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DSL in the Dutch Consumer Broadband Market

Innovation is about more Bandwidth

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Customer KPN

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Summary

Situation

The development of fixed consumer broadband networks is of crucial importance for socioeconomic development. In the Netherlands, there is a strong competition between broadband from DSL and cable with a somewhat smaller role for fibre.

Request KPN

KPN has asked TNO to provide an overview of the necessity, technical possibilities and limitations of the further upgrade of the Dutch DSL networks. In addition KPN has asked to assess the technical impact of the current regulatory regime on the further development of DSL networks in the Netherlands.

Research questions

KPN's request is broken down in four questions:
- What is the position of DSL in the current broadband market?
- What is the status of DSL technology, the current Dutch DSL networks, which further innovations are foreseen or possible and which DSL network features are most urgent to improve?
- What is from the technical viewpoint the impact of loop unbundling on the further DSL network innovations?
- What is from the technical viewpoint the added value of subloop unbundling as compared to wholesale broadband access to differentiate and innovate DSL services?

Approach and sources

In order to address these questions, TNO has performed desk research of publicly available sources, like technical standards, reports of industrial meetings and press releases. TNO has combined this information with its own expertise in copper networks with DSL technology.

Conclusions

Consumer broadband from cable is gradually overtaking broadband from the Dutch DSL networks. A higher DSL bit rate is needed in the future to compete with cable and to stimulate the development of new broadband services.

The DSL offer from the central office is limited in two ways:
- The bit rate of ADSL2+ is insufficient and from this perspective ADSL2+ is becoming outdated,
- The bit rate of VDSL2 from the central office is a modest 40/4 Mbps, but even more important is that only 20% of the market can be reached.

Therefore, there is a need to upgrade DSL networks to VDSL2 from the street cabinet, thus increasing the coverage to 90%.

VDSL2 with vectoring currently is the superior DSL technology for deployment from the street cabinet. The alternative, VDSL2 without vectoring cannot match the bit rate of VDSL2 with vectoring.

Subloop unbundling with two or more DSL operators in the same street cabinet is incompatible with VDSL2 with vectoring. It would greatly reduce the bit rates. From the viewpoint of the highest bit rate, the obligation of subloop unbundling should be lifted.

A mixed deployment of VDSL2 services from the central office and the street cabinet with a cable length ranging from 1000 up to 1500 m, would have a large negative impact on the VDSL2 services from the central office as well as on those from the street cabinet. Moreover, the possibilities of spectral management to repair the bit rate loss appear limited. Therefore, from the viewpoint of innovating towards the highest bit rates, VDSL2 systems in the central office should be phased out to enable VDSL2 services from the street cabinet.

The analysis shows that for consumer DSL services from the street cabinet in the Dutch market, subloop unbundling does not provide:

- Additional technical options to differentiate broadband services as compared to wholesale broadband access based on a network with state-of-the-art VDSL2 with vectoring from the street cabinet,
- Technical options for DSL network innovation for third parties beyond the level of state-of-the-art VDSL2 with vectoring from the street cabinet.

In summary, the analyses in the previous two paragraphs show that existing local loop and subloop unbundling obligations are currently limiting further DSL network innovation.

The analysis in this report is valid for the next two to three years. After these two to three years, G.fast technology will become available in the market. In addition to G.fast, solutions to mitigate cross-talk from alien lines in VDSL2 with vectoring could be developed by then as well. Since these new technologies create new options for network innovation and third-party service differentiation, this analysis needs to be evaluated again after two to three years.

Removal of regulated subloop unbundling and closing down VDSL2 services from the central office will affect the business interests of the current third parties. In this report, considerations of this nature have not been taken into account.

1 Introduction

Modern ICT technologies combined with consumer fixed broadband networks are the main drivers for socio-economic innovation. In international rankings, the Dutch broadband networks are positioned at the top [1].

In the Netherlands two infrastructures have a (nearly) national coverage for fixed consumer broadband: cable and DSL. Cable consists of the hybrid fibre coax networks of the various cable companies. DSL utilizes KPN's twisted-pair copper access network. A detailed description of the cable and DSL networks, their capabilities and future development is given in an accompanying report [2].

As argued in [2], Dutch cable networks are strong rivals of the DSL networks in the consumer broadband market. To compete with these networks and to create a sustainable competitive position, innovation of the DSL networks to deliver higher bit rates is essential.

In the Netherlands, the twisted-pair copper access network of KPN is subject to local loop unbundling and subloop unbundling regulation and wholesale broadband access regulation. Under the provisions of local loop unbundling and subloop unbundling regulation, KPN has to provide other third parties access to individual copper lines. Local loop unbundling has led to a situation in which multiple operators have their own DSL platform in central office locations to provide broadband services to their customers. In the case of wholesale broadband access, a third party can serve its customers using the DSL platform of KPN.

The market liberalization and the ex ante regulatory regime including the local loop unbundling have been important for the development of broadband in the Netherlands. However, considering the most recent DSL technologies, loop unbundling could have a counterproductive effect on the development of the DSL networks, thus limiting their possibility to compete with consumer broadband from the cable.

Considering the need to deliver higher bit rates with DSL networks, there is a concern that further DSL network innovation is hampered by:

- The current deployment of VDSL2 from the central office. These services, could limit the deployment of VDSL2 from the street cabinets because of spectral interference,
- The current obligation of subloop unbundling which could be an obstacle for the use of the most advanced DSL technologies.

Since network innovation of the DSL network is crucial to remain competitive with the cable infrastructure in the consumer market, KPN has asked TNO to provide an analysis on the need and possibilities of DSL network innovation in the Netherlands and to indicate the barriers for such innovation.

To protect the investments and interests of the current third parties, viable alternatives should be identified for wholesale services that appear to hamper DSL network innovations.

The analysis is focussed on the technical aspects of DSL network innovations. Clearly, these innovations may have a large impact on the business interests of current third parties. This analysis does not include these business interests.

This analysis only concerns the consumer broadband services and not the DSL services for the business market. Therefore, the analysis only applies to consumer market services.

This paper is organized as follows. First we analyse the Dutch broadband consumer market developments and substantiate the need for DSL network innovations in section 2. In the next section we provide a review of DSL technology and network innovations, and match the capabilities of the different DSL technologies with the foreseen market demands. With this knowledge we analyse the options to optimize and upgrade the DSL networks in section 4. For a proper understanding of the issue, we elaborate on the impact of loop unbundling measures on the bit rate performance of DSL prior to the elaboration on the options of DSL network upgrades and its impact on the current regulatory arrangements and on the business interests of the third parties. To conclude, we address the question of the added value of subloop unbundling with respect to wholesale broadband access to differentiate services and stimulate innovation in section 5.

2 DSL and Cable in the Dutch Market

In this section we present and discuss the current status of DSL and cable networks in the Dutch broadband market. Specifically we will consider the position of DSL broadband services in the Dutch broadband market in subsection 2.1 and the development of the end-user services and their bit rate demand in subsection 2.2. To conclude we compare the broadband DSL and cable propositions in subsection 2.3.

2.1 Competition from cable

In the Netherlands, DSL and cable networks both have almost 100% coverage while fibre to the home (FttH) has reached about 28% coverage [3].

The quarterly telecom market study by the Dutch Authority Consumer Market (ACM) shows a continuous increase in cable broadband subscriptions during the past two years, whereas DSL subscription numbers are constantly declining, see Figure 1 [4]. In December 2013, cable and DSL respectively had 3.139 and 3.118 million subscribers.

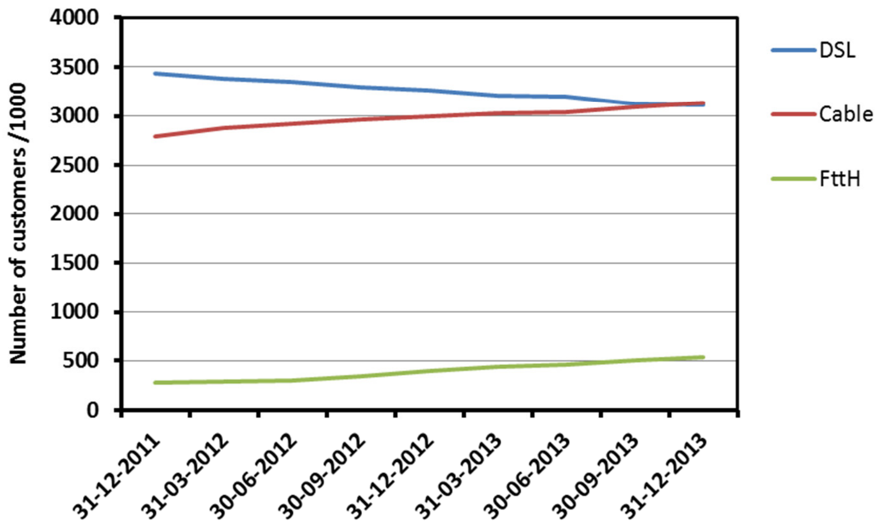

Figure 1 Development of the DSL, cable and FttH broadband market shares. Source: Dutch ACM [4].

The ACM market study presented in [4] included the market shares of DSL, cable and FttH with various broadband profiles, ranging from services with a low bit rate up to those with a bit rate of 100 Mbps or more (see Figure 2). The data of December 2013 show that although cable and DSL have approximately equal market shares, cable dominates the market for services with a bit rate between 30 and 100 Mbps, whereas DSL dominates that of services with a bit rate of 30 Mbps or less. This observation agrees with the conclusion of a study of Dialogic and TNO commissioned by the Dutch Ministry of Economic Affairs that without deployment of an fibre to the curb (FttC)) architecture DSL networks cannot deliver the high bit rates that can be delivered by cable and FttH [5].

In this context, it is worth mentioning that Ziggo, the largest Dutch cable operator with about 1.9 million broadband customers, has increased its service bit rates in 2013 and has implemented a further increase in the spring of 2014 [6], [7]. Ziggo's basic broadband subscription thus is upgraded from 8/1 Mbps in Q1 2013 up to 30/3 Mbps. When including the Ziggo 2014 subscription upgrade in the data of Figure 2, the position of cable in the markets for services with a bit rate above 30 Mbps will further develop, thus widening the gap between cable and DSL.

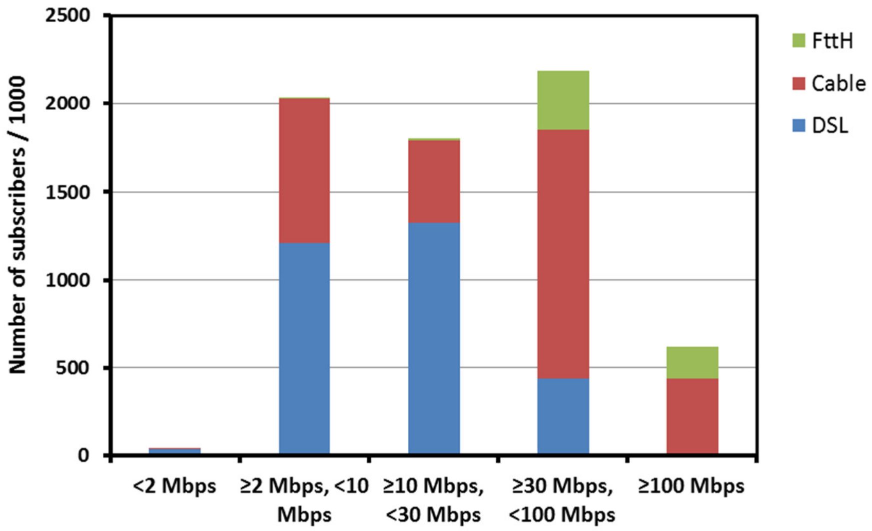

Figure 2 The market shares of DSL, cable and FttH with a bit rate less than 2 Mbps, between 2 and 10 Mbps, 10 and 30 Mbps, 30 and 100 Mbps and above 100 Mbps. Source: Dutch ACM [4].

DSL Broadband bit rates lag behind cable bit rates. To remain at an equal level, bit rates of DSL have to be increased.

2.2 New consumer broadband services

Since the beginning of the internet, the bandwidth demand shows an annual growth of 30 - 40%. For the next years, a traffic growth of about 30% is foreseen [9].

The ample availability of broadband and of tablets and smartphones on which apps for new services are easily installed arguably has fuelled the development of services, including substitutes of the operators premium[1] telephony and television services that are delivered via the internet, the so-called over-the-top (OTT) services. Smart TVs may provide a further boost to the development of OTT services. To list just some examples that will benefit from more bandwidth:

- Skype and web real time communications (webrtc) offer an alternative for telephony services,

[1] In this paper, 'premium services' refers to end-user services with good and guaranteed image, audio, and voice properties and auxiliary properties such as a short delay for telephony and fast zapping for television. Today, such premium services are delivered via fully operator-controlled networks.

- Spotify, Netflix, TV stations,
- Security services like camera surveillance,
- E-Care, e-health and e-learning,
- Cloud services to store photographs, video and other private content,
- Network virtualization of for example home gateway functionalities [10].

Most interesting is the OTT delivery of voice and video services. These services are delivered without a so-called managed network, as explained in subsection 3.5. Apparently, today's networks are sufficiently developed in terms of the bit rate to deliver such services with a quality that is accepted in the market.

From the viewpoint of the DSL network capabilities, in particular new video services like ultra-high definition (UHD) television are most demanding. As an illustration of the bit rate demand of television including UHD-1[2] television, we present some bit rate indications in Table 1. For a good UHD-1 television image quality with a rate of 50 frames per second, a bit rate of about 30 Mbps is needed. Content producers have already adopted UHD-1 and produce movies in this format. Netflix and Amazon offer content in UHD-1 [8]. Samsung announced a partnership with Netflix and Amazon to provide content for its new UHD-1 TV sets [11]. Existing content is also updated. Currently all major television manufacturers have UHD-1 television sets in their portfolio for prices that are rapidly decreasing, whereas the newest tablets have UHD-1 screens as well. TV manufacturers are expected to sell some 12 million UHD-1 TV sets worldwide in 2014, a number that will rise to 62 million in 2017 [12]. A sufficient penetration of UHD-1 TV sets and a sufficient availability of 4k content are crucial for the success of UHD-1 TV, but clearly content producers and manufacturers work together to create this condition.

Table 1: Video services, video codecs and the bit rates required for a reasonable and good image quality. Source TNO and [13].

	Codec	Mbps
SD TV	MPEG-2	4 – 8
SD TV	MPEG-4 AVC / H.264	2 - 4
HD Ready TV (1080i/720p)	MPEG-4 AVC / H.264	4 - 8
Full HD TV (1080p)	MPEG-4 AVC / H.264	6 – 12
UHD-1 TV @ 25 fps[2]	MPEG-4 AVC / H.264	15 - 30
UHD-1 TV @ 25 fps	MPEG HEVC / H.265	10 - 20
UHD-1 TV @ 50 fps	MPEG HEVC / H.265	15 - 30

Many new video-based services and applications have been developed during the past two or three decades, for instance videophone, videoconferencing, the virtual class room, the virtual doctor, camera surveillance, etc. Until now, these

[2] UHD-1 TV refers to a 4k video format with 2160 x 3840 pixels. Frame rates and other parameters are currently under development and standardization. The term "UHD-2" is reserved for 8k video formats.

applications have not been rolled out on a wide scale. In recent years a number of developments facilitating these services have come together:

- tablets and smart televisions combine an appropriate user interface with large computational power and easy installation of application software,
- IP-based broadband networks have reached maturity and a large penetration,
- IP video technology has mastered the delivery of high-quality television services.

These developments have created new conditions for the development of advanced video-based services and applications.

The current broadband networks have enabled innovation, which is flourishing at the service level. Service providers are exploring the possibility to deliver over-the-top voice and video services, without the use of a managed service lane. Some of the new services like UHD-1 TV require networks with a bit rate of about 30 Mbps.

2.3 Service propositions for cable and DSL

Current consumer offerings of the Dutch cable and DSL providers are more or less similar with a focus on 'triple-play' bundles consisting of:

- Broadband internet,
- Premium telephony services,
- Premium television and video services.

A summary of the consumer offerings (April 2014) is given in Annex A. Below we present a more qualitative comparison, to highlight the differences.

Consumer broadband internet from cable and from DSL consists of best-effort internet of a mainly asymmetrical nature with downstream bit rates between 8 and 200 Mbits and as a rule upstream bit rates about 10 times smaller. As already pointed out in subsection 2.1, the current DSL services cannot meet the maximum bit rates of cable. Furthermore, DSL has some more disadvantages:

- In the DSL network, the available bit rate is used to deliver the best-effort internet service and the premium television and video services. Thus, when watching television, only part of the bit rate can be used for internet access,
- The bit rate of DSL decreases for longer copper lines. On top of this lower bit rate, crosstalk between copper wires often yields a further bit rate reduction [2].

Premium telephony from cable and DSL networks is largely a VOIP-based voice service that is managed by the operator and which can be used by consumers with their fixed or wireless telephone.

Most Dutch DSL and cable digital television and video offers are more or less comparable[3].These offers comprise *i)* a basic package of about 50 or more digital channels, including the Dutch and Belgian public channels and main commercial channels targeting the Dutch market with at least 10 channels in HD, *ii)* additional thematic packages and *iii)* catch-up television. On top of this television proposition, the large operators have a video-on-demand offer. In both infrastructures, these services are delivered via a managed service lane, thus guaranteeing the quality of

[3] Online and Canal Digital combine the broadband offer with terrestrial and satellite television.

the service [2]. Cable providers as well as KPN have introduced a so-called ‘second screen’ service to watch television on a tablet. In summary, we note that in terms of the type of television services and the number of channels, the Dutch cable and DSL operators have a comparable offer. However, there are some structural differences between the cable and DSL television offers too:

- For a DSL line the number of channels that can be simultaneously delivered to a home is limited by the line bit rate. Cable, in contrast, simultaneously delivers all channels to the customer.[4] In particular for DSL customers with an ADSL2+ connection and the 10-15 Mbps bit rate that can be delivered with such a line [2], the limited throughput is becoming a restriction to watch programmes on two television sets. Table 2 gives an illustration of the network capabilities of ADSL2+, VDSL2 and cable. To solve the problem of simultaneous watching and recording the DSL operators offer a network personal video recorder (PVR) service,
- Since the available capacity of DSL and in particular ADSL2+ is limited, DSL providers use lower video encoding rates for their television services.

Table 2: Network capability to simultaneously deliver best-effort internet and television services. Source: TNO

Simultaneous Services			Network[5]		
BE Internet	TV	Combined bit rate[6]	ADSL2+	VDSL2 from central office	Cable
5	1 Full HD	11	+/-[7]	+	+
5	1 Full HD + 1 SD	13	+/-	+	+
15	1 Full HD + 1 SD	23	-	+	+
30	2 Full HD	42	-	+/-	+
30	3 Full HD	48	-	-	+
60	3 Full HD	78	-	-	+

Analogue television is still used by many cable customers but in line with a continuously rising market share of digital television, it can be expected that this use will reduce over time. Clearly, the availability of HD channels and HD television sets

[4] In practice, cable providers offer their customers 3 smart cards, thus limiting simultaneous watching/recording.
[5] The bit rates that can respectively be delivered by ADSL2+ and VDSL2 are 10-15/1 Mbps and 40/8 Mbps [2].
[6] The bit rates for the television services are taken from Table 1 assuming MPEG-4 AVC / H.264 coding.
[7] Legend: ‘+’: can be delivered to all customers, ‘+/-’ can be delivered to most customers and ‘-’ can be delivered to few or none of the customers. The network capabilities are taken from *Table 3*.

is a driver for digital television. It can be expected that cable operators will reduce and eventually eliminate analogue services to free up spectrum for broadband services. Two Dutch cable operators (CAIW and Rekam) already have switched off analogue, but such a drastic policy has not found any followers so far. Apparently, analogue television still is a differentiator, but, looking at the future, one of diminishing importance.

Apart from the analogue television service, DSL and cable operators have comparable consumer triple-play service propositions, provided the DSL connection delivers a sufficient bit rate. Specifically for ADSL2+ the limited bit rate of many lines is becoming a restriction to deliver a full-fledged triple-play service offer.

2.4 Summary

In this section we have argued that broadband bit rates for DSL lag behind cable bit rates while new services and new over-the-top service delivery models continuously appear. Some of the new services like UHD-1 TV require networks with a bit rate of 30 Mbps or even more.

Apart from the analogue television service, DSL and cable operators have comparable consumer triple-play service propositions, provided the DSL connection can deliver a sufficient bit rate. Specifically for ADSL2+ the limited bit rate of many lines is becoming a restriction to deliver a full-fledged triple-play service offer. Moreover, considering the rapid development of the cable broadband proposition, it is questionable if even an upgrade to VDSL2 with a 40/8 Mbps bit rate will be sufficient to catch up.

Therefore, to stay competitive with cable networks, the Dutch DSL networks have to be upgraded to deliver higher bit rates.

3 Evolution of DSL technology and innovation in the DSL networks

In this section we will give a summary of the past and forthcoming DSL technology and DSL access network innovations. This summary is intended to provide the scope of the innovation possibilities of DSL networks and identify what further innovations are needed and foreseen.

Innovation in communication networks can be seen as a two-step process with two actors, the network equipment manufacturers and the network operators. First, the manufacturers have to develop and produce the technology and next the operators have to develop the deployment concepts and subsequently deploy the technology in the networks. Although both actors have shared interests, their specific activities are driven by their own business interests and are therefore not necessarily always aligned. In the following we will discuss the development of the DSL networks from this two-step innovation process.

3.1 DSL technology evolution

Driven by broadband market demand of the past decades, telecommunication equipment manufacturers have developed a series of DSL transmission technologies: ADSL, SDSL, ESDSL, ADSL2, ADSL2+, VDSL, VDSL2 and most recently G.fast. An overview of these technologies can be found in paper [2]. As an illustration of the capabilities of such technologies we show the performance of ADSL2+ and VDSL2 in Figure 3. In addition, manufacturers have developed a series of technologies to boost the performance of these technologies like vectoring which cancels crosstalk noise and bonding of two copper lines [2].

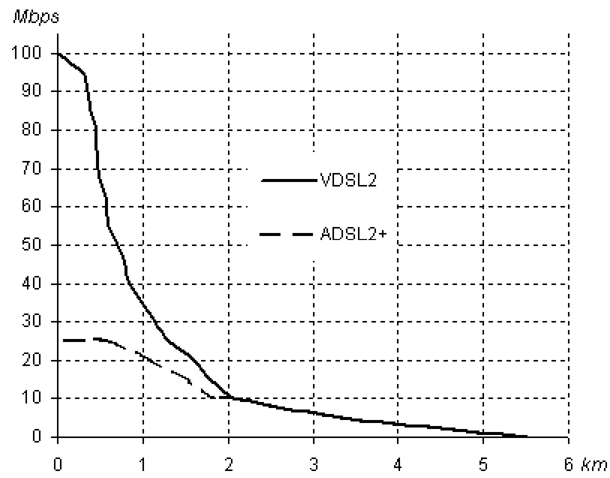

Figure 3. The bit rate of ADSL2+ and VDSL2 versus the length of the copper line. The data do not account for crosstalk noise, and as such the bit rates are optimistic. Source: Alsotel

The manufacturer's decision to develop these technologies is based on economic considerations in terms of the added value and the foreseen demand. Vectoring is an attractive technology because it boosts the average bit rate of the VDSL2 lines by a factor two [14]. In addition, by elimination of the large statistical bit rate spread of VDSL2 for copper lines of the same length, a homogenous service is created [2].

For the vectoring scheme to work, all the VDSL2 lines in a cable must be connected to the same ‘vectoring group’ in which the coordination of all the transmit signals takes place. It is widely accepted in the xDSL industry that the presence of even a few lines not connected to the vectoring group (so-called “alien” lines) can destroy most of the vectoring benefits [3] [15]. This property makes vectoring very hard to combine with sub-loop unbundling, i.e. a situation where different operators have their own DSLAMs located at the cabinet. A few companies claim that their solutions can mitigate this impact somewhat, but the general industry consensus is that the impact of alien systems will remain very large [16][17]. Moreover, to the knowledge of TNO, DSL equipment manufacturers have not placed such solutions to mitigate cross talk of alien lines on their roadmaps. Therefore, it appears unlikely that these could become available during the next three years[8].

Bonding too, yields a doubling of the average bit rate of the DSL service; though the large statistical spread of the bit rate of the lines is not eliminated. Incidentally, in case of two good wire pairs, bonding without vectoring could yield a higher bit rate service than vectoring using a single copper line. However, the bit rate of two bonded lines without vectoring cannot match that of two bonded lines with vectoring. The average bit rate of VDSL2 with bonding and vectoring is twice that of VDSL2 with bonding and no vectoring. Therefore, from the viewpoint of the bit rate, VDSL2 with vectoring has to be considered as the superior technology, with or without bonding.

For bonding two wire pairs are needed, and there are only few countries with telephony networks with two wire pairs in the access network, making the equipment more costly. In addition, the provisioning of two lines is more complicated which results in extra provisioning costs [18]. Therefore, VDSL2 with bonding is a more expensive product than VDSL2 without bonding.

At universities and in the research and development laboratories of the manufacturers there still are novel concepts and technologies that can improve DSL bit rates, but because of a smaller added value and a limited market demand are not likely to be taken into production. Phantoming is an example of such a technology. Phantoming yields a bit rate gain of about 30%, which is rather poor as compared to the 100% bit rate improvement of vectoring and bonding, and in addition it requires two wire pairs. For these reasons, manufacturers currently do not further pursue this technology. Moreover, to the knowledge of TNO there are no initiatives or projects to standardize this technology so far. Therefore, even in the most optimistic case it would take several years to standardize phantoming technology and to start production of the equipment.

G.fast is a more promising technology that can deliver bit rates up to about 1 Gbps [2]. Recently, the standard has obtained the first-stage approval in ITU [19]. The technology will be available in the market by 2016 – 2017 [2]. For G.fast, the copper lines have to be shortened further, down to several hundreds of meters. Therefore, G.fast is positioned as a technology for future upgrades, after the upgrade to VDSL2 from the street cabinet.

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[8] Since interoperability between equipment of different vendors is essential in a solution to mitigate cross-talk of alien lines, standardization and interoperability testing of the technology is needed. Because standardization has not started, it can be safely assumed that within the next three years such a technology will not appear on the market.

3.2 Past DSL network innovations

Up to today, the network operators have built and innovated their digital access networks using the subsequently developed DSL technologies. In the year 2000, KPN built the first commercial ADSL internet access network, MxStream with a 1024/256 kbps service [21]. In the same year, the KPN network was opened and various third parties built their own fibre networks to the KPN central offices and installed their own DSLAMs with ADSL technology using the regulated KPN unbundled local loop wholesale offer. A few years later, in 2004, when more advanced ADSL2 and ADSL2+ technologies arrived on the market, third parties rapidly deployed these improved ADSL systems to improve their service bit rates. Over the following years, third parties took the lead in further network innovations, and subsequently they introduced new enhanced symmetric subscriber line (E-SDSL) technology for the business market (2005) and VDSL2 technology from the central office (2007). Figure 4 gives an indication of the time line of the DSL network innovations of Dutch third parties and KPN.

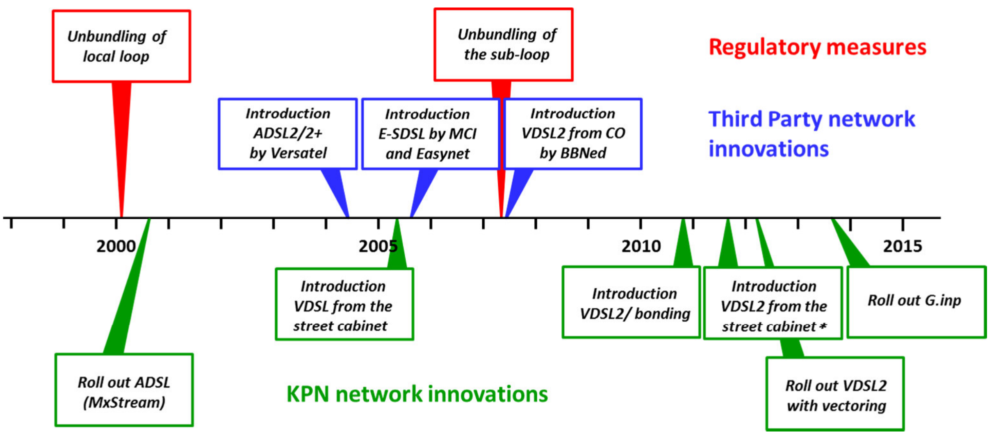

Figure 4: Time line of the first deployment of new DSL technologies in the Netherlands by third parties or KPN. The technology introduction dates are approximate, as there typically is a significant lead time between first discussions and (substantial) roll-out of a new technology.

3.3 The need for further DSL network innovations

For ADSL and ADSL2 frequencies up to 2.2 MHz are used. To further increase the bit rate, ADSL2+ and VDSL2 use frequency spectrum above 2.2 MHz. Due to the small signal attenuation, the lower frequency spectrum can be used to convey digital information over longer distances. In contrast, higher frequency signals experience stronger attenuation, and can therefore only be used to convey data over shorter lines, not over long ones. Thus, higher frequencies can be used to increase the bit rate of short wire pairs as illustrated for ADSL2+ and VDSL2 in Figure 3. A summary of the performance of the different DSL technologies when deployed from the central office or from the street cabinet is given in Table 3.

Table 3: Summary of the downstream and upstream bit rates for the various DSL technologies. Source: [2].

	Bit rate DS/US (Mbps)	
	Max.	**Market Majority**
ADSL2+ / CO	24/(1-2)[9]	(10-15)[9]/1
VDSL2	50/10	40/8
VDSL2 plus Vectoring	100/30	80/16
VDSL2 plus Bonding	100/30	80/16
VDSL2 plus Vectoring + Bonding	200/60	160/32
G.fast	About 1000[10]	About 500[10]
G.fast plus Bonding	About 2000[10]	About 1000[10]

The copper lines from the central office are rather long, up to 6–7 km, but customers living nearby have short lines. Therefore, an operator can offer those customers with a short line to the central office a service with a higher bit rate using higher frequencies, without having to invest in the deployment of VDSL2 from the street cabinet. As shown in Figure 3, the bit rate gain of VDSL2 as compared to ADSL2+ for wire pairs of 500 m and less is huge, but for longer lines the gain strongly declines and for lines longer than 2 km there is no advantage any more.

In the Netherlands, the copper lines with a length of 1 km or less from the central office serve about 20% of the market and the lines of 2 km or less 40%. Hence, when VDSL2 is deployed from the central office, 60% of the market cannot be offered a higher bit rate, 20% of the market can have an attractive but limited improvement of the bit rate and only 20% can have the full benefits of VDSL2. In contrast, the copper lines with a length of 1 km or less from the street cabinet account for 90% of the market. Thus, when VDSL2 is deployed from the street cabinet, a high bit rate can be delivered to 90% of the Dutch market instead of 20% of VDSL2 from the central office.

In summary, to deliver a higher bit rate there are two options:

A. The operator can place VDSL2 technology that uses higher frequencies in the central office. In this way a higher bit rate can be offered to only 20–40% of the homes,
B. The operator can invest in deep fibre, new DSLAMs with VDSL2 technology and possibly new street cabinets [2]. Thus higher bit rates can be offered to more than 90% of the homes.

From the purely technical and market reach viewpoints, it would be best to choose for option B. However, for economic or business reasons, operators could prefer option A.

The data in Figure 4 show that the Dutch third parties have rolled out new DSL technologies from the central office, but that they have not deployed DSL technology from the street cabinets. To the knowledge of TNO, the Dutch third parties have not announced plans to significantly invest in networks with DSL

[9] Because of the statistical nature and various technical uncertainties, it is not possible to give a specific and undisputable value. Instead we indicate a typical bit rate range, see paper [2].
[10] The aggregate bit rate of the US and DS is given.

deployed from the street cabinet, i.e. option B. In contrast, KPN has started the upgrade to VDSL2 from the street cabinet in 2011 for cabinets with a cable length of 1500 m or more to the central office, and by now the upgrade of these street cabinets is approaching completion[11]. Moreover, KPN has announced further investments in VDSL2 from the street cabinet as part of its network strategy.

In section 2 we concluded that the DSL networks have to be upgraded to deliver higher bit rates. In particular the analysis showed that ADSL2+ cannot compete with cable bit rates and only allows the delivery of an already limited service offer. However, taking into account the progress of the market, of the new services and of the broadband bit rates from cable, arguably even a 40/8 Mbps offer of VDSL2 from the street cabinet will be of limited value to remain competitive. To stay in the race, VDSL2 with vectoring, possibly in combination with bonding, is probably needed. VDSL2 with vectoring would create more head room to stay competitive for a longer time.

3.4 DSL technology and network innovations to improve DSL line quality

The DSL bit error rate and packet loss on the one hand and the bit rate of the line on the other hand are correlated parameters. Using error coding techniques, bit errors and packet loss can be reduced, but error coding consumes part of the available bit rate. In the networks some lines are more susceptible to crosstalk noise than other lines. To minimize the throughput loss, the error coding of each individual copper line is individually optimized using so-called dynamic line management technologies.

Part of the copper wire pairs is susceptible to external distortion signals like impulse and burst noise, for example from modern (switched) power adaptors. Error coding cannot handle this kind of distortion, not even when using the highest coding level. Therefore, a new technology (G.inp) has been developed and implemented. G.inp arranges a fast retransmission of corrupted data packages in the DSL network [2], without the need to sacrifice a substantial part of the bit rate to error coding.

With dynamic line management and G.inp DSL technology has reached its theoretical maximum bit rate. Further improvement of the quality of the DSL connection is not to be expected.

3.5 Managed networks to support premium services

To deliver premium services, a managed network is considered necessary by default. In the conventional copper telephone networks and cable television networks, the services were delivered using a managed network services. For a telephone conversation, an end-to-end dedicated connection was provided with a guaranteed bit rate of 64 kbps (ISDN) or a dedicated circuit of 64 kbps to two central offices in combination with two twisted-pair copper subscriber lines (POTS). For cable televisions, each analogue television signal was distributed using its own frequency channel. For both PSTN telephony and cable television services the networks were designed to exclude degradation of the services by other services.

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[11] Because of VDSL services from the central office, VDSL2 from the street cabinet cannot be deployed in the case of street cabinets with a cable length shorter than 1500 m; see also subsection 4.3.

With DSL networks and IP technology, it became possible to innovate the conventional PSTN telephony services and even to deliver television services via the copper network. Telephony based on voice-over-IP technology and IP-television were developed and introduced. However, VoIP and IPTV services are delivered via the same DSL connection used for internet access services, and without additional network provisions, the VoIP and IPTV services could degrade in case of congestion caused by simultaneous internet traffic. Without appropriate provisions in the network, the VoIP and IPTV services could suffer from degradation caused by internet services.

Therefore, to protect premium VoIP and IPTV services on the DSL connection, different virtual DSL connections are configured with different priorities at the Ethernet layer. Using these virtual connections, the data packets of the service with the highest priority are protected in case of congestion. Thus so-called managed and unmanaged service lanes are respectively created for premium VoIP and IPTV services and best-effort internet services. Networks with these technologies are already deployed for some time to deliver premium telephony and television services.

3.6 Summary

The above analysis can be summarized as follows:

- DSL technologies for deployment from the street cabinet are approaching their theoretical performance limit in terms of the highest bit rate at a negligible bit error rate and packet loss,
- With the prioritization of data packets at the Ethernet layer, managed service lanes with a guaranteed quality for premium services can be defined,
- VDSL2 vectoring and bonding technologies are available on the market;
- VDSL2 with vectoring is a superior and more attractive technology as compared to VDSL2 without vectoring,
- The development of DSL services from the central office has reached its limits in terms of bit rate, coverage and quality,
- To offer consumer DSL broadband services with a significantly higher bit rate to 90% of the homes in the Netherlands, the access networks have to be upgraded to VDSL2 from the street cabinet,
- By 2016-2017, G.fast will become available for large scale deployment,
- Current VDSL2 vectoring technology is inconsistent with subloop unbundling because it would damage the benefits of vectoring. Conceivably there are solutions to mitigate the negative impact of alien VDSL2 lines, but such solutions are not foreseen in the next three years.

4 Optimizing the DSL networks

In the previous section we have concluded that to compete with broadband from the cable networks, the Dutch DSL networks have to be upgraded to VDSL2 from the street cabinet. Basic VDSL2 delivers a bit rate of 40/4 Mbps, which can be considered as a limited improvement as compared to the current broadband offer of the cable. Therefore, we have to evaluate the deployment of VDSL2 with vectoring and bonding.

Physical unbundling of the copper loop is one of the regulatory instruments that has been used to stimulate competition in the telecommunication market. In the case of subloop unbundling, each operator needs to install his own DSLAM in the street cabinet. However, the deployment of VDSL2 with vectoring requires that there is only one DSLAM in the street cabinet. Hence, subloop unbundling and vectoring are conflicting concepts. The one excludes the other, which introduces a rather inconvenient interdependency in the Dutch consumer broadband market with its demand for higher bit rates. Thus, the question arises how appropriate it is to try to stimulate competition through regulated sub-loop unbundling, given that that same instrument limits the ability of DSL providers to compete with cable providers for consumers that demand high bit rates.

In this section, we analyse the technical options to maximize the DSL bit rate. First we describe the technical challenge of optimizing DSL networks in general and the current Dutch approach to manage the mutual interference between DSL systems of different operators in the same network. Next in subsections 4.2 and 4.3 the technical challenge to maximize the DSL bit rate for VDSL2 from the cabinet is analysed. The different VDSL2 technology variants for consumer services are discussed in subsection 4.2. In the subsection 4.3 we analyse the impact of coexistence of VDSL2 services from the central office and from the street cabinet.

4.1 Performance of DSL networks

Before the development of vectoring, the main limitation to the DSL performance was crosstalk from other systems in the cable. Many DSL technologies are optimized for a self-interference scenario, and can suffer substantial performance loss when deployed in combination with other DSL technologies.

4.1.1 Examples of performance loss in mixed DSL deployments

There are two types of mixed DSL deployment scenarios:

1. deployment of different DSL technologies from the same physical location in the network, for instance from the central office,
2. deployment of the same or different DSL technologies from different physical locations, for example from the central office and from the street cabinet.

An example of the first kind is the mixed deployment from the central office of (Enhanced) Symmetric DSL (SDSL, E-SDSL) with Asymmetric DSL (ADSL/ADSL2/ADSL2+). All ADSL variants use different frequency bands for upstream and for downstream.[12] Such a frequency division duplexing scheme eliminates near-end crosstalk in the network. This frequency duplexing scheme of the ADSL variants is compromised by the deployment of SDSL. Especially the E-SDSL variants use high frequencies when configured for high bit rates. The upstream signal from such an E-SDSL modem at a customer location will lead to downstream performance loss on the ADSLx lines, especially at longer loop lengths.

When DSL technologies with overlapping frequency bands are deployed from different physical locations, the impact can be even larger (see Figure 5). When ADSL2+ from the CO is combined with VDSL2 from the cabinet, the crosstalk from the cabinet-deployed system will be very strong compared to the signal from the CO-based system that has already been attenuated by the cable between CO and cabinet. The result is a serious degradation of the downstream performance of the CO-based service.

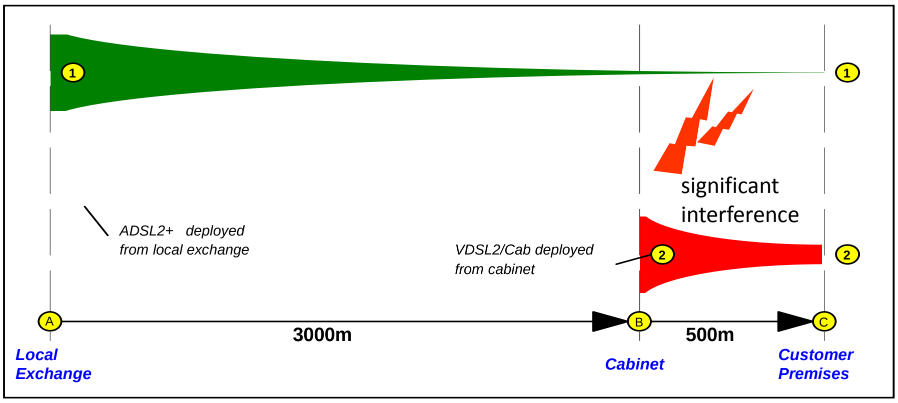

Figure 5: The problem of simultaneous deployment from the CO and the cabinet: strong crosstalk from equipment in the cabinet (VDSL2) disturbs the already weakened signal from the CO (ADSL2+).

Heterogeneous deployment of DSL technologies, either different technologies from the same location or the same DSL technologies from different locations, results in a (substantial) loss of the throughput.

4.1.2 Spectral Management: Balancing the impact in case of mixed deployments

From the technical viewpoint of maximizing the bit rates, mixed deployment scenarios are highly undesired. However, the real-world deployment is typically heterogeneous with different transmission technologies in the network.

Often, there are historic or economic reasons for maintaining earlier DSL systems in the network. However, there can also be valid reasons to deploy different new DSL technologies, even though they may have a negative performance impact on each other. For instance, business reasons required both symmetric and asymmetric services, which led to the need for both SDSL and ADSL systems in the network.

[12] Some exceptions exist, but in those cases most of the ADSL downstream band is not used for ADSL upstream transmission either.

In the case of an unbundled network, the situation is considerably more complicated because different operators may have different business and market interests, resulting in different DSL technological needs. To balance these different needs against the potential detrimental impact of DSL techniques on each other, spectral management rules have been put in place in the Dutch network.

Spectral management rules serve to limit the amount of impact of the various systems on each other, and to create a level playing field for all operators involved. In the Netherlands, the spectral management rules are developed in the Spectraal Overleg Orgaan (SOO), which is a discussion platform for the operators involved.[13]

The typical procedure in the SOO is as follows. If an operator wants to introduce a new technology in the network, an impact study on existing technologies is required. Any detrimental impact must then be weighed against the benefits of the new technology, in order to decide if and how the new technology may be allowed in the network. In this way, various innovative techniques have been allowed into the network.

It was described above how Enhanced-SDSL impacts the performance of ADSL. In 2005, the approval to introduce Enhanced-SDSL was requested by competitive third parties [23][14]. After due consideration in the SOO, it was decided to allow Enhanced-SDSL in the network, with a restriction on the loop lengths on which it may be deployed: the higher the frequency range used by the Enhanced-SDSL system, the lower the maximum allowed deployment distance [24], [25]. In this way, a trade-off was achieved between the interests of all operators involved.

Another example was the introduction of VDSL2 from the street cabinet by KPN. This technique would lead to a serious degradation for ADSL2+ from the central office that was deployed by the third parties and by KPN. The compromise reached in this case was to apply power spectral density shaping to VDSL2 from the street cabinet.[15] In the overlapping frequencies, VDSL2 from the street cabinet is required to reduce its transmit power spectral density such that its impact on ADSL2+ systems is similar to that of other ADSL2+ from the central office [26][14], [27][14], [28], [29]. This reduces the distortion on ADSL2+ systems, at the price of reduced performance of VDSL2 from the street cabinet.

In summary, spectral management has been developed as a concept to limit the impact of DSL different techniques on each other. The resulting solutions are compromises in which the individual techniques do not reach their maximum performance as in a homogeneous deployment scenario. Part of the bit rate is used to implement a mixed deployment in a manner that is satisfactory for all.

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[13] The SOO is a platform where KPN and the third parties meet on a regular basis to discuss the deployment of DSL technologies in the KPN network and to define fair solutions in case of conflicting DSL interests. See for example ETSI STC TM6 meeting, 16- 20 February 2004 TD26 Sophia Antipolis, France.

[14] As a rule, reports of the SOO are confidential.

[15] Power Spectral Density (PSD) is the signal power in a (small) frequency band.

4.2 Which DSL technology from the street cabinet?

In section 2 the analysis of the Dutch broadband market showed that the ADSL2+ service is becoming an outdated product that needs replacement by a DSL service with a higher bit rate. In section 2 we argued that for a large (90%) coverage of the market, the DSL networks have to be upgraded to an architecture with DSL from the street cabinet. Basically, there are four options:

A. Basic VDSL2 with an average bit rate of 40/8 Mbps to the majority of the market,
B. VDSL2 with vectoring with a homogeneous 80/16 Mbps service to the majority of the market,
C. VDSL2 with bonding with an average 80/16 Mbps to the majority of the market,
D. VDSL2 with vectoring and bonding with 160/32 Mbps to the majority of the market.

Vectoring is the more attractive technology. However, as said, vectoring is feasible only if all lines from a street cabinet are served by a single DSLAM. As such, vectoring challenges the existing regulatory concepts of physical subloop unbundling since there are only two options:

- Subloop unbundling is enforced. If so, two (or more) operators could deploy a DSLAM in the same street cabinet with the consequence that vectoring cannot be used. Thus the average bit rate of the VDSL2 lines is limited to 40/8 Mbps or 80/16 Mbps in case of bonding,
- Subloop unbundling is not enforced. In this case only one operator can deploy VDSL2 from the street cabinet and, with vectoring, a homogeneous 80/16 Mbps broadband services can be delivered, or a homogeneous 160/32 Mbps service when combined with bonding.

Therefore, if the aim is to achieve high bit rates to compete with cable consumer broadband services, subloop unbundling is highly undesirable and from this perspective it would be best if the regulatory obligations for subloop unbundling would be removed. Obviously, such a change in regulatory obligations would have consequences in other areas than bit rates as well. It would need to be accompanied by appropriate measures to secure the investments and business interests of the various network operators.

In this context, it is worth noting that up till now, there has been limited interest from Dutch third parties to invest in VDSL2 from the street cabinet based on subloop unbundling. A recent study points out that for economic reasons, only one operator can invest in VDSL2 from the street cabinet [30]. As mentioned before, to the knowledge of TNO, none of the Dutch third parties have communicated plans to roll out VDSL2 from the street cabinet. Therefore, if only one operator is interested and capable to invest in upgrading the DSL network, deployment of VDSL2 with vectoring appears sensible.

As discussed in subsection 3.1, current VDSL2 technology does not provide options to mitigate the negative impact of alien VDSL2 lines on the performance of VDSL2 with vectoring. However, such solutions could become available in three years from now. If so, the above analysis has to be reconsidered by that time.

4.3 VDSL2 from the central office blocks VDSL2 from the street cabinet

As mentioned in subsection 3, third parties and KPN already deploy VDSL2 services from the central office. However, as argued, there is a need to introduce VDSL2 services from the street cabinet. As such the question is what the impact is of coexistence of VDSL2 from the central office and from the street cabinet.

Prior to the deployment of VDSL2 technology from the central office, its impact on a future introduction of VDSL2 services from the street cabinet was taken into consideration and discussed in the SOO, and a spectral management rule was adopted stating that VDSL2 from the central office is allowed only in the case of street cabinets located within 1500 m cable length from the central office. Because of the need to offer services with a bit rate larger than that of ADSL2+, this has led to the deployment of VDSL2 from the central office by third parties and KPN.

For street cabinets with a cable length above 1500 m to the central office, there are, apart from the protection of ADSL2+ services as discussed in paragraph 4.1.2, no restrictions to deploy VDSL2 services from the street cabinet. If VDSL2 with vectoring is deployed, this will result in an increase of the bit rate from 10/1 Mbps of ADSL2+ on long lines up to 40/8 or 80/16 Mbps respectively for VDSL2 without and with vectoring.

Recently, TNO has made a quantitative analyses of the impact of a mixed deployment of VDSL2 from the central office and from the street cabinet on the bit rate. This analysis was limited to the co-deployment of VDSL2 from street cabinets with a cable length ranging from 1000 up to 1500 m. Furthermore, no measures were taken to protect either one of the DSL systems. The analysis showed that both systems mutually interfere with each other, substantially degrading their performance. In particular, the downstream bit rate of the VDSL2 service from the central office and the upstream bit rate of VDSL2 from the street cabinet are significantly damaged, as shown in Table 4.

Table 4 Impact of a mixed deployment of VDSL2 from the central office and the street cabinet on their performance.

VDSL2 victim	**Impact on the victim's bit rate**	
	DS	**US**
VDSL2 from the central office	Bit rate gain with reference to ADSL2+ is lost	No impact
VDSL2 from the street cabinet	Vectoring not affected for cable lengths larger than 250 m	30-60% bit rate loss Vectoring damaged for cable lengths larger than 250m

In the case of heterogeneous deployment of ADSL2+ from the central office and VDSL2 from the street cabinet, the impact of VDSL2 on ADSL2+ is limited by power spectral density shaping of the VDSL2 transmit signal; see paragraph 4.1.2. In the case of coexistence of VDSL2 services from the central office and from the street cabinet, the possibilities for spectral management appear to be limited:

- The downstream signal of VDSL2 from the street cabinet will disturb the downstream signals of VDSL2 from the central office. This can be repaired by power spectral density shaping; however, this will substantially reduce the bit rate of the VDSL2 system in the street cabinet,
- In the upstream signal, the VDSL2 power back-off protocol will force the VDSL2 customer modems connected to the DSLAM in the street cabinet to transmit at a reduced signal level whereas those modems served from the central office will transmit at their maximum signal level. Because of this unbalance, the upstream VDSL2 signals for the DSLAM in the street cabinet will suffer from disproportional crosstalk distortions from the upstream signals for the DSLAM in the central office, thus degrading the upstream bit rate of VDSL2 from the street cabinet,
- The training sequence of the VDSL2 modems connected to the central office may cause instability problems for the VDSL2 systems deployed from the street cabinet,
- The different VDSL2 customer modems deployed make repair of the above problems difficult and challenging.

The above points show that the mixed deployment of VDSL2 from the central office and the street cabinet is not attractive for cable lengths ranging from 1000 up to 1500 m because:

- The bit rate of both systems is substantially damaged whereas,
- The possibilities of spectral management to provide a satisfactory solution appear limited.

Stated differently, VDSL2 from the central office is hindering the deployment of VDSL2 from the street cabinet, which is the next step in DSL network innovation.

As a rule of a thumb, the impact of mixed VDSL2 deployment from the central office and the street cabinet will gradually decrease with the cable length.

Therefore, from the viewpoint of the highest bit rate, VDSL2 systems in the central office would need to be phased out to enable VDSL2 services from the street cabinets. The need for such a shutdown increases with an increasing cable length. Again, shutdown of VDSL2 services from the central office would have consequences in other areas than bit rates as well. It would need to be accompanied by appropriate measures to secure the investments and business interests of the various network operators.

The availability of G.fast in the future will lead to new mixed deployment scenarios not considered here. By then, the impact of a mixed VDSL2 / G.fast deployment should be considered.

4.4 Summary

Mixed deployment of DSL technologies, either different technologies from the same location or the same DSL technologies from different locations, results in a (substantial) loss of the throughput.

Spectral management has been developed as a concept to minimize the impact of DSL different techniques on each other. The resulting solutions are compromises in which the individual techniques do not reach their maximum performance that would have been possible in a homogeneous deployment scenario. For spectral management, part of the bit rate has to be sacrificed.

The network upgrade to VDSL2 with vectoring has to be considered as the more attractive choice in terms of bit rate and statistical variation of the bit rate as compared to an upgrade to VDSL2 without vectoring. In combination with bonding, VDSL2 with vectoring offers the highest possible bit rate of 160/32 Mbps for DSL from the street cabinet.

The use of VDSL2 with vectoring currently cannot be combined with subloop unbundling; vectoring and subloop unbundling are mutually exclusive. Therefore, if the aim is to achieve high bit rates to compete with cable broadband offers, subloop unbundling is highly undesirable and from this perspective it would be best to lift the regulatory obligations for subloop unbundling.

A mixed deployment of VDSL2 from the central office and from the street cabinet with a cable length in the range from 1000 up to 1500 m is not attractive because both systems are substantially damaged whereas the possibilities of spectral management to repair the bit rate loss appear limited. Therefore, from the viewpoint of innovating towards the highest bit rates, VDSL2 systems in the central office would need to be phased out to enable VDSL2 services from such street cabinets.

Lifting of the subloop unbundling obligation and termination of services from the central office would both have consequences in other areas than bit rates and DSL network innovations as well. It would need to be accompanied by appropriate measures to secure the investments and business interests of the third-party network operators.

Two to three years from now, solutions and technologies may become available that could affect the analysis here. By then, this analysis needs evaluation.

5 Innovation and service differentiation in DSL networks

The need to create an open telecommunications market with competing providers was recognized some thirty years ago. The market was liberalized and an ex ante regulatory regime was implemented to enable new entrants to offer competing services via the telephone networks. Both measures, the market liberalization and the ex ante regulatory regime have been important for the development of broadband in the Netherlands. The arrangement has brought triple-play services from different networks and different operators.

For the twisted pair copper networks, the ex ante regulatory regime includes third-party access to the copper wire pairs and wholesale broadband access which is based on access to the DSL networks of KPN. Access to the copper wire pairs is offered in two variants, the unbundled local loop and subloop unbundling. To offer own services using KPN's unbundled copper lines, third parties have to place an own DSLAM in the central office or street cabinet and to build a fibre network connecting the DSLAMs to their network.

In case of wholesale broadband access, KPN offers access to its DSLAMs in combination with an optical backhaul service to aggregate the third-party's traffic to one or more national points.

From the regulatory viewpoint, loop unbundling and wholesale broadband access are seen as complementary and necessary access obligations to create the option for new network and service providers to enter the market and to stimulate competition between the incumbent operator and third parties [31], [32].

On the one hand, the measure of loop unbundling allows third parties to invest in an own national and regional optical network infrastructure including the DSL transmission systems for the copper lines. On the other hand it should enable third parties to innovate their DSL networks and to differentiate their DSL transmission services independent of KPN, stimulating KPN to improve its networks as well. Loop unbundling should create the possibility for third parties to fully compete with KPN on the communication network apart from the copper wire pairs. Since 2000 the price is regulated for the copper wires. As shown in Figure 4, the objective to enable third parties to innovate their networks independent KPN has worked well in the Dutch situation until 2010. In later years we do not observe significant DSL network innovations initiated by third parties anymore. Moreover, the innovations of third parties were limited to innovations of the DSL deployed from the central office.

As substantiated in subsection 2.2, the main network improvement needed in the current Dutch consumer market is a higher DSL consumer bit rate. Therefore, from the viewpoint of a higher bit rate, VDSL2 with vectoring from the street cabinet is the preferred network upgrade.

Irrespective of its proven value to stimulate innovation in Dutch DSL networks from the central office, there is a concern that loop unbundling in case of DSL from the street cabinet would hamper further DSL network innovation. VDSL2 with vectoring from the street cabinet is the largest innovation currently possible. However, as discussed in section 4, subloop unbundling implicates a substantial bit rate loss. Therefore, the question is whether subloop unbundling will contribute to the regulatory objectives to stimulate network innovations and to enable third parties to differentiate their services as compared to a wholesale broadband access service.

In the following subsections 5.1 and 5.2 we respectively present an analysis of the possibilities of third parties to innovate and differentiate their consumer market DSL services from the street cabinet with reference to a state-of-the-art WBA service.

This analysis is limited to consumer market services because these require a most economic implementation which relies on the deployment of the main stream technology offered by the manufacturers.

With a state-of-the-art WBA service we refer to a wholesale vectored VDSL2 service with the maximum line rate that includes and supports dynamic line management, G.inp and managed service lanes as discussed in the subsections 3.4 and 3.5.

In the following analysis, we have not taken into account the optical backhaul of a WBA service. Although this backhaul is relevant from the business perspective, it is not relevant for discussion of the technical capabilities of the DSL part of the WBA service.

5.1 DSL network innovation

As discussed, various technologies for DSL services from the central office have succeeded one another in the previous decade. However, in the current situation the question is, whether subloop unbundling still can act as an enabler and stimulator for consumer market DSL network innovations beyond the level of a wholesale broadband access service based on a state-of-the-art VDSL2 with vectoring from the street cabinet.

First, as discussed in section 4, subloop unbundling conflicts with VDSL2 with vectoring. Therefore, subloop unbundling would damage the superior performance of VDSL2 with vectoring and as such subloop unbundling has to be seen as an instrument that hampers technical network innovation instead of stimulating innovation.

In section 3, we have argued that with the introduction of VDSL2 with vectoring, G.inp, dynamic line management and managed service lanes, the performance of the DSL network, apart from the bit rate, approaches the theoretical limits, and that apart from G.fast no new major DSL innovations currently are expected. Evidently, when technology innovations are getting exhausted, network innovation will slow down. The first major DSL innovation opportunity will be provided by G.fast, which will become available in two up to three years from now.

Hence, state-of-the-art VDSL2 with vectoring from the street cabinet offers todays best performance and its deployment from the street cabinet can be marked as the most far reaching innovation with today’s technology.

The above analysis of the current prospects of DSL network innovations is based on technological options that are available today or foreseen for the next two to three years. After this period, G.fast will become available for the market, see section 3. In addition, a solution to mitigate the negative impact of alien VDSL2 lines might be developed. Since these new technologies could change the prospects of DSL network innovations by then, this analysis should be evaluated again after two to three years.

5.2 Differentiation of DSL consumer broadband services

The question is whether for DSL services from the street cabinet, subloop unbundling offers third parties options to differentiate their broadband service that are not available in a state-of-the-art WBA service.

The performance of any broadband service can be fully characterized by the following parameters:

- The downstream and upstream bit rate,
- The delay and jitter,
- The quality in terms bit error rate and packet loss,
- The reliability and availability of the service.

As argued in subsection 4.2, subloop unbundling cannot be combined with vectoring. If subloop unbundling would be enforced, third parties could build their own network using VDSL2 technology without vectoring. However, the bit rate of VDSL2 without vectoring is less than, or at best equal to that of VDSL2 with vectoring. For most lines, the bit rates of VDSL2 without vectoring will be lower. Thus from the viewpoint of the possibility to differentiate the bit rate, subloop unbundling yields a lower bit rate as compared to a state-of-the-art wholesale broadband access service; it does not offer the possibility to differentiate in a positive sense.

As a rule, delay and jitter are immediately correlated to the bit rate of the DSL connection. As such, the VDSL2 with vectoring has the least delay and jitter. Subloop unbundling, because of the lower bit rate, would increase the delay and jitter.[16]

As discussed in subsection 3, in VDSL2 with vectoring the bit error rate and packet loss are minimized using error coding, dynamic line management and G.inp whereas the net usable bit rate is maximized. In addition, using managed service lanes, premium services are protected against traffic congestion. Therefore, provided the WBA service includes these provisions, subloop unbundling does not offer the possibility to reduce the bit error rate and packet loss.

The reliability or availability of the DSL network depends mainly on the reliability of the equipment and the power grid. Reliability of the network can be substantially increased by the use of redundant solutions, like power back up to cope with outages of the power grid and redundant DSL line cards. In practice though, for

[16] G.inp is used to protect lines that are susceptible to impulse noise. Instead of using part of the available line bit rate for interleaving and forward error correction, G.inp offers a fast retransmission of the packets that are damaged by an impulse event. Therefore, the use of G.inp concerns a trade-off between a higher net bit rate with possibly some increased jitter caused by the retransmission on the one hand and a lower net bit rate and a longer delay because of the extra interleaving and forward error correction. However, considering the usually sporadic occurrence of impulse noise events, the extra jitter caused by G.inp is very small in practise.

consumer services, redundancy is not used at the periphery of the network because of the costs of such redundancy provisions.

Taking all above arguments together, we conclude that in the current situation, an own DSLAM in combination with a wholesale subloop unbundling service offers no substantial possibilities to positively differentiate services as compared to state-of-the-art WBA services based on VDSL2 with vectoring.

The above analysis of the current possibilities of differentiation of DSL network services is based on technological options that are available today or foreseen for the next two to three years. After this period, G.fast will become available for the market, see section 3. In addition, a solution to mitigate the negative impact of alien VDSL2 lines might be developed. Since these new technologies could change the possibilities of differentiation of DSL network services by then, this analysis should be evaluated again after two to three years.

5.3 Summary

State-of-the-art VDSL2 with vectoring from the street cabinet offers todays best performance and its deployment from the street cabinet can be marked as the most far reaching innovation with today's technology. Therefore, from the viewpoint of a high bit rate, a wholesale broadband access service based on state-of-the-art VDSL2 with vectoring from the street cabinet would be the preferred access service for third parties.

However, with the roll out of state-of-the-art VDSL2 with vectoring from the street cabinet, the options of further DSL network innovations and of service differentiation become exhausted for the next 2 to 3 years. The first major innovation foreseen will be the roll out of G.fast. In addition, a solution to mitigate the negative impact of alien VDSL2 lines might be developed. Since these new technologies could create new options to innovate the DSL network or to differentiation of DSL network services by then, this analysis should be evaluated again after this period of two to three years.

6 Summary

The analysis of section 2 confirms that the broadband consumer market is demanding ever higher bit rates and that the development of new broadband end-user services is flourishing. Moreover, new service providers are exploring over-the-top service delivery. The key factor in these developments is ample bandwidth.

Cable is a strong rival of DSL networks and to remain competitive, the DSL networks need further innovations to deliver higher bit rates. Evidently, a competitive DSL network is crucial to secure the further development of broadband.

Over the past ten to twenty years, DSL technology has continuously been improved. With VDSL2 with vectoring and auxiliary features like dynamic line management and G.inp, the technology approaches its technical and theoretical performance limits in terms of bit rate and packet loss. As compared with non-vectored VDSL2, VDSL2 with vectoring provides two major improvements:

- A double bit rate of 80/16 Mbps and of 160/32 when bonding two lines,
- A homogeneous bit rate; bad lines with a substantial bit rate loss are ‘repaired’.

During the past ten years, the DSL networks have developed as well. Using managed service lanes, extra protection is created for premium consumer services like telephony, television and video. The only drawback to remain competitive with cable is the limited bit rate. Bandwidth is a most crucial factor to compete with cable in the Dutch consumer broadband market.

The development of DSL services from the central office has reached its limits, and as such further innovations of DSL from the central office can be excluded. The current DSL service offer from the central office is limited in two aspects:

- The bit rate of ADSL2+ is insufficient and ADSL2+ is becoming outdated;
- The bit rate of VDSL2 from the central office is a modest 40/4 Mbps, but even more importantly, only 20% of the market can be reached.

Therefore, there is a need to upgrade DSL networks to VDSL2 from the street cabinet, thus increasing the coverage to 90%.

In the past, loop unbundling was devised as an instrument to enable new entrants to compete with KPN.

In case of a mixed deployment of DSL technology, part of the bit rate of each DSL technology has to be sacrificed to avoid unacceptable performance degradation of some of the DSL technologies in the network.

VDSL2 with vectoring requires that all copper pairs from a binder are connected to the same DSLAM. Thus, the benefits of VDSL2 with vectoring are lost when physical subloop unbundling is enforced.

From the viewpoint of the highest bit rate, the obligation of subloop unbundling should be lifted.

A mixed deployment of VDSL2 services from the central office and the street cabinet would have a large negative impact on the VDSL2 services from the central office as well as those from the street cabinet. Moreover, the possibilities of spectral management to repair the bit rate loss appear limited. Therefore, from the viewpoint of innovating towards the highest bit rates, VDSL2 systems in the central office should be phased out to enable VDSL2 services from such street cabinets.

From the regulatory viewpoint, loop unbundling is needed next to wholesale broadband access to allow third parties to differentiate their DSL services from those of the incumbent operator and to stimulate access network innovation. Although local loop unbundling has contributed to the differentiation and improvement of DSL services from the central office in the past, we argue that for consumer DSL services from the street cabinet in the Dutch market subloop unbundling does not provide:

1. Extra options for third parties to positively differentiate their services as compared to a wholesale broadband access service based on state-of-the-art VDSL2 with vectoring from the street cabinet,
2. Third parties DSL network innovation options beyond the level of state-of-the-art VDSL2 with vectoring from the street cabinet.

The analysis in this report of the current prospects of DSL network innovations and third-parties service differentiation is based on the technological options that are available today or foreseen for the next two to three years. After this period, G.fast will become available for the market. In addition, a solution to mitigate the negative impact of alien VDSL2 lines might be developed. Since these new technologies could change the prospects of DSL network innovations and third-parties service differentiation by then, this analysis should be evaluated again after this two to three years period.

Removal of regulated subloop unbundling and closing down VDSL2 services from the central office will affect the business interests of the current third parties. In this report, considerations of this nature have not been taken into account.

Annex

Overview of a selection of consumer cable and DSL broadband offerings in the Netherlands [June 2014]

	Tele2	Online	Solcon	Scarlet	Canal Digitaal	Telfort	XS4All	KPN	Ziggo	UPC
Telephony										
fixed telephony offering	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Internet package with highest bandwidth										
downstream bitrate	40 Mb	50 Mb	40 Mb	50 Mb	50 Mb	50 Mb	50 Mb	80 Mb	180 Mb	200 Mb
upstream bitrate	4 Mb	5 Mb	4 Mb	5 Mb	5 Mb	5 Mb	5 Mb	8 Mb	18 Mb	10 Mb
fixed IP adress	yes	no	yes	no	no	no	yes	yes	no	no
newsgroups	yes	yes	yes	yes	no	no	yes	yes	yes	no
server allowed	yes	yes	no?	yes	yes	yes	yes	yes	no	no
# POP emailaddresses	1	4	5	3	1	5	5	5	5	10
webmail	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
security (antivirus etc.)	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Internet bitrate of other packages										
downstream bitrate	20 Mb	30 Mb	25 Mb	20 Mb	20 Mb	30 Mb	20 Mb	40 Mb	90 Mb	120 Mb
upstream bitrate	1 Mb	3 Mb	3 Mb	1 Mb	1 Mb	3 Mb	2 Mb	4 Mb	9 Mb	6 Mb
downstream bitrate	-	10 Mb	8 Mb	-	-	8 Mb	-	8 Mb	30 Mb	50 Mb
upstream bitrate	-	1 Mb	1 Mb	-	-	1 Mb	-	1 Mb	3 Mb	2,5 Mb
TV										
# channels in package	49	28 (Digitenne)	60	122	248 (satellite)	65	66	60	60	30/70/110*
# HD channels in package	11	no	12	28	46 (satellite)	12	11	12	16	3/15/35*
extra channels possible	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
missed programme catch up	yes	no	yes	yes	no	yes	yes	yes	yes	yes
Video on Demand	yes	no	no	no	no	yes	yes	yes	yes	yes
EPG	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

*) UPC offers different tv subscriptions with 30, 70 or 110 channels and 3, 15 or 35 channels in HD, next to the thematic packages

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