

APPLICATION NOTE

AN 004

DOCSIS 3.0 Analyzer

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Section 1

About this Document

This document contains information on DOCSIS3.0 Analyzer in antenna measuring receiver models AMA 310 (option) or VAROS 107.

1.1 Revisions

V00.01 August 2013
First release

V00.02 June 2014
New feature “speed test“ (data throughput test) in section 3.2 added

1.2 Reference documents

This application note refers to the following documents:

- AMA 310 Antenna Measuring Receiver Operating Instructions
- VAROS 107 Antenna Measuring Receiver Operating Instructions
- Application Note “AN003 DOCSIS-2.0-Analyzer”
(<http://www.kws-electronic.de> → SUPPORT → Application Notes)
- DOCSIS3.0 Specifications
(<http://www.cablelabs.com/cablemodem/specifications/specifications30.html>)

1.3 Notes on VAROS 107 measuring receiver

All screenshots shown in this document were made using measuring receiver AMA 310. The VAROS 107 screens only have minor differences, as the user interface design and operation are based on the AMA 310.

1.4 Notes on fundamental DOCSIS knowledge

In order to keep this document to a reasonable length yet still go into detail on DOCSIS3.0-specific aspects, we assume that readers are familiar with the contents of the KWS document “AN003 DOCSIS-2.0-Analyzer”. In particular, the following fundamentals, terms and workflows are important for understanding the present document:

- DOCSIS Standard, HFC Network, CMTS
- Euro-DOCSIS and US-DOCSIS
- Downstream (MPEG transport stream, PID, FEC, QAM modulation)
- Upstream (multiple access mode, time slot types, QAM modulation)
- Abbreviations: DS for downstream and US for upstream
- Initial and continuous ranging
- Ranging offset
- Upstream equalizer
- Synchronisation between the modem and CMTS and registration of the modem
- Configuration file
- BPI(+) encryption
- PING test
- Ingress
- MAC address
- Downstream quality parameters at the terminal connection socket (TCS)
- Downstream channel utilisation (duty factor)
- TCS = Terminal connection socket (multimedia socket) = Modem and set-top box connection to the broadband cable network

1.5 Contact with the manufacturer

For the latest information on products from KWS-Electronic, visit our website at www.kws-electronic.de. All contact details can be found there.

Section 2

Major Differences Between DOCSIS2.0 and DOCSIS3.0

2.1 Channel bonding

The primary goal in developing the DOCSIS3.0 standard was to multiply the upstream and downstream bandwidths and, as a result, the data rates. DOCSIS3.0 achieves this goal by channel bonding. That means that a cable modem can receive downstream data on multiple channels simultaneously, and can send data upstream on multiple frequencies at the same time accordingly.

The individual upstreams and downstreams do not differ at a physical level (modulation, FEC, access method, coding, etc.) from the DOCSIS1.1 and DOCSIS2.0 standards (with a minor optional exception for upstream, which is explained in greater detail in Section 2.4).

The maximum downstream bandwidth is reached in EuroDOCSIS (8 MHz channels) with the 256 QAM modulation. For example, when bonding 8 downstream channels, the gross data rate is as follows:

$$6952 \times 10^3 \frac{\text{symbols}}{\text{second}} \times 8 \frac{\text{Bit}}{\text{symbol}} \times 8 \text{ Downstreams} = 444,928 \frac{\text{MBit}}{\text{second}}$$

The Euro-DOCSIS and US-DOCSIS standards do not differ in terms of upstream. The maximum gross data rate possible for A-TDMA access mode at a modulation of 64 QAM and the maximum channel bandwidth of 6.4 MHz and bonding of 4 upstreams, for example, is calculated as follows:

$$5120 \times 10^3 \frac{\text{symbols}}{\text{second}} \times 6 \frac{\text{Bit}}{\text{symbol}} \times 4 \text{ Upstreams} = 122,880 \frac{\text{MBit}}{\text{second}}$$

These data rates are exactly equal to the maximum possible DOCSIS2.0 rates multiplied by the number of downstreams or upstreams.

2.2 Primary and secondary downstreams

DOCSIS3.0 distinguishes between primary and secondary downstreams. The CMTS only sends the SYNC packets into the cable network on primary downstreams. These SYNC packets contain timing information without which the cable modem cannot initiate contact with the CMTS.

Therefore, when a modem is activated, it must always scan for a primary downstream. The secondary channels are only used to multiply the data rate and cannot be used by the modem until after advanced registration with the CMTS. It is up to the cable network operators to decide which channels they configure as primary and secondary channels in the network.

One advantage of multiple primary channels is that modems can find a channel for registration at the headend faster after activation. Another benefit is that DOCSIS2.0 modems can also synchronise on these primary channels. However, the data rate overhead for managing the registered modems is higher on these channels.

A cable modem can bond any combination of primary and secondary channels. The only restriction is that cable modems have an upper limit (based on the chipset used) for the total number of channels which can be bonded for downstream and upstream. For upstream, there is no distinction between primary and secondary channels. The two figures below show possible bonding scenarios based on a CMTS with four upstream and four downstream channels (the terms "MAC Domain" and "Bonding Group" are explained in Section 2.8). In Figure 1, all downstreams are primary channels. Figure 2 shows only one primary channel and three secondary channels.

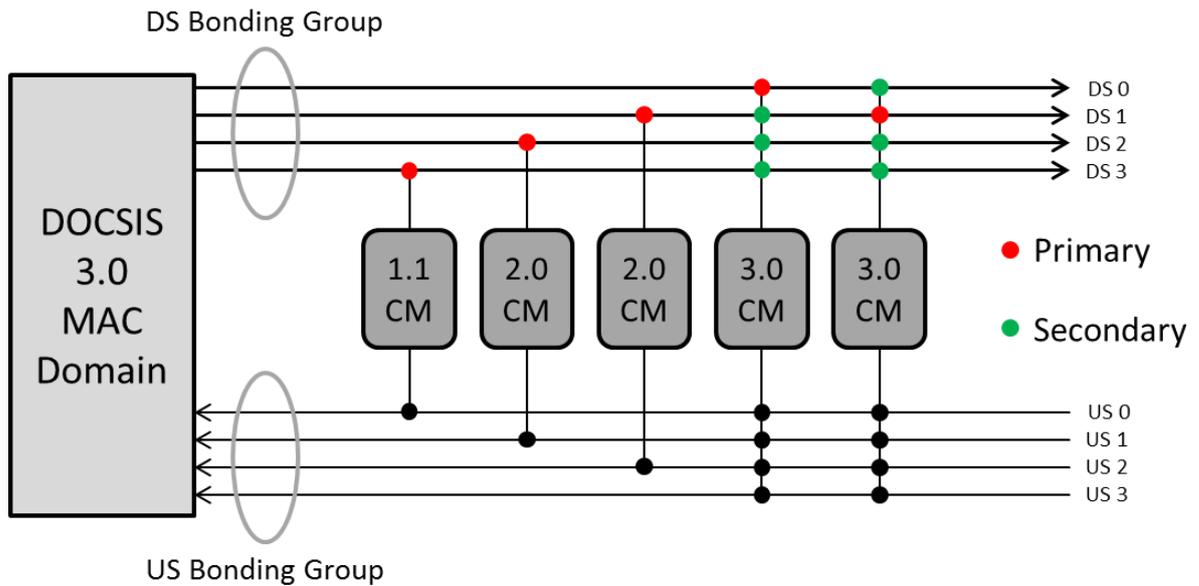


Figure 1

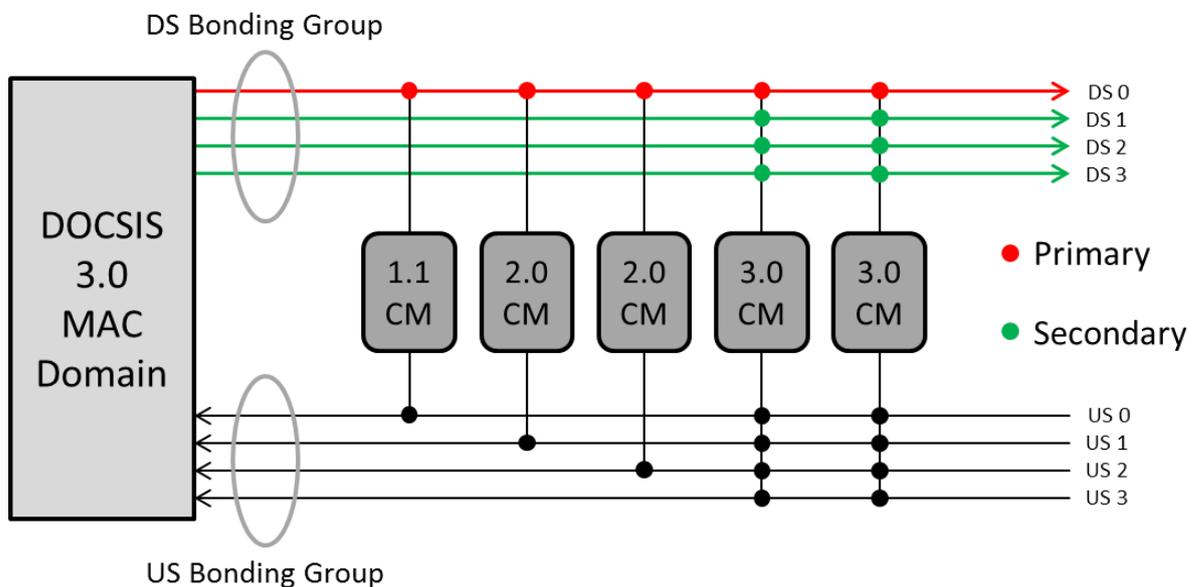


Figure 2

2.3 Upstream transmitting power

In DOCSIS2.0, the minimum transmitting power modems must support is 8 dBmV, which is equal to 68 dBμV. See the table below for the upper transmitting power limit for DOCSIS2.0. It depends on the modulation type and the multiple access mode (conversion: dBμV = dBmV + 60 dB).

Constellation	Constellation Gain G_{const} Relative to 64QAM (dB)	P_{min} (dBmV)	P_{max} (dBmV) TDMA	P_{max} (dBmV) S-CDMA
QPSK	-1.18	8	58	53
8QAM	-0.21	8	55	53
16QAM	-0.21	8	55	53
32QAM	0.00	8	54	53
64QAM	0.00	8	54	53
128QAM	0.05	8	N/A	53

In DOCSIS3.0, the lower limit for the transmitting power is a function of the bandwidth. The following equivalents apply in the tables below: L = 1280, M = 2560 and H = 5120 kSymb/s.

Support for these three bandwidths only is REQUIRED in DOCSIS3.0. For backward compatibility to DOCSIS1.1 or 2.0 systems, they CAN also support the bandwidths 160 kSymb/s, 320 kSymb/s and 640 kSymb/s. In practice, all modems from major manufacturers support these bandwidths. The two tables below show that the lower limits of transmitting power required for modems are far higher than those in DOCSIS1.1/2.0. The number of upstream channels transmitted by the modem determines the upper transmitting power limit, significant, not the bandwidth of the upstream signal. Here, just one, two and three or more upstreams are distinguished. The more upstreams in the system, the lower the maximum transmitting power required or permitted for a modem. This is because intermodulation products can occur both within the modem (e.g. at the US amplifier) and externally in the HFC network (at amplifiers or when converting electric signals to optical signals and back) at non-linear components. They can affect transmission of the DOCSIS data. The higher the transmitting power of an upstream and the more upstream frequencies are used (total transmitting power!), the higher the power of the (undesirable) intermodulation products, and as a result, the greater the interference.

Transmitting power specification for one upstream:

Constellation	Constellation Gain G_{const} Relative to 64 QAM (dB)	P_{min} (dBmV)			P_{max} (dBmV) TDMA	P_{max} (dBmV) S-CDMA
		L	M	H		
QPSK	-1.18	17	20	23	61	56
8 QAM	-0.21	17	20	23	58	56
16 QAM	-0.21	17	20	23	58	56
32 QAM	0.00	17	20	23	57	56
64 QAM	0.00	17	20	23	57	56
128 QAM	0.05	17	20	23	N/A	56

Transmitting power specification for two upstreams:

Constellation	Constellation Gain G_{const} Relative to 64 QAM (dB)	P_{min} (dBmV)			P_{max} (dBmV) TDMA	P_{max} (dBmV) S-CDMA
		L	M	H		
QPSK	-1.18	17	20	23	58	53
8 QAM	-0.21	17	20	23	55	53
16 QAM	-0.21	17	20	23	55	53
32 QAM	0.00	17	20	23	54	53
64 QAM	0.00	17	20	23	54	53
128 QAM	0.05	17	20	23	N/A	53

Transmitting power specification for three or four (or more) upstreams:

Constellation	Constellation Gain G_{const} Relative to 64 QAM (dB)	P_{min} (dBmV)			P_{max} (dBmV) TDMA	P_{max} (dBmV) S-CDMA
		L	M	H		
QPSK	-1.18	17	20	23	55	53
8 QAM	-0.21	17	20	23	52	53
16 QAM	-0.21	17	20	23	52	53
32 QAM	0.00	17	20	23	51	53
64 QAM	0.00	17	20	23	51	53
128 QAM	0.05	17	20	23	N/A	53

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2.4 UCD 35 and DOCSIS3.0 configurations

UCD stands for "Upstream Channel Descriptor". They are data packets transmitted by the CMTS into the cable network, which define precisely how a modem must transmit on an upstream frequency. The CMTS must send a separate UCD message for every upstream on which a modem can transmit, as various upstreams can have different modulation types or bandwidths, for example. The data contained in a UCD message includes e.g.: US frequency, US ID, symbol rate, multiple access mode, QAM order (dependent on the time slot type), information on forward error correction and scrambling (dependent on the time slot type) and much more information. The following list shows all information for ONE DOCSIS3.0 upstream. The data was read for an S-CDMA upstream from the KWS DOCSIS3.0 modem as an example.

```
*****
UCD/BURST PROFILE SHOW
*****
Upstream Channel = 1
Change Count = 7
MiniSlot Size = 64 symbols
MiniSlot Size = 2 ticks
Downstream Id = 169
Symbol Rate = 2560000 sym/sec
Upstream Frequency = 57000000 Hz
Upstream Channel Type = Type 4 (DOCSIS 3.0)
Install Mode = Full Install
Active Data Grant Bd's = 1 (kUseIuc5_6_DoNotUseIuc9_10_11)

Preamble Superstring = (128 bytes)
03 f0 28 33 eb f0 28 33 eb f0 28 33 eb f0 28 33 | ..(3..(3..(3..(3
eb f1 64 28 92 a9 97 47 67 da 04 17 bb c2 75 8f | ..d(...Gg.....u.
36 ff 57 39 35 0d c1 87 19 88 d3 d2 2b 60 3f 29 | 6.W95.....+`?)
6b 0d f3 de c0 ed f3 de c0 ed f3 de c0 ed f3 de | k.....
c0 ed f1 64 28 92 a9 97 47 67 da 04 17 bb c2 75 | ..d(...Gg.....u
8f 36 ff 57 39 35 0d c1 87 19 88 d3 d2 2b 60 3f | .6.W95.....+`?
29 6b 00 00 00 00 00 00 00 00 00 00 00 00 | )k.....
00 00 00 00 00 00 00 00 00 00 00 00 00 00 | .....

Extended Preamble Superstring = (0 bytes)
SCDMA Mode = On
Spreading Intervals/Frame = 16
Codes/MiniSlot = 4
Active Codes = 112
Code Hopping Seed = 0
US Ratio Numerator M = 869
US Ratio Denominator N = 1280
Timestamp Snapshot =
Sof Timestamp = 0x56ea8000 ticks
Sof Timestamp = 0x672faf minislots
Frame Num = 0xc1
SCDMA Max Scheduled Codes = Off
UCD Change Maintain Power = Off
UCD Change Ranging Required = Unicast Initial
*****
Burst Descriptors:
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| | 1 | 2 | 3 | 4 | 5 | 6 | 9 | 10 | 11 |
| IUC | Req | Req/ | Init | Per | Short| Long | Adv | Adv | Adv |
| | | Data | Maint| Maint| Data | Data | Short| Long | UGS |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
Modulation: QPSK XXXX QPSK QPSK 64QAM 64QAM 64QAM 64QAM 64QAM
DiffEncoding: Off XXXX Off Off Off Off Off Off Off Off
PreambleLen: 64 XXXX 384 384 64 64 64 64 64
PreambleOffset: 400 XXXX 6 6 400 400 400 400 400
FEC T Bytes: 0 XXXX 5 5 3 9 6 14 14
FEC K Bytes: 16 XXXX 34 34 76 232 76 220 220
Scrambler Seed: 338 XXXX 338 338 338 338 338 338 338
Max Burst: 0 XXXX 0 0 12 0 6 0 37
Guard Time: 0 XXXX 0 0 0 0 0 0 0
Last Codeword: Fixed XXXX Fixed Fixed Short Short Short Short Short
Scrambler: On XXXX On On On On On On On On
Preamble Type: QPSK0 XXXX QPSK0 QPSK0 QPSK1 QPSK1 QPSK1 QPSK1 QPSK1
Spreader: On XXXX Off Off On On On On On On
CodesPerSubFrm: 2 XXXX 2 2 2 2 2 2 2
IntrnlvrStepSz: 1 XXXX 1 1 1 1 1 1 1
TcmEncoding: Off XXXX Off Off Off Off Off Off Off Off
*****
```

The above list shows that some parameters are globally valid, while many only apply for a specific time slot type (IUC, interval usage code).

The name UCD 35 has the following background: When a modem receives messages via the downstream, various information in the packet header shows the purpose of the packet. The modem can then distinguish whether the data in the packet received has a control function or the packet contains an IP frame (e.g. because the PC behind the modem is currently downloading a file or receiving an e-mail).

UCD messages are also considered control information. When a modem identifies a data packet as a UCD message, three UCD message types can be distinguished based on the MAC header. There are type 2, type 29 and type 35 UCDs. Type 2 UCDs describe DOCSIS1.1 upstreams or upstreams on which DOCSIS1.1 and 2.0 modems can communicate with the headend in mixed mode. Type 29 UCDs describe pure DOCSIS2.0 upstreams. DOCSIS1.1 modems cannot connect with the CMTS on these upstreams. Type 35 UCDs can only be processed by DOCSIS3.0 modems. Backward compatibility always applies, i.e. a DOCSIS3.0 modem can use a type 2 UCD upstream, but a DOCSIS1.1/2.0 modem cannot use a type 35 upstream.

The reason for this difference is that the maximum data rate (and the resistance of the upstream signal to noise and ingress) was increased when transitioning to a new DOCSIS standard. For example, DOCSIS1.1 only permitted QPSK and 16 QAM as upstream modulations, while the modulators of DOCSIS2.0 and 3.0 modems must also be able to send with 8 QAM, 32 QAM, 64 QAM, and even 128 QAM for the S-CDMA access mode. That alone explains why modems specified to earlier standards cannot use UCDs with higher type specifications.

It is the responsibility of cable network operators to configure their networks so that all customer modems can connect to the CMTS. There are no real limits for this. For example, an operator could configure 3 upstream channels exclusively for DOCSIS3.0 modems (channel bonding, sale of higher data rates). Another upstream configured for a DOCSIS1.1/2.0 mixed mode could serve all "old" modems in a network segment. The configuration is always highly individual and depends on many factors (e.g.: How many 1.1, 2.0 and 3.0 modems have to be served in a network segment? Or were only "new" modems issued? Which tariff structure does the network operator provide, i.e. what data rates can customers order? How many customers must be served overall in a network segment? Which upstream frequencies can actually be used in a cluster, and do not suffer from permanent interference due to high noise or heavy ingress?).

An important aspect is that a network operator has two options for connecting the DOCSIS3.0 modems to the CMTS. The first option is to notify the modems of the upstreams to be used by the 3.0 modems via type 35 UCDs. If a type 35 UCD message is received on a primary downstream, it can automatically be assumed to be a DOCSIS3.0 network. However, it is possible to send only type 29 or 2 UCDs, which usually indicate DOCSIS1.1/2.0, and instruct the modem to bond other upstreams to it during registration.

In practice, the major cable network operators in Europe have only used the second method (to date). The reason is that no operator's network consists entirely of new DOCSIS3.0 modems. In the second configuration, the modems continue scanning until they find a primary downstream - every network must contain at least one. The modem receives one or more type 29 or type 2 UCDs on this DS, chooses an upstream and synchronises with the headend. The 3.0 modems follow exactly the same procedure. During the subsequent registration process, the CMTS notifies them of the primary or secondary DS channels and other US channels they can use for channel bonding and, as a result, for bandwidth expansion.

In summary, it is important to know that you can ascertain whether you are in a DOCSIS3.0 network or not based on two aspects. Type 35 UCDs can be sent. Even without channel bonding, it must be a DOCSIS3.0 system, as no 1.1 or 2.0 modems can process these UCDs. However, there may only be DOCSIS1.1/2.0 upstreams and primary downstreams in a network (segment), which means that at first glance, you would assume that it is a DOCSIS1.1/2.0 system. In this case it can, in fact, be a DOCSIS3.0 system if the CMTS allows DOCSIS3.0 modems to use channel bonding.

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2.5 Upstream frequency range

Nothing changes in the upstream frequency range under EuroDOCSIS. As in the previous specifications, frequencies from 5 MHz to 65 MHz are reserved for the upstream(s).

In US-DOCSIS, the upstream frequency range from 5 MHz to 42 MHz was specified for DOCSIS2.0 and earlier. DOCSIS3.0 now requires frequencies from 5 MHz to 85 MHz. Cable modems must support this frequency range; however it is up to network operators to decide to use this frequency range.

There are two reasons for expanding the upstream frequency range. On one hand, experience shows that the network operators often struggle with ingress problems especially at the lower end of the upstream spectrum. However, another important reason is that the specifications must be adapted to changing consumer behaviour. As interactivity increases (e.g. online gaming, video uploads etc.), many Internet users no longer focus solely on the download data rate (i.e. the downstream bandwidth), the upstream data rate is also important to them. Symmetrical transmission is the key to this.

In the next development phase - DOCSIS3.1 - an upstream frequency range of up to 200 MHz (or even 400 MHz) is likely to be specified.

2.6 Encryption

In DOCSIS3.0, the encryption and security mechanisms were improved again. Previously, the primary measures were BPI (encryption of the data between CM and CMTS to protect against "eavesdroppers") and BPI+ (verification of the MAC address and the serial number of the modem to prevent "cloning" of modems, which allowed third parties to use the Internet at the cost of other cable customers).

Now, in addition to the previous standard 56-bit DES encryption algorithm (Data Encryption Standard), a 128-bit AES encryption (Advanced Encryption Standard) has been added to the DOCSIS specification. Modems and CMTS devices must support the new methods. However, it is up to the cable network operator to activate this function.

Other protective measures were introduced for provisioning (registration of the modem at the headend), for the TFTP server and the configuration file the modem downloads there, as well as for the source IP address of terminals behind the modem. The last item is implemented using the SAV method (Source Address Verification). The CMTS rejects all IP packets sent by terminals behind a cable modem or which are to be sent to a terminal, if the IP address of the terminal is not explicitly received from the cable network operator (e.g. via DHCP).

Perhaps the most important innovation among the security measures in DOCSIS3.0 is EAE (Early CM Authentication and Traffic Encryption). Whereas BPI(+) does not take effect until registration between CMTS and CM (i.e. in the OPERATIONAL status), EAE already starts encrypting the data packets after ranging (i.e. configuration of the connection at the lowest physical level). EAE makes DOCSIS networks even more secure, as transmission is already encrypted when downloading the configuration files and obtaining the IP address via DHCP, rendering unauthorised access to the server of the network operator or re-use of a captured IP address extremely difficult. EAE must also be supported by all DOCSIS-3.0-specified devices, but the function can be deactivated at the headend. As EAE is negotiated in special DOCSIS3.0 messages, 1.1 and 2.0 modems cannot use this feature.

2.7 IPv6

The previous transfer protocol (i.e. the "language") with which the data was sent from one source to a receiver on the Internet was (and largely still is) IPv4 (Internet Protocol Version 4). Internet Protocol Version 6 (IPv6) was standardised as early as in 1998. Market acceptance of this version of the protocol has been very hesitant. The vast majority of devices which use the Internet (still) support IPv4. For future-proofing, IPv6 was incorporated in the DOCSIS3.0 standard. All DOCSIS-3.0-specified devices must support IPv6, but are also compatible with IPv4.

The main reason for the introduction of IPv6 was that almost all IPv4 addresses have been used, and many addresses on the Internet only work via NAT (Network Address Translation). That means that data packets from one network segment must be readdressed when they are sent to another segment. On one hand, this can lead to long routing tables, and on the other hand, this practice violates the end-to-end principle, which is a fundamental tenet for data traffic on the Internet. IPv6 now provides enough addresses that every device on the Internet can be assigned an IP address which is absolutely unique worldwide. As originally intended, the network's only task will be to transfer the packets.

IPv4 addresses are 32 bits in length. That permits just under 4.3 billion IP addresses. IPv6 addresses are 128 bits in length. The number of IP addresses is immense (2^{128} or 2^{96} IPv4 addresses). If, as a conceptual experiment, we assume that there are currently roughly 7 billion people on earth, and that each human being has 100 billion brain cells on average, you could give every brain cell $4.9 \times 10^{17} = 490$ million billion IPv6 addresses.

Other advantages or improvements in IPv6 include simplification of the protocol header. As a result DHCP is no longer required for many applications in IPv6, facilitating encryption and authentication of IPv6 packets. QoS (Quality of Service) is also supported. QoS means: Various services on the Internet (e.g. standard data download, IPTV, voice over IP etc.) have different requirements for quality parameters such as packet errors, jitter and latency time. QoS allows different quality classes to be defined, so that data packages can be processed optimally for their quality requirements in the network.

As described above, DOCSIS3.0 modems must support both IPv4 and IPv6. During provisioning (i.e. login, registration and authentication of the modem at the headend), there are four options for how the cable modem can be treated on the IP level. It can be assigned an IPv4 address only, it can receive an IPv6 address, or it can be provided with a combination of the two addressing methods in two different ways.

IPv6 is already very important for German cable network operators. However, until now, the IPv6 addresses are only used for terminals behind cable modems (e.g. for connected PCs). The current state-of-the-art for all major cable network operators is to assign the cable modem itself an IPv4 address. However, tests currently underway, which are to continue in the near future, are assigning IPv6 address to modems too.

2.8 MAC domains and bonding groups

A MAC domain is a logical sub-component of the CMTS. This sub-component is responsible for providing all DOCSIS MAC functions a cable modem requires to register fully and send and receive data without restrictions for a certain number of upstream and downstream channels.

Implementation is generally not prescribed on the hardware side, but can be configured by the network operator at the CMTS. For example, that allows a CMTS with 16 DS outputs and 8 US inputs to either group all channels in a single MAC domain or configure two MAC domains with 8 downstreams and 4 upstreams each.

It is important to note that a cable modem can only ever be registered in one MAC domain.

A HFC network (hybrid fibre coax) is the standard network structure which the modem and CMTS use to communicate with one another. In these networks, the electric signals of the CMTS are combined at the headend via combiners or diplexers, and transmitted optically to a fibre node via a fibre optic cable. There, they are converted back to electric signals. From the fibre node, a housing development, a building complex, a city district etc. can be supplied with DOCSIS (and television) signals via coaxial cables.

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A fibre node generally supplies a network cluster containing tens to hundreds of cable modems.

In practice, a fibre node is generally supplied by one MAC domain, as the modems behind it can only be registered via one MAC domain anyway. However, one MAC domain can also supply multiple nodes. That is shown in the diagram below from the DOCSIS specification (source: Extract CM-SP-MULPIv3.0-I06-071206; MULPI stands for “MAC and Upper Layer Protocols”).

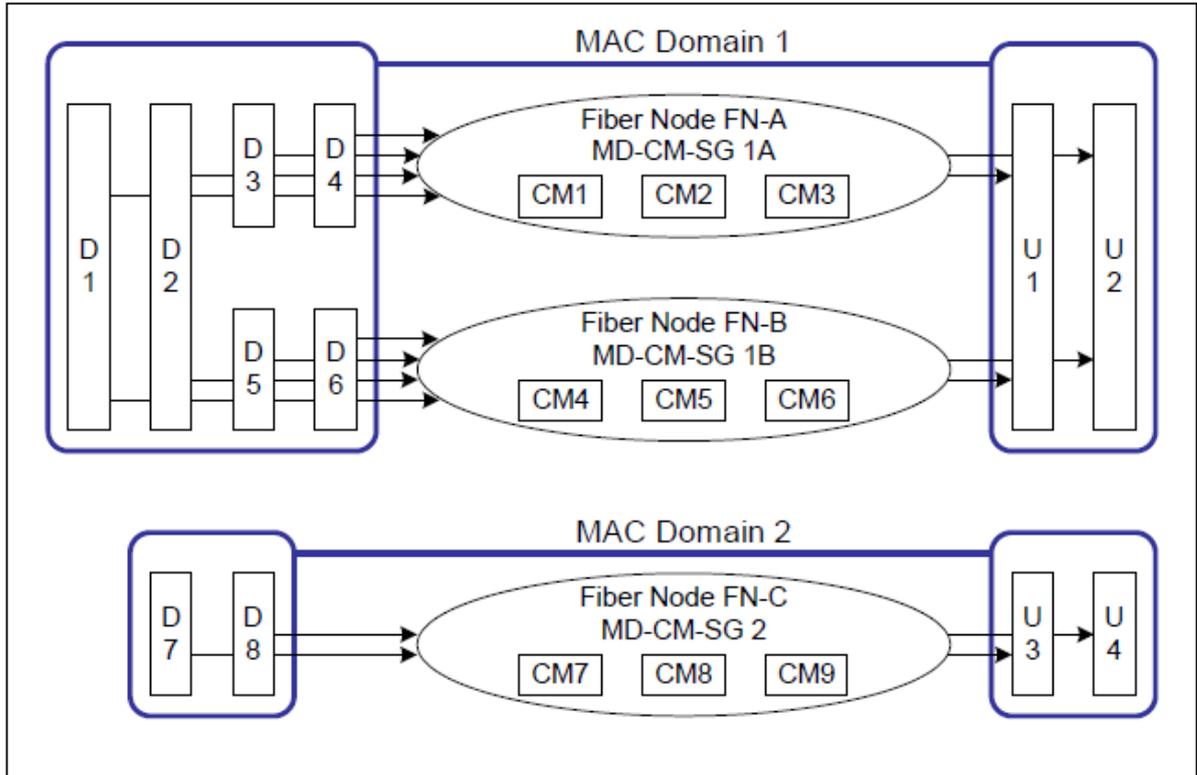


Figure 3

The eight downstreams and four upstreams of this CMTS were broken down into two MAC domains (MD). MD1 has 6 DS and 2 US channels and supplies all modems behind the fibre nodes (FN) A and B. MD2 has 2 US and 2 DS channels and supplies the modems behind FN C.

A bonding group (BG) is a set of channels which a modem can use to multiply the data rate after registration. All channels of a BG must be within the same MAC domain (i.e. in the figure above: D1, D2, D5 and D6 can be bonded in a BG, while D1, D2, D7 and D8 cannot).

As cable modems must always be able to reach all channels of a bonding group, all channels of a BG must always reach at least one fibre node together.

A distinction is made between upstream and downstream bonding groups. Every DS BG must contain at least one primary DS (see Section 2.2).

Figure 4 on the following page shows possible bonding group configurations as an example. DBG stands for DS bonding group; UBG stands for US bonding group. DBG1 consists of DS1 and DS2, DBG2 of DS1, DS2, DS3 and DS4, DBG3 of DS3 and DS4, DBG4 of DS1, DS2, DS5 and DS6, DBG5 of DS5 and DS6 and DBG6 of DS7 and DS8.

There are three US bonding groups, UBG1 consisting of US1 and US2, UBG2 consisting of US3 and US4 and UBG3 consisting of US5 and US6.

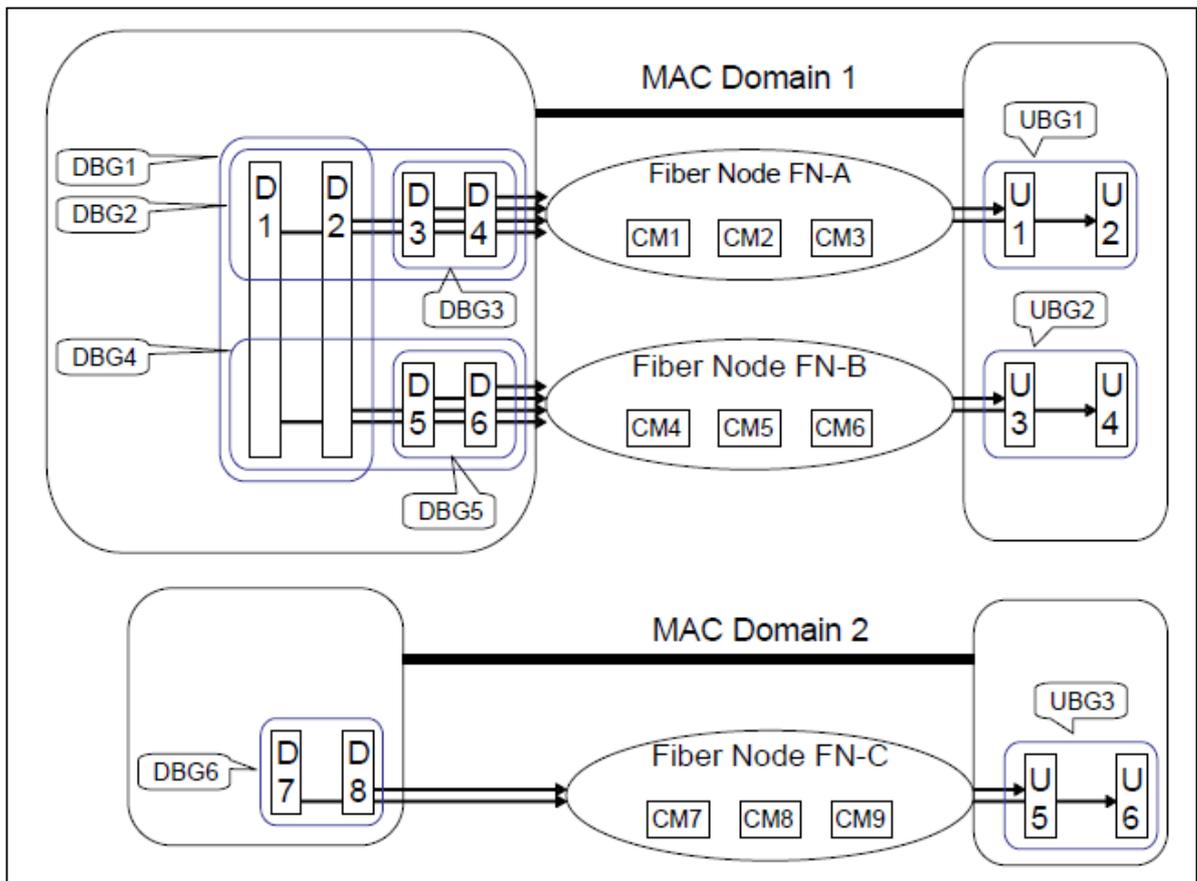


Figure 4

The figure shows that a cable modem can “see” multiple bonding groups on one hand, while on the other hand, the bonding groups can also have a different number of channels.

The reasons for these configurations are extremely varied. One possible reason is that the network operator, who can identify the customers and their tariffs based on the modem’s MAC address, “sends” modems to other BGs if their owners pay for a lower data rate than modems of customers with higher data rates. Different BGs could also be configured for different services. eMTA (embedded multimedia terminal adapter = a cable modem with integrated analogue telephone connection for voice over IP telephony) is an example of this. If a device of this type sends and receives normal Internet data, it can log in to a different BG than it would to process a telephone call over VoIP, as the VoIP packets are prioritised on this BG. Another possibility is that in large clusters with many terminals, two equal bonding groups can be configured, i.e. the number of channels is doubled because more and more customers are connected, who do not achieve the data rates they paid for on one BG. In these cases, load-balancing software at the headend, which ensures uniform utilisation of all channels, can distribute the modems to both BGs evenly. As a result, while the operator must use more bandwidth in its cable spectrum for DOCSIS channels, it does not require structural measures for further segmentation of the network as the number of customers behind a node grows. End customers who use different modems can be another reason for multiple bonding groups at one node. For example, in the early days of DOCSIS3.0, there were modems which could only bond four DS channels. Now, eight channels are standard. If eight DS channels are connected to a node, they can be divided into three BGs, e.g. DBG1 = DS1, DS2, DS3, DS4, DBG2 = DS5, DS6, DS7, DS8 and DBG3 = DS1, DS2, DS3, DS4, DS5, DS6, DS7, DS8. Accordingly, all modems with 4x bonding can be distributed evenly to DBG1 and DBG2. Modems which already allow 8x bonding can use all eight DS channels.

The options for configuring MAC domains and bonding groups are varied and complicated. Registering every modem optimally requires a significant management workload and a whole host of MAC messages. However, this system also offers a high degree of flexibility and the option of incorporating a wide range of device types, tariff structures, use habits and network properties optimally.

2.9 **Synchronisation between the cable modem and CMTS**

A precise description of registration of a DOCSIS3.0 modem at the headend would exceed the remit of this document. The complexity of the synchronisation process is extremely dependent on the functions offered by a modem, the IP standard used or the combination of IPv4 and IPv6, whether only a data modem or a eMTA is to be connected (i.e. on the service scope a terminal wants to use) and on the security and encryption measures and optional features the network operator configured in the CMTS.

Only the following fundamental synchronisation workflow is relevant for handling the AMA 310 and VAROS 107 measuring instruments.

A standard cable modem always scans the entire broadband cable spectrum for a primary downstream after activation. If no primary downstream is found, or the signal quality at the TCS is not good enough, the modem remains in the scan algorithm and does not connect to the headend.

If a primary DS is found, the information on existing upstreams is extracted from it (via UCD messages, see section 2.4), as well as the entire system architecture (e.g. via MDD messages (MAC Domain Descriptor)). The modem then starts a ranging attempt on a random upstream. If an answer is received from the CMTS, registration continues. If ranging is unsuccessful on the selected upstream, another attempt is made on a different upstream. If ranging is impossible on all upstreams - no matter what the reason - the modem scans for a new primary DS. The modem scans for a DS and performs ranging on the available upstreams until a US-DS combination is found to serve the modem in both directions. The key aspect is that even DOCSIS3.0 modems first connect to the headend on **one** primary DS and **one** US.

The modem is not notified of the downstreams and upstreams which can or may be bonded until later in the registration process.

For upstreams, the modem must first perform initial ranging separately on every upstream, followed by continuous ranging. While the upstreams are logically connected, and viewed as one large channel by the higher-order protocol layers, at a physical level, frequency, transmitting power and time synchronisation must be aligned separately and continuously on every US. This fundamental ranging is no different to the mechanisms described in detail for DOCSIS2.0 modems in "AN003 DOCSIS-2.0 Analyzer". An equaliser is also available for every upstream modulator of the modem. The network operator can activate or deactivate it optionally.

Section 3

Measurement with the DOCSIS3.0 Analyzer

3.1 The KWS DOCSIS3.0 modem

The KWS DOCSIS3.0 modem used in AMA 310 and VAROS 107 permits channel bonding via eight downstreams and four upstreams. The eight downstream channels must be within 64 MHz, i.e. directly adjacent. If a bonding group has less than eight DS channels, frequency gaps between the channels are permitted. The sole criterion is that the DSs to be bonded are within 64 MHz.

The upstream frequency range is defined as 5 – 65 MHz. The DOCSIS specification for US-DOCSIS is not fulfilled here. However, as far as we are aware, no systems use frequencies up to 85 MHz for upstream as yet. It does not matter how the up to four upstreams are distributed within the specified frequency range.

There is one unique feature in the DOCSIS analysis, which did not occur with the KWS DOCSIS2.0 Analyzer. If, instead of at the TCS, you make the measurements at a distribution amplifier (DA; see “AN003 DOCSIS-2.0-Analyzer”), where there is no damping by the building distribution system, and therefore far lower US transmitting powers are required than at the TCS, a non-vanishing transmitting power offset can result on the display of the measuring instruments. See Section 2.3 for the reason. Depending on the bandwidth of the upstream selected by a modem for initial contact with the CMTS, minimum transmitting powers far higher than in DOCSIS1.1/2.0 result. Where a transmitting power of 80 dB μ V would be sufficient at a DA with a bandwidth of 6.4 MHz for the CMTS to consider ranging with the modem successful, the AMA 310 indicates a non-vanishing level offset of -3 dB. For the reason, see the tables in Section 2.3. As soon as the CMTS “understands” the modem, it receives correction data based on which it is to reduce the transmitting power. However, the modem adheres to the specification and does not reduce the level below 83 dB μ V. If the CMTS calls for a further level reduction, the modem no longer reacts and the level offset is not equalised. When calibrating the measuring instruments, we can demonstrate that the modem can cope with all levels down to 8 dBmV = 68 dB μ V, but it adheres to the specification in normal operation.

Compared with the DOCSIS2.0 Analyzer, the boot time is slightly longer (18 seconds instead of 11 seconds).

3.2 Measurement

We wish to remind you that we assume familiarity with the fundamental information from AN003 here.

As with DOCSIS2.0, the measuring instrument is connected to the TCS or DA for standard measurement applications. As shown in AN003, measuring these two points allows you to verify that the signal from the network operator side arrives optimally at the house. The losses (quality and level) due to the building distribution system can be evaluated and the return amplifier can be set optimally for the upstream.

Once you have connected the measuring instrument to a point, a primary downstream channel must be entered directly. If you do not know the DOCSIS channels in the network to be measured, you can have the measuring instrument scan for a DOCSIS channel (see the KWS measuring instrument operating instructions for details). However, the measuring instrument only evaluates the symbol rate and the FEC lock as part of this scan. The scan stops when a DOCSIS channel is found and the modem is tuned to the channel found (or entered directly). In **both** cases – after a scan by the measuring instrument host or direct channel entry – we only know that it is a DOCSIS DS channel. We do not know whether it is a primary or a secondary channel. If the modem does not lock in correctly, either the DS signal quality or the DS level is not sufficient, or the channel you entered or found via the scan was a secondary DS channel. As you generally want to measure a channel entered into the measuring instrument, and not just any channel the modem chooses itself,

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any automatic channel scanning by the modem is suppressed. That means that if the modem does not lock in for one of the reasons just mentioned, a new channel must be entered, or the scan must be continued manually.

If the DOCSIS Analyzer is activated, you must first wait for the boot time of roughly 18 seconds to pass. The measuring instrument shows this via the display.

When this time has expired, an overview of the DOCSIS system is shown on the display. If the measuring instrument and CMTS succeed in synchronising, the following display could result, for example.

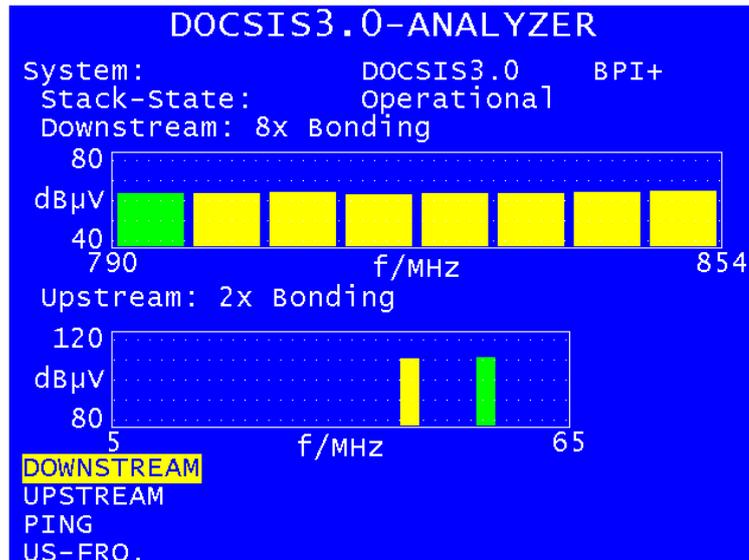


Figure 5

The DOCSIS system and activation of BPI or BPI+ are displayed at the top of the screen. Note that there may be a delay before the system ascertains whether the system uses DOCSIS3.0, before which DOCSIS2.0 could be displayed. The display will then change to DOCSIS3.0 during registration. See Section 2.4 for an explanation. That section states that a system can be identified as a DOCSIS3.0 system through the use of type 35 UCDs alone. However, the individual channels can also be DOCSIS1.1/2.0 channels, whose DOCSIS3.0 characteristics are not identifiable until bonding is established. In this (far more likely) case, it is not immediately clear after booting that DOCSIS3.0 is active.

Below this, the stack state is displayed. This indicates the modem's registration progress at the headend. The terms shown here are the same as those for the 2.0 Analyzer.

This is followed by a summary of the downstreams. A diagram shows how many downstreams the modem has bonded within a bandwidth of 64 MHz, and their frequencies. Once again, this display is not fully valid until the "Operational" stack state is reached. The same also applies for the graphical summary of the bonded upstream channels presented in the diagram below this. In both diagrams, the width of a channel is directly proportional to its bandwidth. In the downstream, all bars are always equal in width, as the channels are either 6 MHz (UsDOCSIS) or 8 MHz (EuroDOCSIS) wide. By contrast, it is frequently the case that three upstream channels are bonded, two of which have a bandwidth of 6.4 MHz and one has a bandwidth of 3.2 MHz.

The home screen gives you a quick overview of the entire DOCSIS system, or of the US and DS bonding group currently used by the modem to contact the headend. Note that the upstream and downstream frequencies and bonding groups can change during measurement, e.g. due to load balancing.

Select the “DOWNSTREAM” menu item for additional information on the individual downstreams. The upper section of the display and the DS diagram remain unchanged. The lower section of the display shows data on the DS channel currently selected. The primary DS specified with the measuring instrument or found via a channel scan is green in the diagram. The yellow channels are the bonded DSs. However, there is no indication as to whether these channels are primary or secondary downstreams. You can move the red cursor around the diagram using the ← and → arrow keys on the measuring instrument. The DS parameters displayed always apply to the channel currently selected. Figure 6 shows the data for the primary DS.

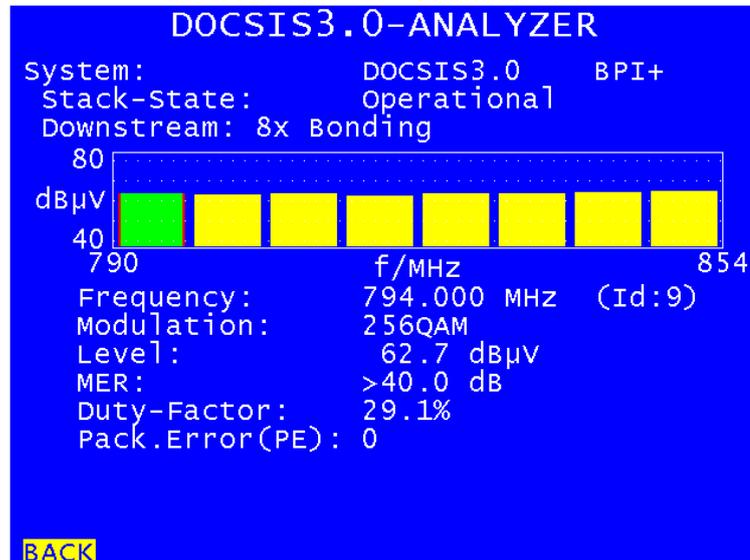


Figure 6

The frequency, ID (a value between 1 and 255), modulation scheme, reception level and MER are displayed. The DS duty factor (see AN003) and the MPEG packet errors are also displayed. As with classic DVB signals, the packet errors should always be 0. The duty factor can only be displayed for the primary DS, as the measuring instrument is tuned to this channel. If you select a secondary channel using the cursor, the display is identical to Figure 6, except that the duty factor line is missing (Figure 7).

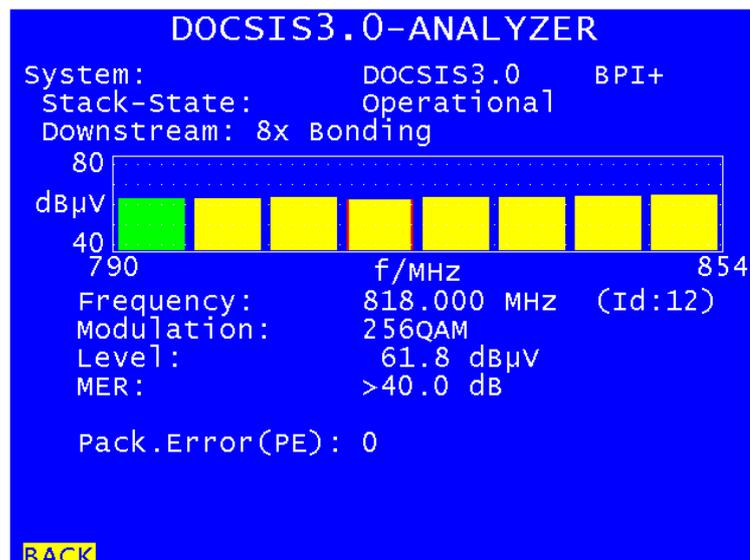


Figure 7

Select the “BACK” menu item to return to the home screen. If you select the “UPSTREAM” item, the following display opens (Figure 8).

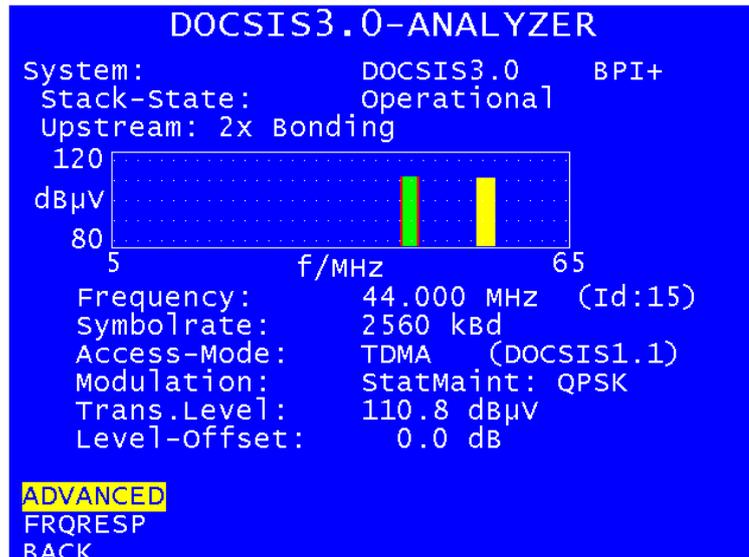


Figure 8

For upstream, there is no distinction between primary and secondary channels. The channel on which the modem first succeeded in contacting the CMTS is shown in green here. The channels subsequently bonded are also shown in yellow here. Once again, the upper section of the display provides global system information, and the US diagram is shown underneath it. It is followed by the detailed US information. You can also use the cursor to select channels for more detailed information on this screen. As above, the details available are the frequency and ID, the symbol rate and the access mode. The DOCSIS system information **for the selected upstream** is shown in brackets after the multiple access mode. We can see here that the selected upstream is a DOCSIS1.1 US, i.e. a US defined by a type 2 UCD (see Section 2.4). In spite of this, the overall system is a DOCSIS3.0 system, as channel bonding is possible. Other parameters displayed include modulation of the station maintenance time interval (see AN003; this time interval is used to validate the US connection between the modem and the CMTS), the current transmitting level and the transmitting level offset. The “ADVANCED” menu item provides information on the modulation of all time slot types offered. This also allows specialists to identify whether the upstream currently viewed is a 1.1, 2.0 or 3.0 channel.

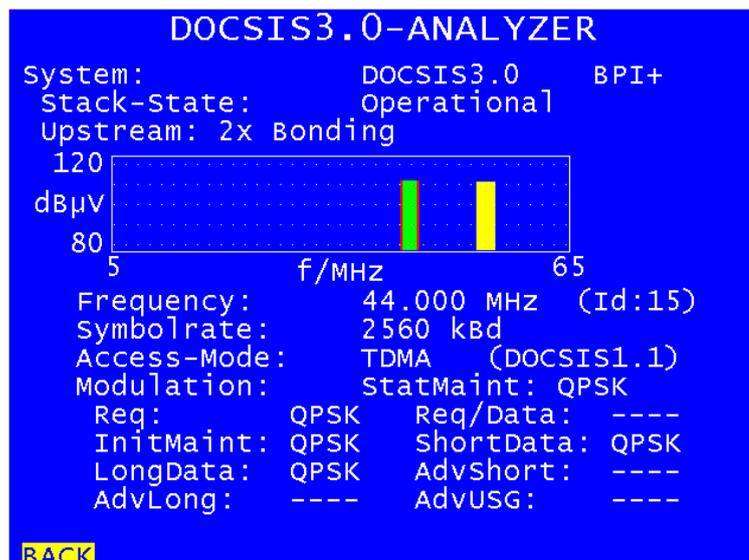


Figure 9

This somewhat unusual example shows that network operator's priority is high download data rates. Two bonded DOCSIS1.1 upstreams with QPSK modulations in all time slots which can be used under DOCSIS1.1 falls far short of maximising the options afforded by DOCSIS3.0.

Select "BACK" to return to the level above, where you can view the frequency response (obtained from the equaliser parameters of the upstream modulator) by selecting the "FRQRESP" item (if activated by the network operator).

We will not provide a screenshot and more detailed explanations here, as the equaliser is identical to that in the DOCSIS2.0 standard (24 complex taps, with 16 bits each for the real and imaginary parts; see AN003).

You can now select the "PING" item from the home screen. The ping test and evaluation are also identical to those in DOCSIS2.0. The test serves as an indicator of the performance and utilisation of the system between the current measurement position and the headend.

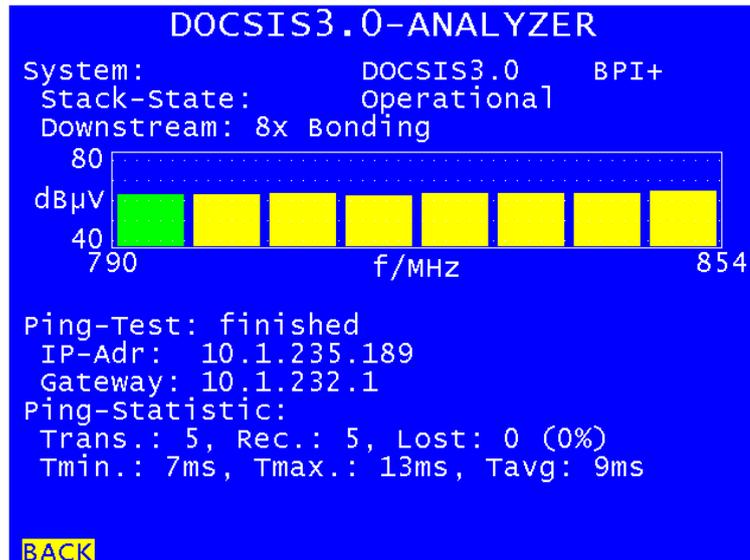


Figure 10

The last item of the main menu's first page is the upstream selection (as was the case in the DOCSIS2.0 Analyzer). All upstreams for which UCD messages can be received via the primary downstream are displayed here.

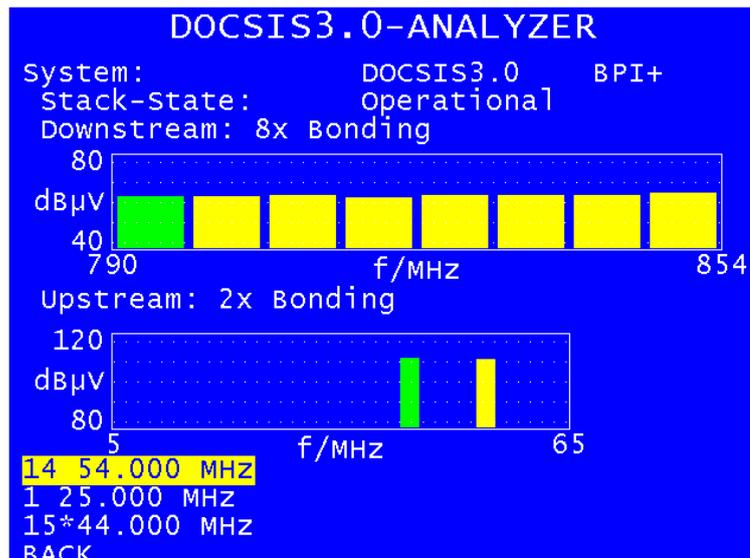


Figure 11

The ID and frequency of every upstream are displayed. If the list contains more than three elements, you can scroll through it using the ← and → arrow keys. The US on which initial ranging was successful for the current connection (i.e. the green US in the diagram) is marked with a star. You can now change the US bonding group by selecting an upstream not currently part of the connection to the headend and pressing the ENTER key. That allows you to extract information such as the

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transmitting level and EQ parameters on other upstreams in the return channel frequency range, helping you better evaluate the entire upstream frequency range.

If you select the US at 50 MHz in the above example (which is already part of the connection), the US at 50 MHz is then shown in green, as the connection was initiated at this frequency. The US at 40 MHz is subsequently bonded with it, and therefore shown in yellow. However, no additional information on the return path can be gathered in this case.

The US selection is subject to all restrictions listed in AN003. For example, bonding groups do not have to be physically connected to the fibre node which supplies the network segment you are measuring (e.g. in Figure 4, US BG2 is only connected to node B but not to node A). However, node A still receives the UCDs for upstreams 3 and 4 via the downstream. If this is the case, the upstream frequencies cannot be changed.

The only feature not available with VAROS 107 is the selection of the upstream(s) for ranging!

A speed test (data throughput test) can be conducted via FTP (file transfer protocol) as an additional analysis tool. This feature was implemented at a later date and for this reason a firmware update of the instrument and / or the DOCSIS analyzer board may be required. For information regarding this please refer to the relevant operating instructions and the website www.kws-electronic.de or contact our service function.

Some prior knowledge of the headend is required for the speed test because it is based on exchanging data with a FTP server connected to the headend. In reality there is always an FTP server available because each DOCSIS modem must download a so-called configuration file during registration at the headend. The modem receives this file by means of FTP from a server connected directly to the headend. Therefore, also with this test, only the path between the headend and the current location is measured. The internet or other data lines "behind" the headend are not involved.

In the case of a download speed test, a file on the FTP server is downloaded by the DOCSIS analyzer. The data rate achieved can be determined from the length of time this process requires and the size of the file. Following the download, the downloaded data is discarded by the DOCSIS analyzer. For the upload speed-test random data is uploaded to the FTP server. The bitrate is also calculated here from the data volume uploaded and the time required. In the latter case, the DOCSIS analyzer deletes the data on the server following a successful speed-test.

The following parameters must be known in order to carry out a speed test:

- IP address of the FTP server
- User name for access to the FTP server
- Password for access to the FTP server
- Name (and, if necessary, path) of the download file (only for download speed test)
- Size of download file (only for download speed test)
- Size of upload file (only for upload speed test)

The data is stored in the instrument and therefore does not have to be re-entered before each test. Furthermore, four profiles are available so that data for measurement at different headends can be stored permanently in the measuring device.

```
FTPServer-IPAdr: 192.168.001.001
Password: password2      User: user2
Downlink-File: filename2
Downlink-Size: 1.0MByte  Uplink-Size: 1.0MByte
                        PROFILE2  APPLY
PROFILE0 | PROFILE1 | PROFILE2 | PROFILE3 | BACK
```

Figure 12

16 characters can be entered for the password, 18 can be entered for the user name. 30 characters are available for the path of the file to be downloaded for the download speed-test (if this file has an extension like .txt or .bin it must be specified here as well). The range of values of the download file size is 0.1 to 2048 MByte and 0.1 to 500 MByte in the upload case. Please refer to the relevant operating instructions for how to configure and select the individual profiles using the instrument.

Registration between the DOCSIS modem and the headend must be fully complete (DHCP, where applicable BPI(+), config. file download), this means the measuring instrument must be at the stack state "Operational". The submenus for conducting a speed-test cannot be accessed prior to this.

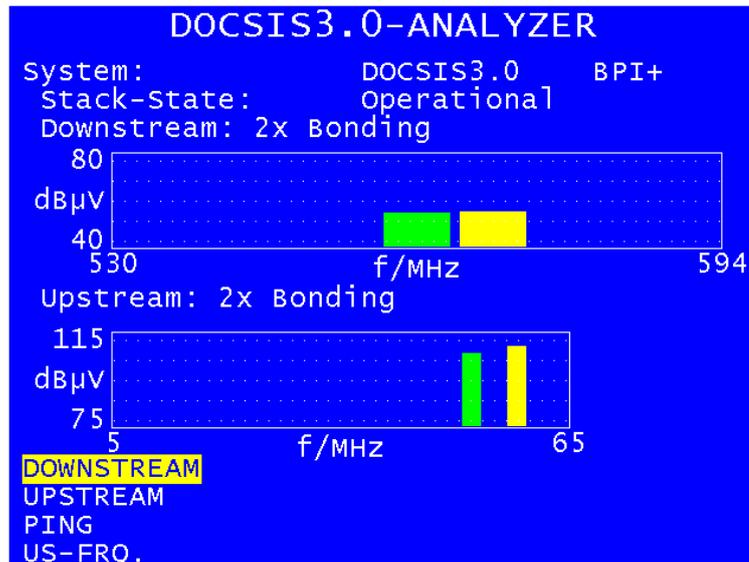


Figure 13

A second page of the main menu containing both options for the speed test can be accessed using the cursor button "→".

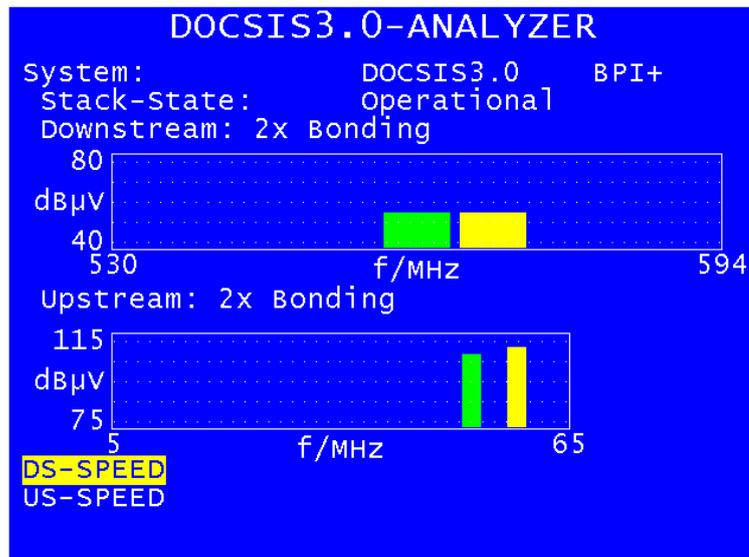


Figure 14

If you access the submenu for the download speed test, you receive the display below. The top line contains the status of the current test. After "started" the test status goes through "initialized", "running..." and "finished". If, for some reason, the test cannot be completed successfully, "aborted" is displayed in place of "finished". It must be taken into account, that the speed test will only be carried out following a successful ranging process. For this reason it can be the case that after entering the uplink or downlink speed test menus some time will elapse before the test finally starts. However, the user does not have to do anything. Once the submenu for a test is activated, a speed-test with the configuration of the current profile selected in the instrument settings is started at the earliest possible point in time.

In the lines following the speed-test status, in the case of downlink, the IP address of the server, the name (and where applicable path) of the file to be downloaded, the file size and the user name are displayed. In this submenu the password is not displayed in cleartext, but in the form of a series of asterisks as is normally the case in PC applications.

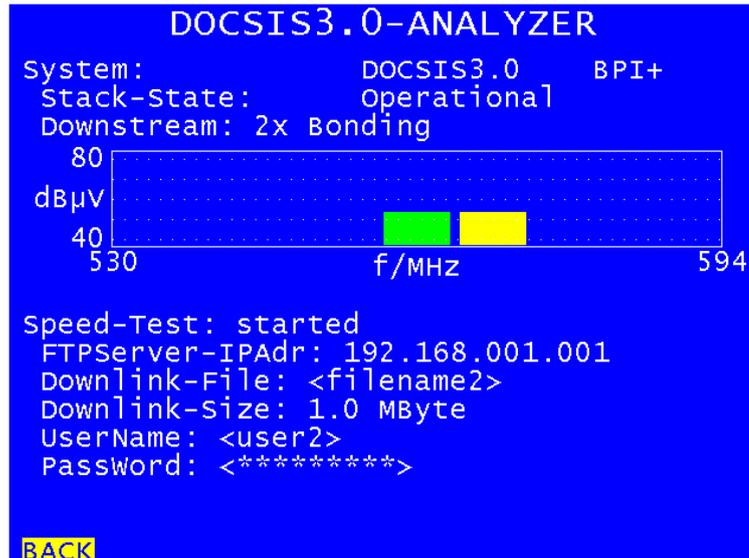


Figure 15

If it has been possible to carry out the downlink test successfully, then the data rate appears in the lowest line of the display:

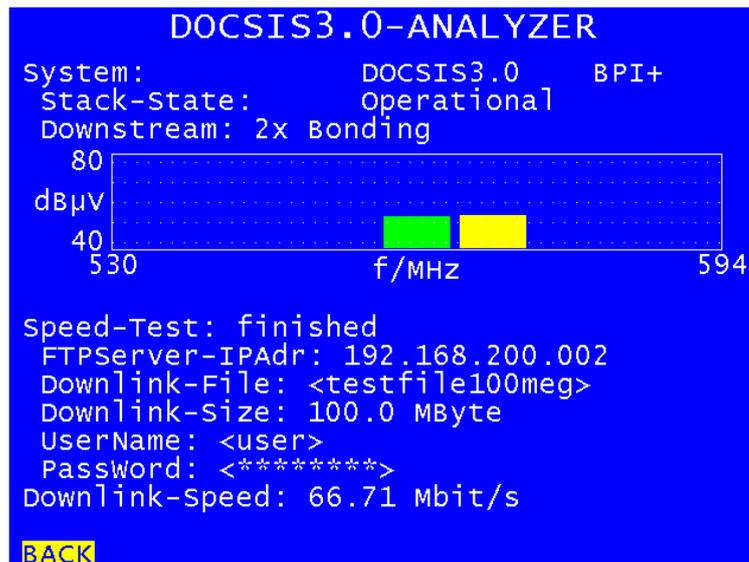


Figure 16

Use "BACK" to exit again from the submenu. If this is done before the end of the speed-test, then the test is aborted by the DOCSIS analyzer. After a successful or aborted DL speed test, the DOCSIS analyzer reverts to the continuous update of all upstream and downstream measurement parameters.

An uplink speed test can also be initiated from the second page of the main menu. The current status is also displayed in the top line of the menu (see figure below). As for the downlink, the login data of the FTP server is displayed (IP address, user name and implied password) as well as the upload data volume. A file name or specification of path is not needed in this case. The data is stored temporarily in the upper most directory of the server and also deleted in this location following the test. Following successful completion of the test the lowest line of the display shows the data rate achieved.

Use "BACK" to exit this submenu and to return to the continuous analysis of parameters. In the case of the uplink speed-test, it is **not possible** to abort the test early using the "BACK" button. The reason is that following a cancellation, the data already transferred to the server is not deleted there. Therefore, if you were to continue starting and aborting tests, the volume of unusable data on the

server would continually increase and use up memory. For this reason you always need to wait for the speed test to finish in the case of an uplink test.

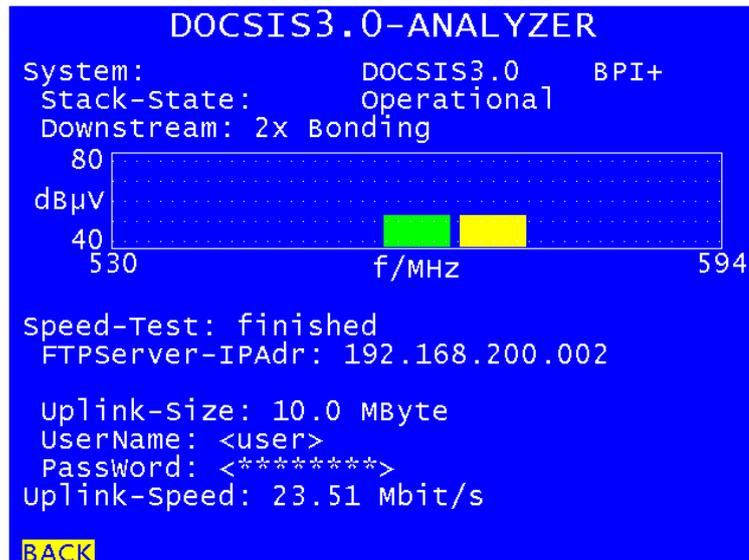


Figure 17

If an uplink or downlink speed test cannot be carried out or cannot be fully carried out then the following display appears.

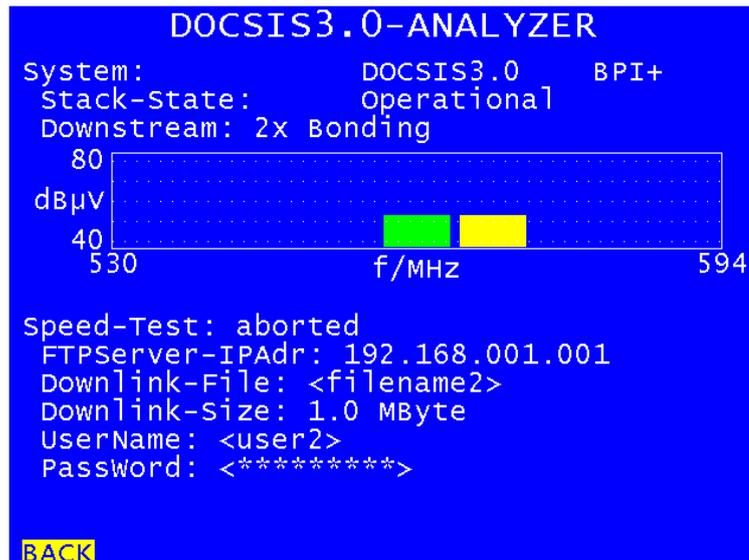


Figure 18

Reasons for this could be that the server IP address, user name or password have been entered incorrectly in the profile currently in use, or that, in the case of a downlink, the file name or path is invalid. Following an aborted speed-test the analyzer automatically reverts to the continual analysis of parameters. In this case also, the speed-test menu can be exited via the "BACK" button.

Whenever a speed-test is carried out in a HFC cluster for the first time, it is recommended not to choose a value for the data volume being transferred which is too high. As described, there is the opportunity to abort the test manually in the case of a downlink, but not in the case of an uplink test. A speed-test can therefore take quite some time depending on a variety of factors.

On the other hand, if a speed test has been carried out successfully, the data volume should be significantly enlarged. The reason is that there is a ramp-up phase, which means that the test does not work with the maximum data rate theoretically possible from the beginning. In order to find out the maximum possible data rate and to get an averaged result close to this data rate, the data volumes must be increased as long as there is no difference in the data rate between two speed tests with different data volumes any more.

Factors influencing the duration of a speed test are the current network load on the one hand, and the data rate guaranteed for the modem via the config file. If a lot of users are active within the cluster being measured, the potential data rate for each individual user reduces, and this is also the case for the measuring instrument. Besides this, the cable network operator can restrict the maximum data rate via the config file which the measuring instrument receives during registration, even if the network is currently not at full capacity.

Also from the FTP server side some conditions must be fulfilled in order to get meaningful results from a speed test. At first the FTP server must allow write accesses from outside. Otherwise an upload test is not possible. Apart from that the server can be configured to reject erase accesses from the modem side. This is also not reasonable because in this case the upload dummy data consume the storage capacity of the server. Furthermore the up- and download data rates of the FTP server can be limited manually. This has to be strictly avoided since in this case not the real service capability of the DOCSIS link is measured.

A speed-test makes most sense when the measuring instrument receives a config file which allows a maximum data rate within the highest tariff range which the operator sells to their customers. In addition the opportunity exists for operators to give selected modems - such as the modem within the measuring instrument - a so-called "unlimited config file". In this case the measuring instrument can use the full channel bandwidth reduced by the bandwidth which is currently reserved for other users. However, it is left to the network operator, who can identify the measuring instrument based on its MAC address, to decide what data rate it allows those doing the measuring!

An example: A cable network operator has four EuroDOCSIS3.0 downstreams (256QAM) in its network. Following the standard calculation set out in section 2.1, this gives a maximum DS data rate of 222 Mbit/s. The usable data rate less error protection, package headers and communication overheads between modems and CMTS for setting up and maintaining the connections is approx. 200 Mbit/s. In such a case a speed test is less meaningful if the measuring instrument is only granted a download data rate of 16 Mbit/s. In this case it can never be established whether a low throughput value is caused by a high network load or through the limiting of the data rate by the operator.

Therefore with a large guaranteed data rate, a reliable statement regarding the performance of the data connection across the HFC network is possible at the time of testing, even in conjunction with the PING test and the display of the DS duty factor.

The following contains further explanation regarding the specification of file size by the user and specification of data rates by the measuring instrument.

It must be ensured that in each profile for the downlink tests, the specification of size of downlink file actually matches the data volume to be downloaded. The data rate achieved is actually calculated from the time required. The measuring instrument can only fully download the file and measure the time required. It is not possible to measure the number of bytes downloaded. If the user enters an incorrect volume for the download file, this incorrect entry will be divided by the download time. This results in an incorrect value for the data rate displayed.

This error cannot occur in the case of an upload. The measuring instrument loads exactly the number of bytes specified by the user onto the server and measures the time required. In this case the data rate is always correct.

Some care is required with entering file sizes and interpreting measurement results. Uplink and downlink file sizes are entered in MByte (megabytes) in the four profiles. A MByte, as is usual in information technology, is understood as 2^{20} bytes or 1048576 bytes. If you want to enter 1 GByte (gigabyte = 2^{30} bytes = $2^{10} * 2^{20}$ bytes = 2^{10} MBytes), the correct value entered must be 1024 MByte. If, for example, 100,000,000 bytes are to be transferred in an upload test, this is not possible by specifying using MByte. The closest possible entry value is $100,000,000 / 1048576$ MByte = 95.3674 MByte \approx 95 MByte. In reality therefore $95 * 1048576$ bytes = 99,614,720 bytes are transferred. This is not critical in the case of an upload as the data rate is always calculated from the actual number of bytes transferred. In the case of a downlink, it must be ensured that the file stored in the FTP server can be measured in MByte. If this is not the case it results in a measurement error (even if only a small one).

It is slightly different, but still in line with standard practice, with the data rate displayed by the measuring instrument. In other words the result of a successful speed test. The display shows Mbit/s (Mega-Bit per second). In this case "Mega" actually stands for $1 \cdot 10^6 = 1.000.000$ (and **not** for $2^{20} = 1024 \cdot 1024 = 1.048.576$). In the case of the measurement result for a downlink test shown above, 66.71 Mbit/s were achieved. This corresponds to a data rate of 66,710,000 Bit/s.

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