WIK-Consult • Report

Study for ACM, The Netherlands

Options of wholesale access to Cable-TV networks with focus on VULA

- Summary and additional questions -

Authors:

Dr. Thomas Plückebaum (WIK-Consult)
Helmut Kohl (ContaQ Consulting)
Markus Muckhoff (ContaQ Consulting)

WIK-Consult GmbH
Rhöndorfer Str. 68
53604 Bad Honnef
Germany

Bad Honnef, 5. February 2015

Contents

1 Introduction

WIK-Consult GmbH has been mandated by the Dutch NRA ACM to organize and hold a workshop on the “Options of wholesale access to Cable-TV networks with a special focus on VULA”. This was intended to prepare ACM in context of the new access market analysis in the Netherlands and in context of the new EC market recommendation (C(2014) 7174 final of 9.10.2014). Preparing and conducting the workshop WIK-Consult had been supported by ContaQ Consulting GmbH.

The Workshop was held 9. July 2014 in den Haag. The slide set used had been made accessible to the stakeholders of the access market review during the public consultation process. A short summary of the conclusions of this workshop is repeated in Section 2. The responses from the market led to an additional set of questions ACM has asked WIK-Consult to answer. The questions deal with

- The Multicast functionality (this report Section 2),
- High quality connections (this report Section 4), and
- Spectrum sharing on Cable-TV networks (this report Section 5).

In this report the questions are listed at the beginning of the three sections. For section 5 there is a wider set of questions requiring subsections to answer, thus the respective question is listed at the beginning of the corresponding subsection.

Since spectrum sharing is not standardized in the cable sphere and has not been addressed in the DOCSIS standard documents the answers we can give in the time frame and budget of this report is our best estimation of technical options and possibilities, based on our expertise and reflected by some market observations in the non-standardized world of implementations.

Furthermore we want to point out already here that DOCSIS is standardizing just the bidirectional data (and voice) communication enhancement of cable-TV networks, dealing with a minor share of todays’ total frequency spectrum of 5 – 862 MHz (see Figure 3-3). The TV- and radio channels are not standardized by DOCSIS. Digital-TV and VoD typically use the TV-channels to be down-streamed and neither the DOCSIS frequencies nor the DOCSIS hardware.

2 Summary of the Workshop

DOSIS is a very powerful technology enabling high bandwidth bidirectional communication with asymmetric capacity allocation. It uses coaxial cable customer access in a shared use mode. While its data communication protocol is typically IP, it can also enable layer 2 based services for business customers by using the BSoD[1] standard, which is an additional standard not necessarily implemented by all suppliers. The BSoD services are in principle supporting the VULA characteristics defined by European NRA and the European Commission, especially supporting dedicated bandwidth on a Layer 2 (Ethernet) protocol. But the BSoD services do not enhance the DOCSIS capacity. They compete for bandwidth with the IP based services and simply reduce their capacity by the guaranteed bandwidth for BSoD. Thus there are only very few connections implementable per coax-cable segment. The number of the connections also depends on the bandwidth required per connection. The scarce capacity here typically is the upstream path. We cannot see these to be sufficient to serve the business customer demand of an coax-cable area. This is getting even worse when the cable-TV provider and potential wholesale customers share these scarce bandwidth[2].

Characteristic of cable-TV networks is that all services (radio-/ TV-channels, Video on demand, Data, Voice) compete for the same frequency space and thus for bandwidth. That has been structured by DOCSIS (and BSoD), where the downstream channels can be expanded to the detriment of the radio/ TV frequency space. In general, a provider intending to increase the capacity of one service significantly will have to decrease the capacity of others and make better use of it, e.g. by migrating from analog to digital TV.

There is a wide spectrum of technical options being realizable based on the DOCSIS platform which had not been in the focus of suppliers and standardization, because there was no intention for a correlated use of the systems.

DOCSIS 3.0 and 3.1 as well as its predecessors so far was not intended to be used for providing wholesale services, especially not in a VULA manner, but may be developed towards such features over time, if there is demand for it. So far especially the old grown-up cable-TV operators used the DOCSIS environment just to complement its established radio and cable-TV offers by bidirectional broadband digital voice and data communication services and to keep pace with the classical telcos and its broadband services including IP-TV. These add-on services are typically sold shortly above

---

1 Business Services over DOCSIS

2 BSoD is a feature for a single provider environment where the provider may determine the number of BSoD customers with regard to the traffic situation on each coax segment individually and then decide on not connection such customer vs. capacity enhancing investments (e.g. node splitting)..

marginal cost and are addressed to their existing customer footprint in the residential and SOHO[3] mass market.

Such wholesale on cable-TV network demand may be caused by new upcoming cable-TV operators seeking to enlarge its customer base above its own directly acquired customers and gaining additional income, knowing that the capacity provided in the network has sufficient space for additional wholesale customers. Such networks may be already designed for adding wholesale services. These network operators may be also open for offering VULA based services and demanding for Cable-TV network equipment supporting it. We are unsure, if there are providers developing into that direction, demanding system support for VULA like services, or if they are satisfied offering bitstream services only. Offering bitstream only in any case may be their strategic position

The demand for VULA support in the DOCSIS platforms will not be stimulated by the regulatory objective to regulate SMP, but by network operators demanding for it. At the moment we observe increasing peak rate offers for IP data communication services by cable-TV service providers, driving the market to higher bandwidth and using the competitive advantage against DSL-based services. This peak rates would be restricted or even reduced when offering additional wholesale services on a spectrum sharing or BSoD approach. Therefore we assume that demand for such services from the cable-TV provider side will be very limited.

3 Small Office, Home Office

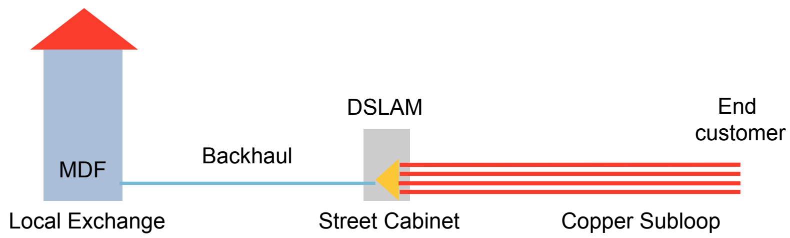
3 Multicast Functionality

1. ACM concludes in the draft decision that implementing a multicast TV technology on cable networks such that alternative operators can offer their own TV stream via the cable network is not very realistic. Could WIK elaborate on the differences and similarities between the possibilities of a multicast technology on cable networks and on copper networks?

Underlying network structures

For a ***copper network*** we assume a xDSL based network, where the DSLAMs are located close to the end customers in order to provide broadband access to the highest capacity technically feasible. In any case the capacity of the point to point access lines between the end-customer and the DSLAM strongly depends on the copper line length for any of the DSL protocols available. The DSLAMs may be located in street cabinets or at the local exchange (Main Distribution Frame, MDF) location. The connection between the DSLAM and the next network layer switch is a fibre connection which is quite insensitive to line length restrictions. Such backhaul line today typically provides a 1 Gbit/s connection, but its upgrade to the next capacity step of 10 Gbit/s per connection just requires appropriate DSLAMs and switches and new interface 10G cards.

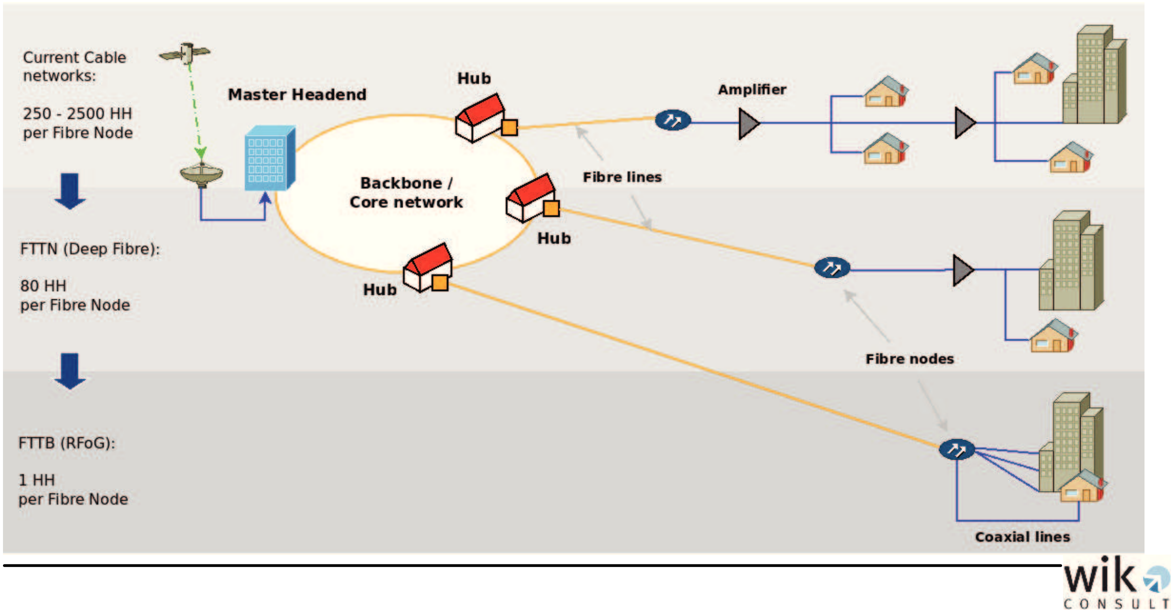
Figure 3-1: Broadband copper access network



Source: WIK

A ***cable-TV network*** operates its end-customer access by a coaxial cable being used in a so called bus structure, as a shared medium, in which all end-customers of a group get access to the same frequency band of the coaxial cable (5 – 858 MHz, coaxial cables allow much higher frequency bands than twisted copper pairs of a telephone network, which are operated today up to 30 MHz in case of VDSL). In its original pure downstream TV-signal distribution all end-customers of a cable-TV network could chose the programs out of the channel bouquet offered by just picking it from the cable. For bidirectional telecommunication purposes some frequency bands below the TV spectrum have been allocated for upstream communication (5 – 65 MHz) and the amplifiers of the cable-TV distribution network (see Figure 3-2), before just enabled for the downstream direction of communication, now have been upgraded for the upstream communication also. On the upper end of the frequency band the downstream data channels typically[4] have been allocated, thus framing the traditional TV and radio channels, today being transmitted in analogue or digital form, SD or HD (see Figure 3-3). A Cable Modem Termination System (CMTS) administers the upstream communication (only one may send at the same time) of all end-customers connected to the same coax string and it addresses the downstream recipient(s) for individual or multicast communication. The data over cable standard (DOCSIS) had been changed over time, enabling more bidirectional communication bandwidth, for the downstream channel by using frequency space formerly dedicated to TV-channels. Due to the digital dividend (less bandwidth for digital than for analogue channels) also in cable-TV this was reasonable without channel bouquet restrictions.

Figure 3-2: DOCSIS network and node splitting reducing households per fibre node

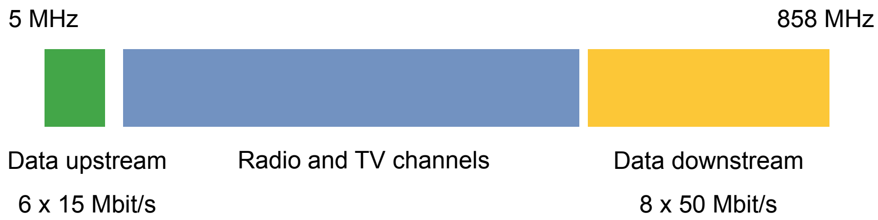


Source: ContaQ and WIK

Today there is a maximum of 6 upstream channels allocated which can be combined to one channel with a total of approximately 90 Mbit/s upstream capacity. Typically a maximum of 8 downstream channels of 50 Mbit/s each can be combined to a maximum capacity of 400 Mbit/s[5].

4 In principle this can be allocated by the provider per CMTS.
5 Up to 8 upstream and 24 downstream channels are technically feasible, but not implemented yet in live networks.

Figure 3-3: Frequency allocation and cannel distribution for DOCSIS 3.0[6]



Source: WIK

Comparing a copper pair broadband access network and a cable-TV based network one has to highlight one important technical difference in advance. The bandwidth (capacity) over DSL based copper pairs strongly depend on the access line length (caused by attenuation) and on crosstalks between the parallel copper pairs of a cable binder. In contrast the coax cable-TV networks are more or less length insensitive regarding the bandwidth transmitted. This is caused partly by the transmission characteristics of the coax cable used, but also by the fact that the signals are amplified in regular distances by amplifiers in the field.

IP-TV-Multicast on a copper network

In order to describe the effects of TV-Multicast in an IP-based telecommunication network we have to make some assumptions about typical digital IP-TV-streams. Let us assume for illustrative reasons[7] that a well compressed SD TV-signal requires 4 Mbit/s, a HD signal requires 9 Mbit/s. (Future downgrade improvements are possible.) The complete channel bundle offered shall consist of 100 channels, of which are 40% HD (360 Mbit/s in total) and 60% SD (540 Mbit/s), at the root of the TV stream 900 Mbit/s will be required. The Multicast is distributed over a tree from the multicast server to end-customer. With dynamic multicast only those channels are distributed over an edge, which are requested by customers downstream. This saves bandwidth and is anyhow required in DSL access networks with its restricted access line bandwidth.

While dynamic multicast requires some reaction time when new channels are selected, some delay occurs, which could result in long zapping intervals. So a compromise has to be found in quick bypassing the multicast stream for channels not yet included in the stream until the channel has been synchronized inside it. This costs additional bandwidth beside the multicast tree.

6 Abstract and simplified presentation.
7 One might chose slightly different figures for the bandwidth demand, but they will not change the principle results described here.

4 TV-program streams shall typically be provided per access (line) in parallel, because of support for several receivers per household (TV-sets plus recorders). Such access line should therefore support approximately 25 Mbit/s downstream. For switching the channels some small upstream bandwidth is required also.

For TV-multicast on copper networks we assume a DSLAM architecture allowing to transmit 25 Mbit/s downstream on a copper pair at least. Lower bandwidth will decrease quality of signals, number of signals, protocol reaction or a combination of it.

If several operators intend to offer TV-multicast over a DSL broadband copper network using a wholesale bitstream product the copper access line (between DSLAM and end customer) has to be allocated to one operator exclusively. The backhaul link between DSLAM and the higher level aggregation network has to be shared by all operators serving customers at that DSLAM. Such backhaul link today has a capacity of 1 Gbit/s. Assuming that every TV-multicast operator has to dynamically provide 1/3 of his channel bouquet to each of these DSLAMs (dynamic multicast) – 300 Mbit/s per operator – there only is capacity for a maximum of three operators in parallel on the same backhaul link. As described this relation depends on the number of channels on the DSLAM backhaul link.

This channel requirement is determined by the number of IP-TV customers per operator, and increases with the degree of requiring different channels in parallel. Thus the backhaul bandwidth demand decreases with a decreasing number of end customers per DSLAM. Nevertheless, the number of operators in parallel is limited and depends also on the size of the DSLAM. This limitation in the number of operators in parallel would be widened by upgrading the DSLAM and its backhaul link to 10G. In fact there is an operator limitation, but it is not so easy to be determined. We believe our initial estimation of a maximum of three operators per DSLAM to be realistic and conservative.

IP-TV multicast in a cable-TV network

DOCSIS 3.0 in our typical example[8] offers a maximum of 90 Mbit/s up and 400 Mbit/s downstream for IP connectivity in its largest standard capacity configuration implemented today. While we do not see upstream capacity limitations for a dynamic IP-TV multicast implementation in a cable-TV network we concentrate on the downstream channel and compare it directly to the DSLAM backhaul links. In the cable-TV network there are 400 Mbit/s only, to be shared by the channels of different operators, each offering its individual channel bouquet. Here the limitations are even tougher than in the DSL network due to the smaller downstream capacity.

8 Technical downstream maximum is 24 x 50 = 1,200 Mbit/s, reducing TV- and radio channel bandwidth.

Also here, like on the DSLAM backhaul, the number of multicast channels in parallel depends on the number of IP-TV customers per operator and also depends on the degree of demand for different channels in parallel. The smaller the number of customers per CMTS and IP-operator, the smaller the bandwidth demand per operator. The size of a CMTS coax string[9] and a DSLAM are comparable to a wide extent (each serving 40 - 2.500 end-customers). According to the conservative assumptions above (DSLAM) there is space for one IP-TV multicast operator with 300 Mbit/s downstream capacity for IP-TV in a cable-TV DOCSIS 3.0 network. Of course the cable-TV platform allows in its TV and radio frequency spectrum for the full bouquet of cable-TV distribution in parallel, so that beside this classical cable-TV there is additional space for one IP-TV operator, thus for two operators in parallel, working on two different distribution technologies (cable-TV-channels (framed by DOCSIS), DOCSIS IP-channels[10]). An IP-TV offer in the DOCSIS bidirectional communication capacities on the other hand would consume the internet downstream capacity to a wide extent (in the example by 75%) and such application has not been intended in the DOCSIS design. The original design intention was upgrading the existing Radio and TV cable network by high bandwidth bidirectional internet communication without the need to support IP-TV in addition, all dedicated to one operator.

IP-TV reselling

The bandwidth restrictions disappear in both network technologies (copper DSL and cable-TV) if the condition, that the additional operators shall distribute their own TV-stream independently from each other is released to some extent by opening resale of the IP-TV bouquet, where the individual operators select “their” channels out of a general channel bouquet, which may be enriched by dedicated channels on demand of single operators which remaining exclusive for their customers[11]. Also in this case there is no principle difference between the DOCSIS 3.0 and the Copper/ DSLAM platform. The downstream channel capacity of DOCSIS 3.0 remains smaller than the DSLAM’s backhaul capacity, but now the TV-bottleneck is released to some extent.

The idea of reselling TV could also be transferred into the cable-TV-channel sphere. Assuming modified Set-Top boxes are available the TV-bundle resold by another operator can be modified, so that some original channels are deleted, but other reseller specific channels will be added.

The aspects of several operators share the DOCSIS frequency space for TV-signal distribution will be discussed under spectrum sharing below. Without widening the frequency space each of the sharing operators only can offer a subset of the Bouquet a single cable-TV operator can provide.

9 A CMTS can support several ports (fibre nodes serving a coax string) in parallel.
10 See Figure 3-3, blue respectively orange frequency space.
11 or will be shared by individual subsets of operators for each of the channels.

Trend towards Smart-TV

Smart-TV systems, directly connected to the internet, allow to download videos or TV-programs stored in media centres at times more convenient than the original emission time. One can observe a significant growth of this kind of TV use, which reduces the demand of parallel IP-TV channels per household, since these channels are no longer to be received at emission time and stored on a recorder but are transmitted at individual times outside the IP-TV bandwidth, thus significantly increasing the internet downstream bandwidth for individual communication, just like Video on Demand (VoD). Increasing demand for VoD and Smart-TV add significant load to the DSLAM backhaul connections and the DOCSIS download channels, thus competing with the IP-TV Multicast channel bandwidth. We expect the VoD/ Smart-TV bandwidth increase to be significantly larger than the IP-TV dynamic multicast channel decrease.

4 High quality connections

2. What are the possibilities of alternative operators to deliver high quality connections (for business users, e.g. connections which are non-overbooked) on cable networks via wholesale access? What are the main differences (in terms of costs and technological possibilities) between offering these connections on copper networks and on cable networks?

High quality connections for business users have a wide range of bandwidth (64 Kbit/s – 10 Gbit/s). This bandwidth is dedicated to the one (business) user and is typically symmetric, thus in both directions of the same size. The demand trend moves towards Ethernet leased lines with at least 10 Mbit/s.

In cable-TV architectures such demand causes quite soon bottlenecks in the upstream communication direction, which in DOCSIS 3.0 as maximum has approximately 90 Mbit/s per CMTS coax string. DOCSIS 3.0 (and below) administers the upstream direction in a time division multiplex (TDM) manner, thus beside dynamic bandwidth use also enabling a fixed bandwidth for single end customers[12]. Nevertheless, the principle option is limited in bandwidth size and number of connections, since these connections permanently consume bandwidth out of the scarce upstream bandwidth band. Thus such option could only support some few lines equal and below 2 Mbit/s. Due to these restrictions cable-TV operators according to our observation do not address the business customer market to a wider extent, and not with high quality connections of higher bandwidth (> 2 Mbit/s bandwidth guarantee).

If a cable-TV network can satisfy the 2 Mbit/s and below high quality connection demand of business customers in an area depends on the size of the coverage area a CMTS coax string serves, and on the demand for such lines in this area. The demand (of a few lines) then could be distributed between the cable-TV operator and wholesale requesters using the cable-TV platform also. This the demand may be also satisfied and thus reduced by competing with (other, e.g. copper) platforms.

One characteristic of cable-TV networks is its shared media design on the access lines, which has its advantages in broadcast and multicast communication, but its disadvantage in bidirectional individual communication, because each individual communication consumes bandwidth else being available to all other customers connected to the same CMTS coax string.

A copper network can support high quality connections on the basis of unbundling copper access lines with speeds up to 10 Mbit/s at the MDF locations[13]. This speed can

12 For details see: http://www.cisco.com/c/en/us/support/docs/broadband-cable/cable-modem-termination-systems-cmts/69704-upstrm-schdlr-uBRCMTS.html#ugs.

13 10 Mbit/s by 5x2 Mbit/s, 2 Mbit/s per copper ULL, 5 copper pairs required, thus also a question of sufficient ULL availability (ULL: unbundled local loop, SLU: subloop unbundling (at street cabinets).

be increased by unbundling at cabinet locations and using SLU to some extent, but due to the asymmetric characteristics of the ADSL and VDSL (higher bandwidth transmission systems) there is no option to achieve 100 Mbit/s symmetric lines over copper. Using VULA as a wholesale product over copper would allow some upscale (doubling) of bandwidth in case of using VDSL Vectoring by the wholesale provider as exclusive technology on all subloops of a cabinet. This increase of bandwidth will typically result in a total upstream bandwidth (thus symmetrical) below 30 Mbit/s, depending on the subloop length.

Key characteristic of the copper access network is that the characteristics of the access lines and the allocated transmission systems limit the bandwidth individually per access line. The copper access lines may be terminated in the local exchanges[14] at different aggregating systems, thus that high quality connections may be routed to other transmission systems (e.g. SDH) than residential customer and other internet traffic. In case of VULA over copper these high quality connections start sharing the capacity with the other customers just behind the aggregating DSLAM on its backhaul link. They consume a guaranteed bandwidth as a share of the DSLAM backhaul link capacity of typically at least 1 Gbit/s symmetrical, compared to the maximum of 90 Mbit/s upstream capacity of DOCSIS 3.0.

The upgrade to a higher backhaul capacity in case of copper (10 Gbit/s) requires upgrading the DSLAM and the switch port at the other side in an Ethernet switch, the fibre remains unchanged. The DSLAM can be upgraded by just exchanging the upstream port, depending on the DSLAM characteristics. The worst case is to exchange the DSLAM completely by a more modern version. Upgrading a cable-TV network in order to enhance its capacity for high quality connections in the upstream direction today typically would be achieved by reducing the footprint of a CMTS coax string and add another string, so divide the related access area in order to get less customers per coax string (also called node splitting). This typically requires some underground construction work and doubling of network nodes and interfaces. Depending on the local circumstances we would expect the copper upgrade (1G backhaul to 10G Backhaul at an existing cabinet location) to be less expensive compared to a cable-TV network upgrade with additional underground construction work and a second fibre node (see Figure 3-2). Capacity upgrades in cable-TV networks could also be achieved by upgrading the DOCSIS release to 3.1, when in future available. But this would be a major, quite expensive cable-TV network upgrade compared to an incremental backhaul connection upgrade in copper networks[15].

14 In principle also at cabinets in case of SLU, but this typically is not economically viable.

15 Capacity upgraded in the *downstream* DOCSIS 3.0 part of a cable-TV network could also be achieved by enhancing the downstream frequency part from 8 to a maximum of 24 channels, reducing the radio and TV-channel frequency space. If at the same time analogue TV-channels are converted into digital channels frequency space will be saved, thus the number of channels in a bouquet may remain the same (saving frequency space by migration from analogue to digital emission is often called digital dividend).

The upgrades in the networks behind (above) the access area in the Ethernet switches and IP Router levels is comparable in both cases.

The main differences can be summarized by:

- Copper access supports bandwidth up to 30 Mbit/s symmetrical, cable-TV only up to 2 Mbit/s
- An upgrade to support increasing high quality demand will be expected to be more expensive in cable-TV networks than in copper networks (but that depends on local circumstances)

5 Spectrum sharing on Cable-TV networks

The subsequent sections all deal with different aspects of spectrum sharing as a methodology coming close to the virtual unbundling approaches VULA (Virtual Unbundled Local Access), being accepted in the new market definition of the EC as alternative to physical unbundling.

5.1 Capacity constraints

3. Some parties argue that ACM did not sufficiently analyze the possibility of spectrum sharing as a substitute for LLU-access. KPN argues that capacity constraints apply to both copper based as well as HFC-networks. Could WIK provide an overview of the differences and similarities of capacity constraints in both network types?

One can understand spectrum sharing as allocating channels within the total cable-TV spectrum to different operators. This could cover the upstream and downstream data channels, but TV-channels also. We exclude the TV-channel sharing from further considerations here and refer to the section about IP-TV resale above (within section 2), which would be applicable here also. Thus we concentrate on the DOCSIS spectrum only. Prerequisite of allocating single upstream and downstream channels to a subset of end-customers and a dedicated customer group at the central side is the support of the CMTS and cable modem systems. This can be realized by the concept of MAC Domains, which are originally intended to separate different services of the same provider[16].

Allocating an up- and downstream channel to another operator (B) reduces the remaining upstream capacity for the network of the original operator (A) by 16.7% (1 of 6 channels) and the downstream capacity by 12.5% (1 of 8 channels (or of even more channels)). Thus the Peak capacity for the customers of operator A in both directions is reduced appropriately, and transmission delays will increase accordingly. Operator A is restricted in its product quality characteristics because its ability to sell peak capacity has been affected. This will not occur in a copper based network with wholesale products to the same extent. The peak capacity for an end customer in a copper based network is restricted to the capacity of the individual copper access line, determined by line length, transmission method (ADSL, VDSL, Vectoring) and crosstalk and typically is significantly lower than on cable-TV networks[17]. The bandwidth sharing occurs on the backhaul line only, and just affects transmission delay in a line which today is rarely overbooked (1 Gbit/s offers 100 customers a permanent capacity of 10 Mbit/s each). The peak capacity of the backhaul line is not affected. Each wholesale end-customer

16 See DOCSIS 3.0 MAC and Upper Layer Protocols Interface Specification CM-SP-MULPIv3.0-I25-140729, section 5.2.1.1.2 and 5.2.7.

17 A copper network operator arguing for spectrum sharing would benefit from the reduction of the peak bandwidth difference between the two quite different network approaches.

consumes a small proportion of the total backhaul capacity, a customer increment for each new customer. The cable-TV spectrum sharing approach as described above takes larger relative increments, already for a first end-customer.

The wholesale operator B using the shared spectrum channels can only offer a small peak bandwidth of 15 Mbit/s up- and 50 Mbit/s downstream, which is not so competitive to operator A, but may be in line with copper access operators. One may wonder if such approach finds entrants to the market, since the spectrum allocation and its capacity consumption in the cable-TV network justifies to immediately allocate 12,5 – 16,7% of the network cost to the new wholesale based operator, independently of the number of customers operated. Thus the ramp-up cost for a wholesale market entrance over a cable-TV network are high compared to a wholesale market entrance on copper based access networks, and it does not offer any bandwidth advantage.

Of course one might allocate more up- and downstream channels to another operator (B), thus increasing his capacity to the detriment of the first operator (A), even up to the point of equal capacity for both operators. The considerations made above have to be adapted accordingly, but do not change in its principles except the considerations regarding the competitive disadvantages.

5.2 Spectrum sharing as alternative to LLU

4. Could WIK give an overview of the pros and cons of spectrum sharing on cable networks as an alternative for LLU-access? Please include at least the following elements:

- *Between how many players is spectrum sharing possible? What would be the consequence (in terms of bandwidth, guarantees, product differentiation etc.) if for example three alternative operators would demand access in addition to the cable network operator itself? What are the differences with (virtual) copper access?*

- *To what extent would it be possible to offer non-overbooked connections to end-users when spectrum is shared? What are the differences with (virtual) copper access?*

- *Which options are there to increase possibilities of spectrum sharing? Is node-splitting a realistic manner to facilitate competition on cable networks? Is this an economic viable option?*

- *What would be the implications and consequences of spectrum sharing with regard to the introduction of DOCSIS 3.1?*

Spectrum sharing as based on the approach of section 5.1 would allow for 6 channels upstream allocated to 6 different operators, each being able to offer a peak upstream capacity of 15 Mbit/s und thus being in line with the copper access line based operators using VDSL at the cabinets. There are up to 8 downstream channels with 50 Mbit/s peak capacity each, which may be allocated to the 6 operators. Thus 2 of them might get another downstream channel allowing for 100 Mbit/s downstream or one operator gets the two channels, being enabled for a peak capacity of 150 Mbit/s, or the two channels are not allocated at all thus treating all operators equal. Since this reads well and easy in theory one of the practical problems might be to take away channels from the already operating networks and harming the existing customers by significantly poorer performance than they had before.

If three additional customers want to access the cable-TV platform in a spectrum sharing manner it is already questionable how to allocate the upstream channels. Each of the new entrants gets one channel, and the old operator (supplier, A in Table 5-1) keeps 3, while the 8 downstream channels will be distributed fairly, two for each of the four operators in total, or 5 for the old and one each for the new operators? What happens if the success of one operator causes demand for an additional channel? The uneven distribution of channels results in an uneven peak capacity (and delay behaviour) for the different operators and to competitive advantages/ disadvantages.

Table 5-1: Two alternatives for channel combinations in case of spectrum sharing with 3 additional operators.

Operator	Up-Channel [No]	[Mbit/s]	Down-channel [No]	[Mbit/s]	Up-Channel [No]	[Mbit/s]	Down-channel [No]	[Mbit/s]
A (supplier)	3	45	2	100	2	30	5	250
B	1	15	2	100	2	30	1	50
C	1	15	2	100	1	15	1	50
D	1	15	2	100	1	15	1	50

Comparing the situation of spectrum sharing with the situation of wholesale access in copper networks we find: In case of unbundled copper access (ULL) each wholesale seeker has the same chance to offer bandwidth to the end customer, because the bandwidth is determined by the physical conditions of the access copper pair (length etc.). A difference may exist due to different DSLAMs and their backhaul capacity, both being under the responsibility of the individual operators. In case of virtual copper access the conditions for peak bandwidth and delay are equal between all operators, if no intended discrimination occurs, since they all use the same network platform with incremental influences by additional customers being added or deleted. (If a customer changes from one operator to another no impact to the other customers should happen.

- *To what extent would it be possible to offer non-overbooked connections to end-users when spectrum is shared? What are the differences with (virtual) copper access?*

Non overbooked connections (high quality connections) may be provided under the same principles as described in section 4. Once again we assume symmetrical bandwidth and thus concentrate on the scarce capacity upstream channel[18]. And once again we restrict the offer to lines up to 2 Mbit/s capacity, because with the reduced channel spectrum it is even less reasonable to offer higher bandwidth. Taking 2 Mbit/s from 15 Mbit/s peak capacity is a significantly higher negative impact to the other customers of the respective operator than in the case of one single operator working in the complete upstream frequency space. It is quite obvious that the supplying operator of the cable-TV network in case of the channel distributions of Table 5-1 has a competitive advantage in offering high quality connections than the other operators. He can offer more of those and is less restricted regarding his other customers.

Once again, comparing the situation with the copper access network in case of ULL there is no impact when offering non overbooked connections, in case of a virtual access there is some minor impact on the level of the DSLAM backhaul lines.

- *Which options are there to increase possibilities of spectrum sharing? Is node-splitting a realistic manner to facilitate competition on cable networks? Is this an economic viable option?*

Since the frequency distribution and use within DOCSIS 3.0 is fixed to a wide extent we see no way out of the uneven peak bandwidth distribution and all the related characteristics above. Node splitting reduces the problems described, the decreasing areas lead to a decreasing number of customers, each offering a higher throughput as before, but keeping the peak bandwidth as low as before. The probability that a high quality connection has to be provided decreases, but the bandwidth for these connections remain the same, up to 2 Mbit/s, with decreasing demand and increasing demand for Ethernet access with 10 Mbit/s and above, thus a poor competitive situation compared to copper access networks. If a business building has demand for 3 -5 lines of 2 Mbit/s these cannot be provided by a wholesale based operator using a cable-TV access network, even in a node splitting approach, since the whole demand would be concentrated in one single building, thus within the same micro-area[19].

Node splitting is a viable option for cable-TV network operators using their full spectrum of peak bandwidth while competing with copper cable based operators, which might split up their DSLAMs at the cabinets in a next step into G.fast nodes in front of the buildings, then offering a peak bandwidth of up to 500 Mbit/s[20] symmetrical. These nodes will be connected by a 10 G backhaul line. In order to be competitive with such

18 One can transfer the considerations to the downstream channel in an analogue manner.
19 When the building is covered by two different cable-TV areas the capacity will increase also here.
20 All bandwidth combinations up- and downstream with a sum of 1 Gbit/s are configurable.

infrastructure the cable-TV operator requires splitted nodes serving a comparable number of end customers and using the full peak bandwidth of DOCSIS 3.0[21].

In contrast a node splitting under spectrum sharing conditions does not appear to be economically attractive because the investment will not allow competition with copper DSLAM comparable product characteristics, for none of the operators sharing the cable spectrum. If it is viable depends on the contributions the wholesale customers have to pay for node splitting.

We are convinced that there will come up vivid debates anyhow who will have to contribute for the additional cost of node splitting, the one coming at its segment capacity edge first or all operators according to their share of spectrum that has been allocated to them, or by their number of customers, by their turn over per month, …?

- *What would be the implications and consequences of spectrum sharing with regard to the introduction of DOCSIS 3.1?*

DOCSIS 3.1 increases the frequency space used, changes the transmission coding and thus increases bandwidth for bidirectional communication over time significantly to 1 Gbit/s upstream and 10 Gbit/s downstream. DOCSIS 3.1 incorporates a migration option from the old channel structures and coding to the new, thus allowing to exchange equipment over time. Therefore nobody should expect cable operators to exchange their existing platform in a single or in multiple quick steps, but more smoothly over time. This might be different in new roll-out areas, where a homogenous DOCSIS 3.1 platform can be assumed.

Table 5-2: EuroDOCSIS Migration path and characteristics

			TODAY	
Category	**Property**	**EuroDOCSIS 2.0**	**EuroDOCSIS 3.0**	**EuroDOCSIS 3.1**
Common	Launch date	2001	2006	2013 - 2016
Downstream	**typical offer per customer**	**2 Mbps**	**16 – 100 Mbps**	**1 – 6 Gbps (up to 10+ Gbps)**
	Bandwidth	112 – 858 MHz	112 – 858 MHz (must) 85 – 999 MHz (may be)	1st Step: 112 – 1002 MHz (6 Gbps) 2nd Step: 112 – 1200 MHz (7+ Gbps, amp upgrade) 3rd Step: 200 – 1700 MHz (10+ Gbps, tap upgrade)
	Bandwidth per channel	8 MHz	8 MHz	200 MHz OFDM block spectrum 20 – 50 KHz subchannels
	Max. nominal data rate (per channel)	~37 Mbps (64 QAM) ~50 Mbps (256 QAM)	m * 37 Mbps (64 QAM) m * 50 Mbps (256 QAM)	no channels anymore
Upstream	**typical offer per customer**	**128kbps**	**1 – 6 Mbps**	**100 Mbps (up to 1 Gbps)**
	Bandwidth	5 – 65 MHz	5 – 65 MHz	1st Step: 42/65 MHz (200 Mbps) 2nd Step: 85 MHz (400 Mbps) 3rd Step: ~230 MHz (1 Gbps)
	Bandwidth per channel	0.2 – 6.4 MHz	0.2 – 6.4 MHz	OFDM block spectrum
	Max. nominal data rate (per channel)	~32 Mbps (128 QAM)	m * 32 Mbps (128 QAM)	no channels anymore

Source: ContaQ

21 without sharing the bandwidth with other wholesale networks.

Since DOCSIS 3.1 is intended to increase the digital bidirectional network capacity, rolling out of DOCSIS 3.1 and node splitting contradicts each other to some extent. It is not required to do both approaches for increasing bandwidth. The migration towards a higher DOCSIS release may require significantly less underground construction work than node splitting. But this depends on the cable network topology.

The DOCSIS 3.1 frequency space is subdivided into 25 KHz or 50 KHz subcarriers, which can be bonded by 16 respectively 8 to 400 KHz channels upstream and 200 MHz channels downstream. Like in DOCSIS 3.0 these channels are used in parallel in order to increase the peak capacity per end customer. Thus in principle the impacts of spectrum sharing on the DOCSIS 3.1 architecture follow similar principles compared to DOCSIS 3.0, but at another scale. Already the bandwidth for the IP-Up- and downstream channels are much larger, thus bottleneck considerations for sharing the bandwidth with third party traffic (e.g. bitstream) may change, but one has to keep in mind that these limitations will be lifted over time in a migration process, also requiring major investment due to the exchange of the cable modems, repeaters and amplifiers in the field and fibre nodes and CMTS upgrades.

As we can recognize from standard literature so far the MAC-Domain methodology continues to exist[22], but still is related to the channel structure and not to subcarriers. Thus also here the principle considerations made above are still valid, at another scale. There is a trade of between peak bandwidth reduction against additional competitors in the network, there remain the questions of how to allocate the channel capacity amongst the network operators, which could be performed in a finer granularity compared to DOCSIS 3.0 with its fixed channel sizes. The restrictions for high quality bandwidth connections will be lifted to some extent regarding bandwidth per connection and number of connections, but are still limited in the total capacity consumed by such connections. This total capacity is once again no longer available on the last (coax) access mile connection to the rest of the customers connected. So far it still remains unclear for us if such connections would meet the VULA characteristics of the EC market recommendation for market 3a.

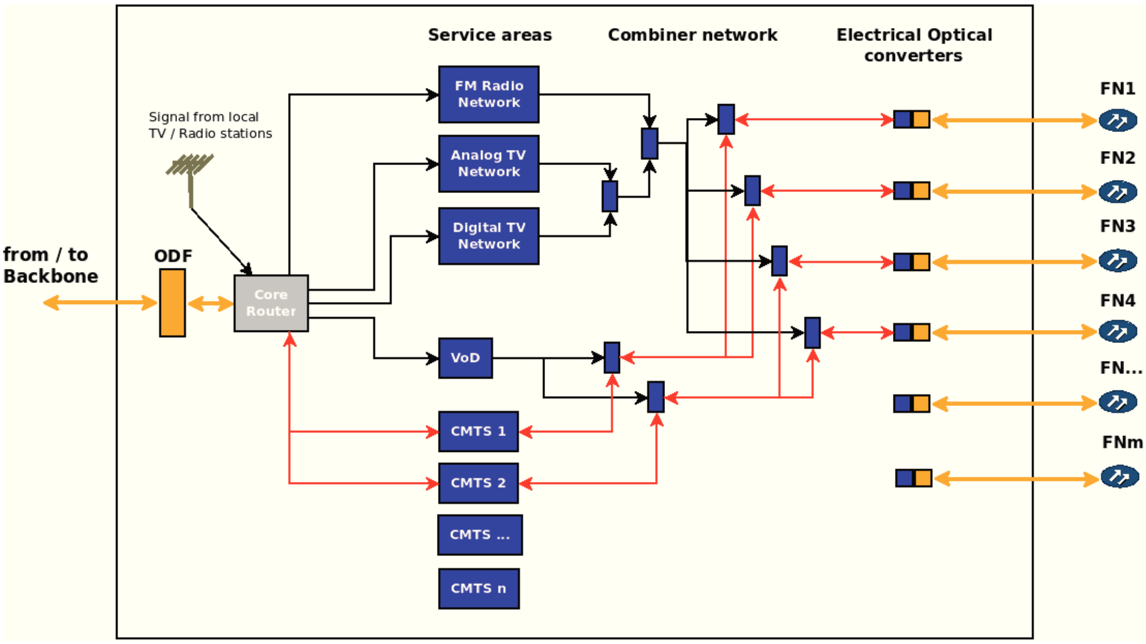
22 See DOCSIS 3.1 MAC and Upper Layer Protocols Interface specification CM-SP-MULPIv3.1-I04-141218, section 5.2.1.1.2 and 5.2.11.

5.3 Harderwijk example of parallel CMTS

Furthermore ACM received feedback based on slide 61 of the WIK-workshop, where it is stated that “E.g. especially in the upstream bandwidth both CMTS have to work in the range from 5 – 65 MHz (edge to edge), which is impossible”.
One party informed us that in ‘Harderwijk’ (on the ‘CAI Harderwijk’ cable network) two CMTS operate parallel and several ISPs deliver internet and fixed telephony services to end users. On one of those two CMTS there are three ISP’s connected to their own “virtual CMTS”.

By enhancing standard DOCSIS 3.0 equipment beyond the standard description it is imaginable that two CMTS work in parallel on the same Cable-TV infrastructure. They have to subdivide the total up- and downstream frequency space and its allocated channel control in a manner that it cannot occur that the communication between the two CMTS and their allocated end-customers will be mixed up. Such solutions then are vendor specific implementations of the MAC-Domain concept. One CMTS is managing and accessing its frequency spaces for up- and downstream coordinated with each other by the network provider. Even since such cooperation is not foreseen in the standard it is not impossible to realize it, beside the standard and on a volunteer manner (CAI Harderwijk invited competitors to bring additional load to their network, quite a reasonable approach to cover cost). It is a more complex coordination to arrange and couple the appropriate frequencies for each CMTS in the combiner network between the central location (service areas in Figure 5-1 below) and the fibre nodes (Electrical Optical converters in Figure 5-1) with regard to signal strength and attenuation and frequencies of all systems attached. This would require a major administrative effort, especially for long time grown up networks. Greenfield new networks may be in a better position in this regard.

Figure 5-1: Example of a simple combiner network



Source: ContaQ

In the DOCSIS 3.0 networks it is also possible to offer third party Internet and VoIP telephony services. We doubt it will be possible to offer high quality access services or VULA like services with guaranteed, non overbookable bandwidth to a major extent. Nevertheless, due to the lack of more detailed information we cannot analyse the approach chosen in Harderwijk in more detail.

5.4 Multiple CMTS

5. Could WIK explain under which circumstances it would be possible to operate multiple CMTS next to each other? What would be the consequences in terms of bandwidth, guarantees, product differentiation etc.?

The DOCSIS architecture is originally not intended to be used by 2 CMTS operating in parallel and accessing the same coax cable infrastructure and its frequency space. Such architectures had been developed in the past very successfully, but base on a quite different technology, the Ethernet standard. Ethernets' basic feature is the collision detection when two senders access the transmission medium at the same time starting to transmit. In case of collision both senders withdraw its first trial to send and repeat it with an arbitrary delay. In contrast DOCSIS is administrating the access to the transmission media in a deterministic manner. The possible upstream senders (cable modems) are regularly requested (polled) by the CMTS. If there is anything to send the right to use the common transmission medium is granted by the CMTS to the cable modem for transmission. For the downstream direction it is easier – the cable modem is addressed by the CMTS and picks its information from the cable, the other modems are listening, but ignoring the transmission.

Thus, the transmission of several CMTS on the same cable-TV network infrastructure requires to allocate the frequency spectrum to the different CMTS (spectrum sharing), at least for a coordinated time[23]. And also the upstream administration function controlling the access to the shared upstream medium has to be coordinated in a manner that access is only granted to frequency spectra allocated to the respective CMTS. This features are not part of any DOCSIS standard, but may be a result of bilateral agreements[24] between the network operators offering and requesting access by this way and between the operators and their CMTS suppliers. Regarding bandwidth availability and provisioning of high quality services we see the same problems as already described with spectrum sharing.

Using a separate CMTS may have the advantage that each operator can manage its own CMTS in case of providing new services, new customers, ceasing services or adapting them, supervising performance and analysing faults and repair them, but these management features should be coordinated in a manner that the customers of the other operators are not harmed with respect i.a. of data security or service stability, … And one has to keep in mind that the access network still remains a shared medium where all activities have to be coordinated.

Another advantage at a first glance is the independence of the operators from each other regarding the CMTS software releases and inherent specific product features. This enables a higher degree of product independence from each other. But this independence can only hold as long the required interrelation/ interaction of the different CMTS systems is not harmed, especially in the shared access network.

5.5 Virtual CMTS

6. Parties argue that something like a virtual CMTS could perform a similar function like VULA over copper. Please clarify the capabilities of a virtual CMTS, and provide a comparison of virtual CMTS and DLSAM-based VULA in terms of pros and cons?

---

23 DOCSIS 3.0 does not include a time dependant frequency allocation, but a fixed one, thus once again considering such options we are beyond the standard.

24 Such agreements should include also many operational aspects like fault identification, management and repair (who is responsible for what and who is paying for?), change management, additional capacity requirement, …

We understand a virtual CMTS to be one or several (logical) CMTS systems being incorporated in one physical CMTS. This characteristic also is called multitenancy in software and system engineering. Typically this feature cannot be introduced into a system ex post, as add-on feature, but has to be designed from the beginning of the system design onwards, because all data structures have to be designed in a manner that tenant (A) cannot see or influence system behaviour or customer characteristics belonging to another tenant (B). It should also allow for designing and implementing product characteristics being different per tenant, to the extend the physical and logical framework of the CMTS will allow. Each tenant will provide, monitor and correct the connections of his own customers, typically by connecting the CMTS to the tenants specific OSS system. We so far do not know about multitenant CMTS being available in the market, nor do we know about suppliers intending to offer these. But we observe a technology development path towards Network Function Virtualisation and Software defined networking, leading to a much higher degree of flexibility than todays' network systems architectures. Nevertheless, these will be framed by the physical conditions of a fibre coax network and its frequency allocation. In any case the following considerations are a speculation on future development derived in limited time and without major research.

Thus, continuing the idea of virtual CMTS we see on the network, at least in theory, two options of sharing the transmission capacity, either by separating the frequency space in a manner comparable to the spectrum sharing already addressed above, with its fixed borders of capacity and the advantages and disadvantages already discussed above, or by sharing the full up- and downstream bandwidth space with the option to smoothly move borders of bandwidth between the operators. Nevertheless, in both cases the remaining major problem is the question of performance updates for the individual operators, how to organize it (node splitting?, upgrading to DOCSIS 3.1?, …) and who has to pay for it. This includes the question of who is providing high quality services and to which extent they can be provided.

The physical constraints of a cable-TV access network (regarding bandwidth, shared medium, …) cannot be overcome with the concept of virtual CMTS, but some disadvantages of self-provisioning and operating without the strong dependency from a wholesale provider can be achieved.

Comparing the concept of a Virtual CMTS with the VULA concept quite soon shows, that VULA at least in theory can be implemented without any overbooking of bandwidth for each of the access lines served. And this can be done line per line individually. This in any case is true on the access line between end-customer and DSLAM, but could also be configured on the DSLAM backhaul. Of course the incumbent operators obliged to offer a VULA service will argue that this kind of over-dimensioning the DSLAM and the backhaul line is not required and not state of the art, but at least there are no physical limitations, and the backhaul capacity may be adjusted according to demand. This will not work in DOCSIS 3.0 access networks. The bandwidth guaranteed per end customer depends on the number of all other customers (and of all providers) in the same network segment, virtually sharing the CMTS. This can be influenced by node splitting, but then soon requires a significant demand of underground infrastructure development compared to a backhaul line upgrade in the DSL VULA case.

While we have not heard about virtualisation of CMTS we have already observed multitenancy features in ADSL DSLAM systems of the supplier Alcatel-Lucent some 7 years ago, allowing the tenants to provide their own services and monitor and reset their end-customers access lines. This feature disappeared from the market due to low demand and had been replaced by VDSL vectoring, which requires control of all access lines of a DSLAM by one operator in order to enable crosstalk suppression for higher bandwidth. Also here a Virtual DSLAM concept in the context of VULA should be supportive for the coming wholesale demand.

But now a debate of so called node level vectoring came up which should allow for crosstalk suppression among several VDSL-vectoring DSLAMs of different network operators approaching for SLU unbundling at the same cabinet location. Thus each competitive operator should deploy a VDSL-vectoring DSLAM at the cabinet sites, which shall exchange information for the crosstalk suppression. This information exchange is not standardized yet and also is hard to implement because of the tight time constraints for the real-time cross talk suppression required.

The virtual DSLAM (multitenancy DSLAM) can be compared to the virtual CMTS regarding product differentiation, the node level vectoring could be also compared in this regard to the Multi CMTS approach. The use of such features strongly depend on the market availability of these functions, but without operator demand with higher systems volumes we expect no supplier to develop appropriate systems.

Table 5-3: Comparison of DSLAM copper VULA/ Virtual CMTS

Characteristic	VULA/ copper DSLAM	Virtual CMTS
Bandwidth flexibility per operator	determined by access line, but not by backhaul	determined by limited backhaul capacity
Performance upgrade	easy, backhaul upgrade	complex coordination, to the detriment of others in the same network segment or node splitting
High quality bandwidth	configurable per end customer; max. appr. 10 Mbit/s	strictly limited, max. 2 Mbit/s
Multitenancy features	per operator	per operator

5.6 Other options of spectrum sharing

Another option of spectrum sharing would be to enable the access network capacity for transmitting in the frequency space up to 2.7 GHz. This Frequency space is familiar for satellite transmission. Now one could realize 3 DOCSIS 3.0 architectures in parallel using the same coax (and fibre) cable infrastructure. The frequencies of the higher band are transformed to the original DOCSIS 3.0 frequencies or the network components' receivers are exchanged. Thus one could allow for more than one DOCSIS 3.0 operator in parallel, realizing competition on this level. Of course the number of cable-TV operators competing with each other is fixed, but the number of operators then may be expanded by the other methods discussed before, with the strength and weaknesses also described.

6 Conclusion

A cable-TV network is best suited for non-IP-based TV-Multicast, for which it was originally designed for. It allows for down streaming a rich radio and TV-channel bouquet in analogue and digital coding and of a wide spectrum of digital signal quality. Its abilities for a bidirectional data and voice telephony communication are limited and its scalability is also limited, but both are better than todays' FTTC VDSL based copper networks, assuming low bandwidth conflicts on the shared access line, just due to the fact that a copper line has a significant poorer characteristic for transmitting high frequencies (and bandwidth) than a coax cable has. This changes with an increasing number of customers, and will be even more limited with additional wholesale providers sharing the access line. The cable-TV limitations are caused by the coax-cable sharing by all customer connected to it, while in the copper network each end-customer is addressed by an individual narrowband copper pair, whose capacity is also driven by the line length. Thus a cable-TV network is best suited for TV-multicast and bidirectional communications in case that a single operator can make full use of it.

A copper pair IP-TV-Multicast requires some minimum bandwidth on the access line, so that some channels may be transmitted per line in parallel. Zapping/ channel changing may become less comfortable compared to the cable-TV network due to higher switching/ change over times. Opening an additional IP-TV offer in the cable-TV IP-downstream data path (DOCSIS) can result in channel bouquet limitations. Wholesale IP-TV Multicast in both architectures may soon cause bottlenecks, depending on channel bouquet size and take-up of the service. The bottlenecks will come sooner in a DOCSIS than a copper pair network. Nevertheless, both may be overcome by TV-channel reselling, while it is even more efficient for a cable-TV network (radio and TV-channels outside DOCSIS) than for a coper pair network with regard to the remaining data communication bandwidth.

We observe a trend towards increasing use of smart-TV and its individual video-on-demand like communication. This releases some bandwidth demand in the multicast environment but increases the bandwidth demand for individual communication significantly much more.

The offer of high quality connections is limited in both network architectures, but in cable-TV networks it is limited much more due to the shared transmission medium, both regarding bandwidth and number of connections. This cable-TV disadvantage is getting even worse by subdividing the frequency space of the downstream channels-, but even more of the upstream channels for several operators' use. Increasing bandwidth demand of one operator will act as a detriment for the others. The peak bandwidth per operator will be capped or even reduced. Multiple CMTS or virtual CMTS approaches cannot help in this regard, but may improve the wholesale seekers product design independence from the wholesale supplier. Both approaches are beyond existing and upcoming standardization, thus network equipment supplier specific.

While DOCSIS 3.0 is fixed in an eight MHz channel raster being allocable to different services or providers, DOCSIS 3.1 offers wider flexibility by releasing or changing the channel frequency allocation. Nevertheless, the bandwidth is limited, and adding new wholesale service customers to an existing network typically results in restricting or reducing the bandwidth for existing customers.

The migration towards DOCSIS 3.1 will take time, can be organized network segment per network segment in an individual manner and will increase the capacity for the data channels significantly, but cannot overcome the disadvantages of a shared medium in general. Taking into account that the end-customer demand for data communication will increase also for the cable-TV network operator the migration to DOCSIS 3.1 and the investment required will be decided in order to satisfy their customers' demand and in order to keep a competitive position with other NGA based operators instead of adding capacity for an additional wholesale business. Nevertheless, it also may be a business decision to construct a new cable-TV based network and offer capacity to wholesale seekers in order to fill the network and improve revenues, being enabled by supplier specific equipment beyond existing standards.

Also node splitting is a capacity improving approach for cable-TV networks, requiring additional investment and in its final state ending in a FTTB comparable approach. Such approaches could also been chosen for copper pair based networks in order to increase the total capacity, and here even more, by shortening the copper loop in order to increase capacity. G.fast is here the next technological step under development.

VULA on FTTC DSLAMs can also be improved by a Multi-DSLAM approach (e.g. node level vectoring) or by virtual DSLAMs if demand comes up and then are better suited for the wholesale business than a virtual or Multi CMTS approach would be.

Imprint

WIK-Consult GmbH
Rhöndorfer Str. 68
53604 Bad Honnef
Germany
Phone: +49 2224 9225-0
Fax: +49 2224 9225-63
eMail: info(at)wik-consult.com
www.wik-consult.com

Person authorised to sign on behalf of the organisation

General Manager	Dr. Iris Henseler-Unger
Head of Department Postal Services, Logistics, and Transport	Alex Kalevi Dieke
Director	J. Scott Marcus
Director	Dr. Ulrich Stumpf
Head of Administration	Karl-Hubert Strüver
Chairman of the Supervisory Board	Winfried Ulmen
Registered at	Amtsgericht Siegburg, HRB 7043
Tax No.	222/5751/0926
VAT-ID	DE 123 383 795