0.7%**	**-11.1%**	**10.2%**	**17.4%**	**21.0%**	**18.4%**	**17.3%**

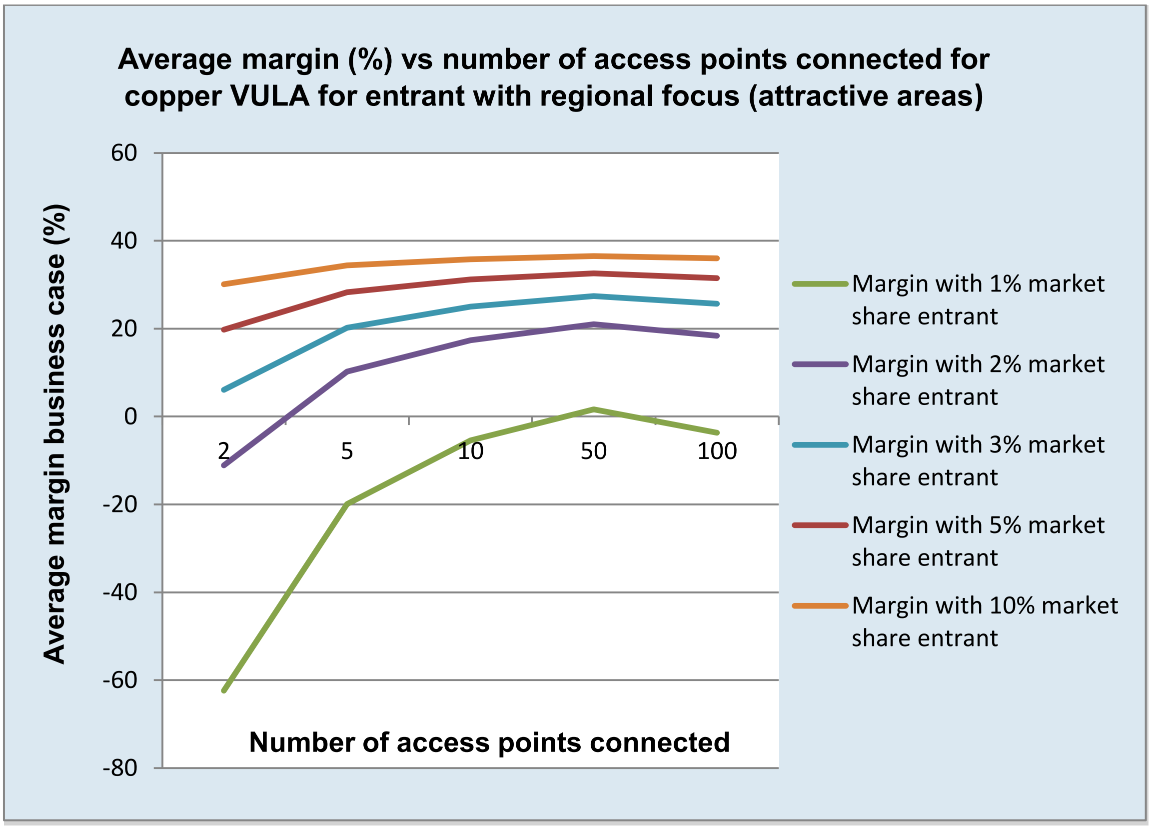
Based on a realistic market share of 2% of homes passed and having the 3 largest access points connected, the business case for the new entrant via WBA VULA becomes positive with [✂] customers. The entrant with 2% market share of homes passed is most likely not to roll out further than [✂] of the 161 access points with an average margin of 17.3%

As mentioned above, two parameters play a role in this scenario: the number of access points connected and the market share. If the marketshare is lower, more nodes need to be connected in order to collect a similar amount of customers and to cover the additional connection costs of the extra nodes. For example, with 1% market share, the entrant needs to connect the 18 largest access points to break even.

Also this model is sensitive to wholesale costs and ARPU. Decrease and increase of wholesale costs leads to variation in the business case margin of 4.1%. If the ARPU increases, the margin increases with 7.2%. Decreasing the ARPU has an even stronger effect on the margin (8.8% decrease).

Aggregating the tables with results of combinations for market share and number of connected handover points, lead Figure 6-1 below.

Figure 6-1: Business case margin for scenario 3: entrant with regional coverage based on copper VULA for different market shares and connected access points



As shown in the graph, an entrant having 1% market share would end up with a negative business case in almost all instances except when running just positive with 50 access points connected. As observed in the table above, with a market share of 2% the business case runs positive when the 3 largest access points are connected by the entrant. And from 3% market share onwards, an entrant would already run break-even if it connected the 2 largest access points.

Therefore, the targeting of attractive regional acreas with WBA VULA is a realistic scenario for an entrant. Alternative operators, which operate regionally are known to achieve significant higher market shares (in those areas) compared to country wide operating alternative operators. This makes scenario 3 a logical complement on scenario 1 where the entrant covers the complete KPN copper and fibre network via WCA with national handover.

6.2.4 Scenario 4 – Entrant with complete fibre network coverage based on LLU for KPN's fibre network

For testing this scenario, the KPN fibre model is used. In this scenario, the new entrant connects its core network with all [✂] handover points (City PoP or Metro Core (MC) locations) for ODF access in KPN's fibre network. A MC location is used when the underlying City PoP location has less than 10,000 lines and there is no other alternative operators present to share the connection costs with. Under these conditions, KPN will provide ODF backhaul from the City PoP to the relevant MC location where the demand is aggregated. The model considers these additional backhaul costs.

Complete geographical coverage means here connecting to all [✂] access points as KPN's fibre network does not have a national coverage. See Table 6-4 for an overview of the tested scenarios.

Table 6-4: Results of the business case for scenario 4 – Entrant with complete network coverage based on LLU for KPN's copper network

Scenario 4 – Entrant with complete network coverage based on LLU for KPN's fibre network							
Marketshare (% of available homes passed on KPN's fibre network [✂])	**8.5%**	**0.5%**	**1%**	**2%**	**3%**	**5%**	**10%**
Resulting number of customers for the entrant	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**
Resulting overall margin for the entrant's business case	**0.3%**	**-293.9%**	**-134.9%**	**-55.6%**	**-29.6%**	**-10.7%**	**2.7%**

The wholesale costs are 55% of the total costs, which is high compared to WBA VULA where this is 50%. The largest component of the wholesale costs are the monthly line rental costs of 17.06 € after discount, which is 73% of the total wholesale costs. Due to the high wholesale costs and the lower concentration of homes passed per access point (see Table 6-5), the business case for an entrant using fibre unbundling and covering the complete fibre network is only getting positive with a very high market share of 8.5% of homes passed with fibre. This implies a market share of 17% of all homes activated with fibre and is considering the market situation in the Netherlands not realistic. Even at a hypothetical 10% market share the resulting margin for the entrant is 6 times lower than using WCA (2.7% versus 16.8% margin). This makes it unlikely than an entrant using WCA will shift to using LLU on KPN's fibre network.

This model is sensitive to ARPU and wholesale costs; increasing the ARPU with 10% would increase the resulting margin of the business case with 9%, decreasing the ARPU with 10% would decrease the business case with 11%. 10% increase or decrease in the wholesale costs would vary the margin of the business case with respectively -5.5% and +5.5%.

Table 6-5: Average number of homes passed per access points in the KPN and VodafoneZiggo networks in the Netherlands

Network	Average number of homes passed per access point
KPN copper (metro core locations)	[✂]
VodafoneZiggo coax (CMTS locations)	[✂]
KPN fibre (ODF locations)	[✂]

As observed in Table 6-5, the number of available homes passed per access points (hence available customers for the entrant in the business case) is [✂] times lower for Fibre LLU compared to Copper VULA and twice as low as for Coax VULA. Despite higher expected ARPU per customer for fibre LLU based services, this explains the less positive results from the business case. In addition, the transport of each fibre (per estimated customer for the entrant) is more expensive than the transport over ethernet virtual circuits which are used for retail services based on KPN's WBA wholesale service (both WBA with national handover and WBA VULA).

6.2.5 Scenario 5 – Entrant with partial network coverage based on LLU for KPN's fibre network

For testing this scenario, the KPN fibre model is used. In this scenario, the new entrant connects its core network only to the attractive ODF access points of KPN's fibre network.

In the same manner as scenario 3, variation is not only possible in marketshare but also in the number of connected handover points (read how far the entrant rolls out its own network). Therefore, there are multiple tables available, which are aggregated in a graphic. The most likely marketshare scenario of 2% is included in the text as table for comparison to the other scenarios.

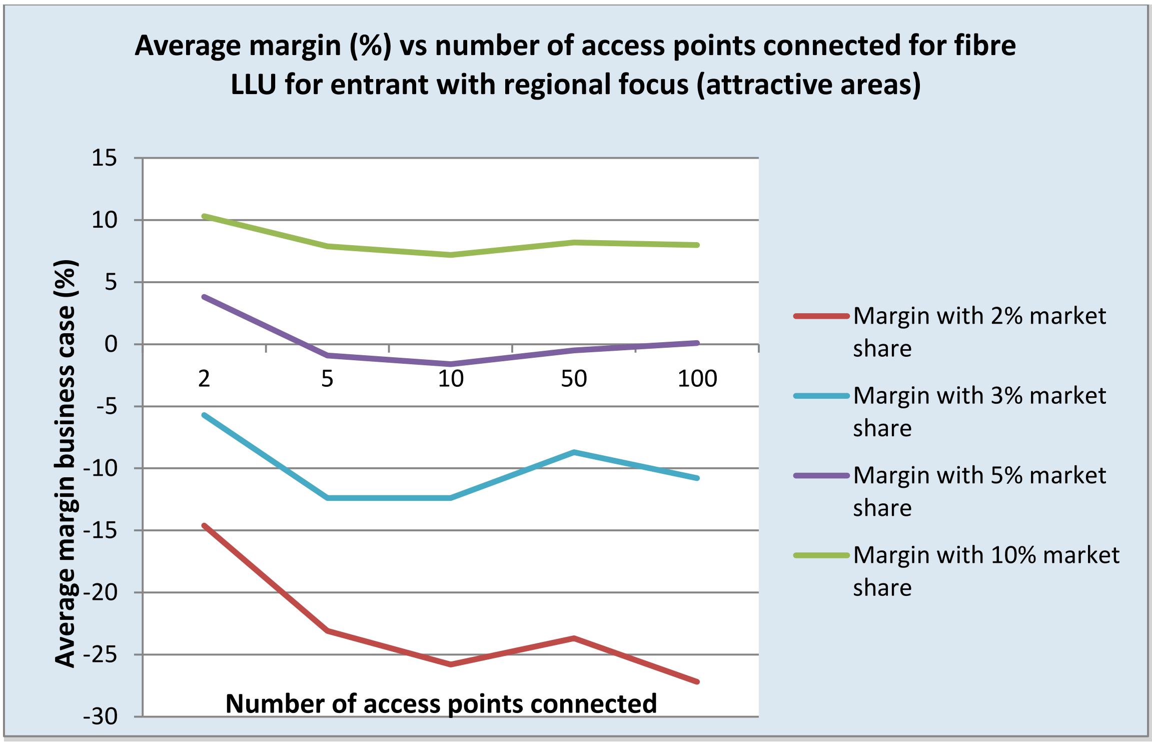
Also for comparison reasons, below Table 6-6 has an additional red marked column at the end intended to show where a profitable roll-out of the entrant stops. However, due to the negative results for the complete base case scenario of 2% there is no roll-out maximum and hence the column is empty.

Table 6-6: Results of the business case for scenario 5– Entrant with partial network coverage based on LLU for KPN's fibre network

Scenario 5 – Entrant with partial network coverage based on LLU for KPN's fibre network							
Marketshare (% of available homes passed on KPN's fibre network (depending on connected access points max [✂]))	**2%**						
Number of largest access points connected (max 161)	**1**	**2**	**5**	**10**	**50**	**100**	
Resulting number of customers for the entrant	[✂]	[✂]	[✂]	[✂]	[✂]	[✂]	
Resulting overall margin for the entrant's business case	**-0.2%**	**-14.6%**	**-23.1%**	**-25.8%**	**-23.7%**	**-27.2%**	

The different combinations of market share and number of access points connected are shown in Figure 6-2 below.

Figure 6-2: Business case margin for scenario 5: entrant with partial network coverage based on LLU for KPN's fibre networks and connected access points



Up to 5% market share an entrant would have a very limited business case as it could only profitable connect the 3 largest access points. Any roll-out beyond those 3 access points would render the business case negative or in the best case neutral with the effort of connecting up to 100 access points. This is due to the higher costs of connecting the separate unbundled fibres (and related port/equipment costs for the alternative operator) but also due to the fact that the access points in KPN's fibre network are linked to significantly less homes passed compared to KPN's copper network [✂] and also compared to VodafoneZiggo's coax network [✂].

An entrant would need to achieve at least 5.5% market share of homes passed before the business case becomes viable while allowing him to expand its roll-out. One could defend this high market share by assuming the entrant focuses its marketing approach very locally. However, this would assume that the largest access points for fibre are more or less geographically clubbed together.

6.2.6 Scenario 6 – Entrant with national coverage based on WCA for a coax network

For testing this scenario, the VodafoneZiggo coax model is used. In this scenario, the new entrant connects its core network with 2 handover points with a national coax network via WCA.

As there is no existing reference offer for coax WBA, the model applied the cost structure as observed for national WCA over KPN's copper and fibre network. When there are differences between copper and fibre cost components we have used for coax the fibre components as these networks are more similar. For the EVC we have used the asymmetrical components as the coax network is also asymmetric.

Table 6-7 below displays the different outcomes for the business case depending on market share achieved by the entrant.

Table 6-7: Results of the business case for scenario 6 – Entrant with national coverage based on WCA for VodafoneZiggo's coax network

Scenario 6 – Entrant with national coverage based on WCA for a coax network							
Marketshare (% of available homes passed on VodafoneZiggo's coax network [✂])	**0.25%**	**0.5%**	**1%**	**2%**	**3%**	**5%**	**10%**
Resulting number of customers for the entrant	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**
Resulting overall margin for the entrant's business case	**1.5%**	**8.9%**	**12.5%**	**14.4%**	**14.9%**	**15.4%**	**15.7%**

From [✂] customers (0.25% market share) the business case for WCA over coax is already positive. From 2% market share the profitability stabilises and slowly improves to 15%. Therefore this scenario is considerd economically viable. However, when comparing the business case for WCA over coax with WCA over copper, it is noted that an entrant would need a higher (1.5%) market share to reach a roughly comparable average margin (14% vs 16.8% for WCA). The lower margin for WCA over coax is due to the high volume discounts of KPN given on one time charges of WCA over copper (up to 15%). So if a WCA service over coax is considered, this difference should be balanced out in order for an access seeker to consider using VodafoneZiggo's coax infrastructure above KPN's copper/fibre infrastructure.

With a market share of 2% ([✂] customers), the wholesale costs are over 60% of the total costs, hence they have a significant impact on the profitability. Similar to WCA for copper, most of the wholesale costs increase also linearly with the number of customers. Variations in the wholesale costs of 10% lead to variations in the resulting margin of around 5%. ARPU is another important input; increases of 10% lead to almost 8% margin increase and decreases of 10% lead to almost 10% decrease in resulting margin.

6.2.7 Scenario 7 – Entrant with national coverage based on VULA for a coax network

For testing this scenario, the VofdafoneZiggo coax model is used. In this scenario, the new entrant connects its core network with all [✂] handover points with a national coax network via VULA.

Equal to scenario 6, due to the absence of existing wholesale access services for coax, KPN's WBA VULA cost structure is used for this business case. A further note is that a VULA service for coax with characteristics comparable with copper VULA and Fibre LLU only becomes available with Docsis 3.1 Full duplex, [✂].

See Table 6-8 below for an overview of the different outcomes for the business case depending on marketshare achieved by the entrant.

Table 6-8: Results of the business case for scenario 7 – Entrant with national coverage based on VULA for VodafoneZiggo's coax network

Scenario 7 – Entrant with national coverage based on VULA for a coax network							
Marketshare (% of available homes passed on VodafoneZiggo's coax network [✂])	**2.5%**	**0.5%**	**1%**	**2%**	**3%**	**5%**	**10%**
Resulting number of customers for the entrant	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**
Resulting overall margin for the entrant's business case	**0.0%**	**-190.0%**	**-71.3%**	**-11.9%**	**7.9%**	**23.7%**	**35.6%**

The business case for a new entrant connecting all [✂] handover points for VULA to have a national coverage only becomes positive from [✂] customers (2.5% market share of homes passed, which equals around 5% of homes activated). This is due to the high connecting charges of all the handover points and the related lower amount of homes passed connected to each access points (compared to KPN's copper network).

Considering the current market share of all alternative operators together (10-15%), 5% market share for another new entrant is quite high and therefore the economic viability of this scenario limited.

6.2.8 Scenario 8 – Entrant with regional coverage based on VULA for a coax network

For testing this scenario, the VodafoneZiggo coax model is used. In this scenario, the new entrant connects its core network only with the most attractive handover points in the coax network for the purpose of using VULA. The maximum number of access points is [✂].

Similar to scenario 7, KPN's WBA VULA service is used as input for this scenario. A further note is that a VULA service for coax with characteristics comparable with copper VULA and Fibre LLU only becomes available with Docsis 3.1 Full duplex, [✂].

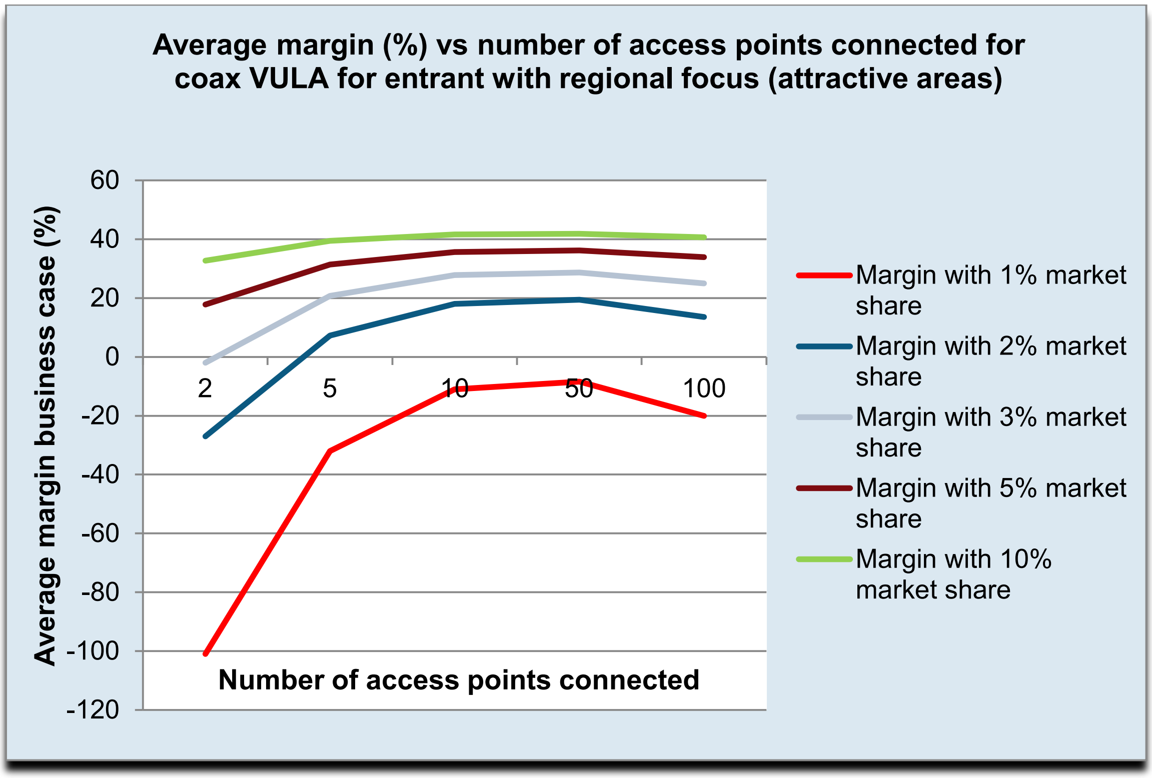
See Table 6-9 below for an overview of the different outcomes for the base case scenario of 2% market share. In the consequetive Figure 6-3 the other market shares are graphically displayed.

Table 6-9: Results of the business case for scenario 8 – Entrant with regional network coverage based on VULA for VodafoneZiggo's coax network

Scenario 8: Entrant with regional coverage based on VULA for VodafoneZiggo's coax network							
Marketshare (% of available homes passed on VodafoneZiggo's coax network (depending on connected access points max [✂]))	**2%**						
Number of largest access points connected (max [✂])	**4**	**2**	**5**	**10**	**50**	**100**	**75**
Resulting number of customers for the entrant	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**	**[✂]**
Resulting overall margin for the entrant's business case	**1.9%**	**-26.7%**	**7.5%**	**18.1%**	**19.5%**	**13.7%**	**16.6%**

So for an entrant with 2% market share, the business case becomes positive when the 4 largest access points (CMTS locations) are connected. Having between 10 and 50 access points connected, the margin grows to around 19%. The red column at the right displays that from having the 75 largest access points connected, the additional revenue does not justify the additional costs of rolling out your network further. This is the point where the absolute margin for the entrant is maximised.

Figure 6-3: Business case margin for scenario 8: entrant with regional coverage based on coax VULA for different market shares and connected access points



For an entrant with a market share of 1% (of homes passed), the entrant business case will not get viable. At least 1.5% market share (of homes passed, so roughly 3% of homes activated) and connecting the 7 largest CMTS locations are required. For 2% and 3% market share, the business case is positive from having respectively the 4 and 2 largest CMTS locations connected ([✂]). Therefore this option is considered economically viable.

This scenario is very well suited for an entrant operator acting very locally (for example in [✂]). However, for the base case scenario of 2% market share, the maximum roll-out is to 75 access points, hence one can assume that an entrant would not only focus on [✂] but will target a larger geographical area and is therefore able to cluster larger and smaller CMTS locations which are in the close vicinity of eachother.

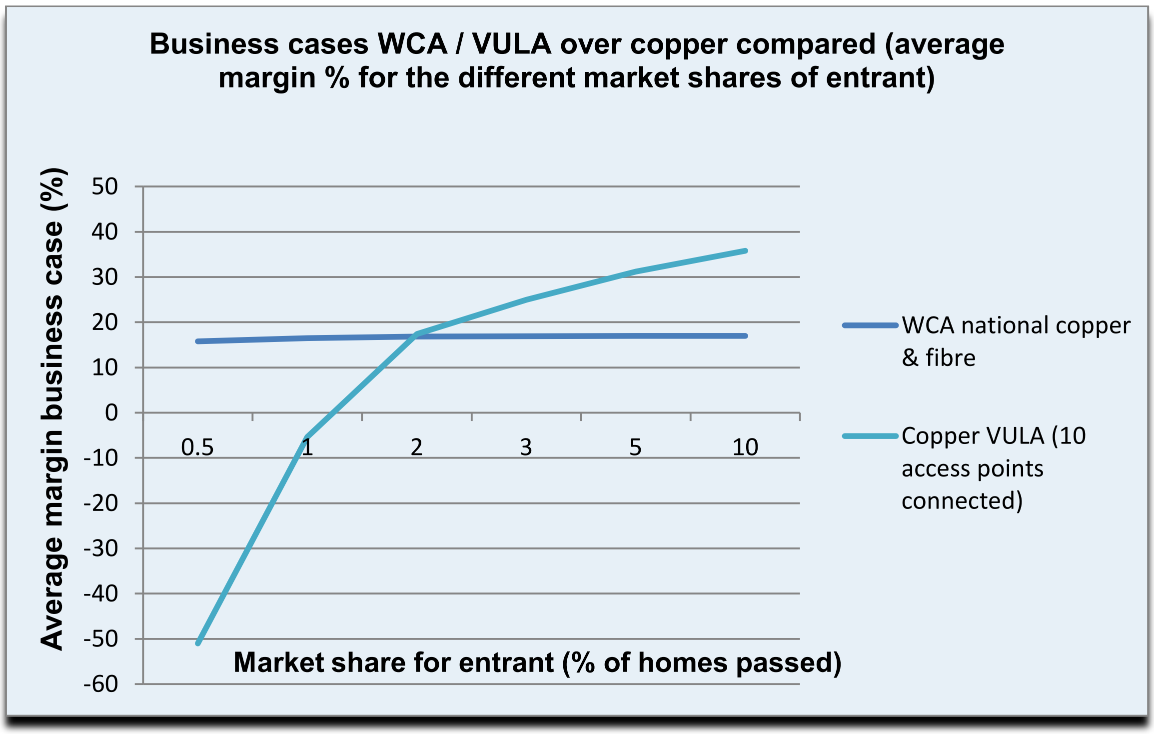
The coax model is also sensitive to wholesale costs and ARPU. Variations of 10% in the wholesale costs lead to variations around 4% of the resulting margin of the business case. A 10% increased ARPU leads to 7.3% increased margin, a 10% decreased ARPU decreases the resulting margin of the business case with almost 9%.

6.2.9 Switching from WCA to VULA/LLU on KPN's copper and fibre networks

From a certain scale onwards, it becomes attractive for an access seeker to connect at a lower level of the access provider's network in order to decrease its wholesale costs and to use wholesale services which enable them a higher degree of flexibility of designing their retail services (in terms of quality, available download speeds etc.)

An access seeker using WCA to access KPN's copper and fibre network has the option to use VULA for KPN's copper network and LLU for KPN's fibre network. Below Figure 6-4 compares the resulting business case margins from the national WCA scenario over KPN's copper and fibre network versus the regional focused VULA over copper scenario.

Figure 6-4: Comparison of using WCA by the entrant versus VULA for KPN's copper network



The dark blue line represents the business case of an entrant using WCA over KPN's copper and fibre network. AS noted before, it is clearly an economically viable option as an access seeker can achieve around 16.8% average margin from a low market share onwards (0.5%).

If alternative operators scale up with WCA over KPN's networks to 2% market share of homes passed, they can achieve a higher margin by combining WCA with copper VULA (light blue line) for targeted areas. However this is only if they take the effort of connecting to a minimum number of the 10 largest access points and or combine this with a higher market share (from 3% onwards) in the targeted areas. In those cases, an access seeker can achieve higher average margins compared to WCA (from 17% to 25%). As long as the alternative operator succeeds in growing and maintaining its marketshare of 3% in all areas, it can even roll-out to almost all 161 VULA access points with margins between 20% and 25% and getting the benefit of getting more product flexibility due to the VULA product over the WCA access product. However this applies only to the copper covered geographical area (and not the 30% households covered by KPN's fibre network).

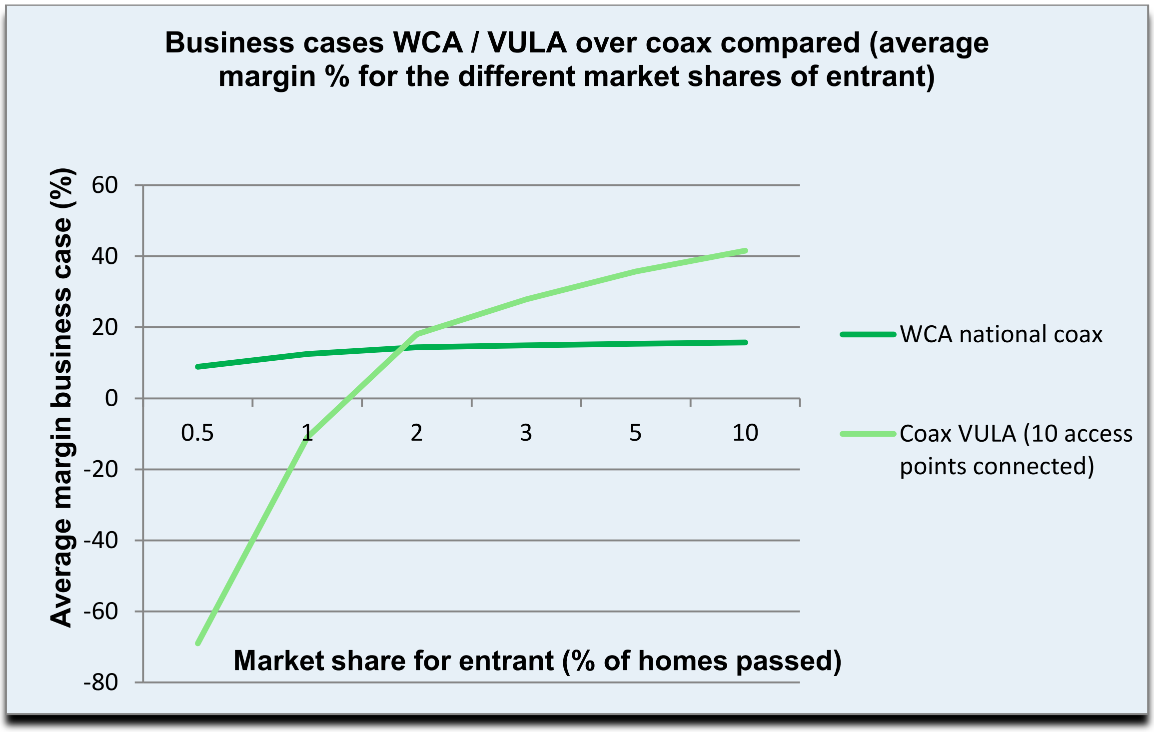
In combination with the above approach, an alternative operator might also consider targeting specific fibre covered areas and replace WCA by Fibre LLU (as VULA is not available for KPN's fibre network). However, due to the network structure and cost structure this makes economically no sense as even very high market shares from 10% of homes passed onwards will not result in a similar average margin as achieved with WCA (only around 7% versus 16.8% for WCA). Replacing WCA in all fibre areas by Fibre LLU is therefore not a viable option.

6.2.10 Switching from WCA to VULA on VodafoneZiggo's coax network

Similar to access seekers using KPN's networks, it would also make sense for an access seeker using the (currently hypothetical) WCA services over VodafoneZiggo's coax network to shift at a certain point to a (currently hypothetical) VULA service at the CMTS locations for certain areas.

Below Figure 6-5 displays the results of a potential WCA service over coax business case versus a potential regional VULA service over VodafoneZiggo's network.

Figure 6-5: Comparison of using WCA by the entrant versus VULA for VodafoneZiggo's coax network



The business case margin for WCA over coax is displayed in dark green and 14.4% for 2% market share. The business case margins for using VULA in targeted areas is displayed in lighter green. Similar to copper VULA, an entrant would need at least 2% market share in targeted areas while connecting the 10 largest access points to achieve a higher margin (18%) compared to WCA over coax.

VULA, however, will not be available before 2025 unless VodafoneZiggo's is forced to invest significantly in their network in the coming years and upgrade to DOCSIS 3.1 Full Duplex. On the other side, a bitstream service at CMTS location is a technically feasible option (but with different product characteristics as VULA) which should have lower costs compared to the WCA service with national hand over.

Due to the larger amount of access points for coax VULA compared to copper VULA ([✂] versus 161), it only makes economic sense for an entrant to connect up to 200 CMTS locations (connecting more would decrease the margin below the margin achieved by using solely WCA over coax with 14.4% margin).

7 Conclusions

The current and foreseeable future technical developments in fixed telecommunication infrastructures in the Netherlands are:

Copper Network Access:

- VDSL technology is widely deployed in the Netherlands. [✂].
- The next step in the evolution of the copper network could be the roll-out of G.fast. [✂], but focuses the implementation of Vplus (VDSL Profile 35b).
- The deployment of XG.fast in the Netherlands is not expected to happen in the near future.

Fibre Network Access:

- A PtP fibre network is currently deployed in the Netherlands. Passive PtMP topologies might be implemented in the near future. KPN confirmed that GPON technology has been tested, and it might be considered to be implemented in the future.
- [✂].

Cable Network Access:

- The VodafoneZiggo´s HFC network is based on DOCSIS 3.0, and [✂].
- Full Duplex DOCSIS 3.1 and/or XG-Cable require fibre to the last amplifier or beyond together with the installation of fully bi-directional amplification. Deploying fibre deeper into the network and the installation of bi-directional amplifiers would require significant time and investment. [✂].

The discussed technical developments were assessed on their impact on the whosale access options via LLU, VULA and WCA (chapter 4). The main findings are:

- DOCSIS network archtectures are shared media architectures which in principle are not suited for physical unbundling.
- An alternative to physical unbundling as defined in market 3a is virtual unbundling, which shall offer the wholesale seeker a similar product definition freedom as physical unbundling. This cannot be offered by the DOCSIS architectures, because they are in principle Layer 3 (IP) based.
- There are two major reasons for this restriction in the DOCSIS architecture:
  1. The handover protocol for a VULA should be based on Layer 2, because this allows for more product definition freedom than Layer 3. DOCSIS (all releases above 3.0) only support Layer 2 with a non mandatory add-on Business Services Over Docsis (BSOD), which is not implemented in most DOCSIS networks and also not in the VodafoneZiggo network.
  2. With and without BSOD there is a bandwidth scarcity problem in the upstream path, which becomes less restrictive with a network upgrade towards DOCSIS 3.1 and even better towards Full Duplex (FD) 3.1. FD is not yet standardized or available on the market.
- The implementation of DOCSIS 3.1 FD requires fibre to the last amplifier (FTTLA) with a huge fibre demand and investment.
- According to our Dutch market and international supplier interviews we see these investments not to be started to a sufficient extent in the Netherlands before 2025.
- WCA/WBA can be offered based on a Layer 3 protocol (IP) without major technical restrictions. The wholesale bandwidth sold is typically shared with all customers on that network. It is inefficient to use the IP-communication capacity for linear TV-Multicast. Such programs are expected to become available as resale.
- Any wholesale offer adds additional traffic in the DOCSIS transmission capacity.
- Any wholesale service offer in a cable-TV network, which today does not serve wholesale at all, requires changes in the BSS and OSS systems of the operator at significant additional cost, because these systems are not prepared for wholesale business or even multi-tenancy. (Small operators with a small number of wholesale end-customers may operate the business in a manual manner.)

The roll-out of FTTH [✄].

This may be supported by the competitive threat of the cable-TV networks.

In addition to the technical review, business case modelling has been done to review the economic viability of a business case for an entrant using the different wholesale access services over copper, fibre and coax networks in the Netherlands in a time span up to 2025. The main assumptions and the setup of the modelling are:

- The aim of the business case modelling is to assess the economic viability of technically feasible entry options for the access options of national WBA (WCA) based on copper, fiber and coax infrastructure, (regional) VULA based on copper and coax infrastructure and LLU based on fiber infrastructure.
- Economic viability is measured by the opportunity to generate profits from the roll-out in the long run. The built models follow a steady state approach.
- The entrant's customer base is determined as a percentage of the homes passed it can reach at the interconnection nodes he has access to according to his roll-out. Homes passed per access node are derived from actual data of KPN and VodafoneZiggo. For the (regional) roll-out it is assumed that the entrant will connect to those access nodes first that offer the highest customer potential (homes passed).
- The ARPU of the entrant is considered relative to the blended ARPU of the network incumbent. In the base case scenario a 10% discount for the entrant is assumed to reach its intended market share.
- On the cost side currently existing wholesale tariffs are used for WCA, VULA and ODF access to pin down the wholesale cost of the entrant including auxiliary services like co-location. For coax based entry we proxy the wholesale costs with the help of the existing wholesale tariffs for WCA and VULA of KPN to create a reference point in the coax case.
- For each access option the results compare total revenues and total costs and compute the profit margin to judge the viability of the access option.

The resulting 8 main scenarios are summarized in Table 7-1. It displays per scenario under which conditions the business case gets positive. The economic viability is indicated in colours: from (clearly) viable in dark and light green to neutral white and limited viability and difficult in light and dark red.

For all tested scenarios it is noted that the model results are sensitive for the applied ARPU and wholesale costs. Variations in the wholesale costs of 10% lead to variations in the resulting margin between 4% and 5%. Increased ARPU of 10% can lead to increased margin up to 8% where decreases in the ARPU of 10% can even lead to 10% decreases in margin.

Table 7-1: Overview of the tested business case scenarios and their respective break even points

Scenarios	Market share where business case positive	Number estimated customers for entrant	Margin (for the break even point)
1) National coverage with WCA KPN Copper & Fibre network	0.04%	[✂]	0.2%
2) National coverage with VULA KPN copper network	1.4%	[✂]	0.9%
3) Regional coverage with VULA KPN copper network	2% (3 access points connected)	[✂]	0.7%
4) Complete network coverage with Fibre LLU KPN fibre network	8.5%	[✂]	0.3%
5) Partial network coverage with Fibre LLU KPN network	5.5% (5 access points connected)	[✂]	0.8%
6) National coverage with WCA for VodafoneZiggo coax network	0.25%	[✂]	1.5%
7) National coverage with VULA for VodafoneZiggo coax network	2.5%	[✂]	0%
8) Regional coverage with VULA for VodafoneZiggo coax network	1,5% (7 access points connected)	[✂]	2.4%

Table 7-2 indicates for each scenario what the business case margin is for the base case scenario of 2% market share. In addition, we have mentioned an indicative margin for 10% market share. It needs to be noted that 10% market share of homes passed might only be realistic for an alternative operator focusing on certain areas (the regional business case) considering the current market shares of alternative operators in the Netherlands.

Table 7-2: Overview of the tested business case scenarios and their respective possible margins

Scenarios	Margin (for base case of 2% market share)	Indicative margin (for hypothetical 10% market share)
1) National coverage with WCA KPN Copper & Fibre network	16.8%	16.8%
2) National coverage with VULA KPN copper network	12.8%	34.8%
3) Regional coverage with VULA KPN copper network	17.4% With 10 largest access points connected	35.8% With 10 largest access points connected
4) Complete network coverage with Fibre LLU KPN fibre network	-55.6%	2.7%
5) Partial network coverage with Fibre LLU KPN network	-25.8% With 10 largest access points connected	7.2% With 10 largest access points connected
6) National coverage with WCA for VodafoneZiggo coax network	14.4%	15.7%
7) National coverage with VULA for VodafoneZiggo coax network	-11.9%	35.6%
8) Regional coverage with VULA for VodafoneZiggo coax network	18.1% With 10 largest access points connected	41.6% With 10 largest access points connected

As observed in the second column of Table 7-1, the scenarios in which an entrant targets the complete national market based on WCA are economically viable for KPN's copper and fibre networks but also for the (hypothetical) scenario for VodafoneZiggo's coax network (scenario 1 and 6). From small market shares onwards the business cases get positive and from a realistic market share of homes passed (2%) the margin reaches 16.8% and 14.4% respectively (see Table 7-2). The lower margin for the coax business case is explained by the significant volume discount (15%) for KPN's WCA service, which is applicable for its copper network only.

An entrant could target the complete national market as well based on VULA for KPN's copper network (scenario 2) and LLU (scenario 4) for KPN's fibre network or via (hypothetical) VULA for VodafoneZiggo's coax network (scenario 7). There are significant one-time costs for VULA and there are more and also smaller access points to be connected by the entrant compared to WCA with 2 handover points (see Table 7-3 below).

Table 7-3: Access point size per operator

Network	Average number of homes passed per access point
KPN copper (metro core locations)	[✂]
VodafoneZiggo coax (CMTS locations)	[✂]
KPN fibre (ODF locations)	[✂]

As a consequence, for an entrant with a market share of 2% of homes passed its business case covering the complete KPN copper network based on VULA is delivering a lower margin than using WCA (12.8% versus 16.8%). When the achieved market share of the entrant goes beyond 2.5% market share the resulting margin becomes higher than using WCA (18.3%). Therefore, this does not stimulate an entrant to use copper VULA at a national level (scenario 2) unless it considers a market share of 2.5% of homes passed achievable or if it decides that it requires the better product characteristics of VULA versus WCA.

Using VULA throughout VodafoneZiggo's coax network (scenario 7) is due to the high number of access points strongly negative for the base case of 2% market share (-11.9%). Only from 2.5% onwards the business case gets positive and only from 4% market share for the entrant the resulting margin is higher than using WCA over coax (17.8% versus 15%).

Due to the even lower average number of homes passed in KPN's fibre network, the business case for covering all of KPN's fibre network based on LLU (scenario 4) becomes only positive with very high market shares (8.5% of homes passed). Even at a hypothetical 10% market share the resulting margin for the entrant is 6 times lower than using WCA (2.7% versus 16.8% margin). This makes it unlikely than an entrant using WCA will shift to using LLU on KPN's fibre network.

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