ETSI ES 205 200-2-4 V1.1.1 (2015-06)

Integrated broadband cable telecommunication networks (CABLE);
Energy management;
Global KPIs;
Operational infrastructures;
Part 2: Specific requirements;
Sub-part 4: Cable Access Networks

Reference
DES/CABLE-00005

Keywords
CABLE, energy efficiency

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Contents

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://ipr.etsi.org).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

This ETSI Standard (ES) has been produced by ETSI Technical Committee Integrated broadband cable telecommunication networks (CABLE).

The present document is part 2, sub-part 4 of a multi-part deliverable covering operational energy management and sustainability of broadband deployment, as identified below:

Part 1: "General requirements ";

Part 2: "Specific requirements":

Sub-part 1: "Data centres";

Sub-part 2: "Fixed (excluding cable) access networks";

Sub-part 3: "Mobile access networks";

Sub-part 4: "Cable Access Networks";

Part 3: "Monitoring of sustainability".

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Introduction

Energy costs rise steadily, a trend that will continue in the future, while broadband penetration is introducing new active equipment to the network architecture. In this context, and to reflect other environmental aspects of sustainability, it is vital that the main telecommunication actors implement effective general engineering of fixed and mobile broadband networks and sites provisioning, managing or using those networks (i.e. operator sites, operator data centres and customer data centres) in order to respond to critical issues of energy consumption while proposing essential solutions to true broadband deployment. To guide this process, it is essential that metrics are defined, termed Global Key Performance Indicators (*KPIs*) that enable energy usage to be managed more effectively.

The ETSI ES 205 200 series comprises:

- ETSI ES 205 200-1 [1]: a generic requirements document addressing Global KPIs for operational infrastructures;

NOTE 1: Global KPIs do not address design/operation of components or subsystems of broadband deployment networks.

- sub-series ETSI ES 205 200-2: definition of the Global KPIs and energy management targets for specific operational networks and sites including descriptions on how the Global KPIs are to be applied (which may be used to support future regulatory objectives):
  - ETSI ES 205 200-2-1 [i.12]: applies to data centres;
  - ETSI ES 205 200-2-2 [i.13]: applies to fixed broadband access networks (excluding Cable Access Networks);
  - ETSI ES 205 200-2-3 [i.14]: applies to mobile access networks;
  - **ETSI ES 205 200-2-4 (the present document): applies to broadband Cable Access Networks.**

  These documents do not define KPI limits or targets (which is outside the scope of the ETSI ES 205 200 series).

These documents will accelerate:

- availability of operational infrastructure architectures and network implementations that use energy more efficiently;
- the definition and attainment of sustainability objectives for operational broadband networks.

Within the present document:

- Clause 4 provides a short explanation of a fixed broadband Cable Access Network's hybrid fiber coax (HFC) architecture in terms of the systems it comprises and the boundaries that apply and defines several formulae relating the objective and global KPIs to such a network.
- Clause 5 describes KPIs in terms of parameters applying to the Cable Access Network (CAN) and the inter-relationship between the technical, objective and global KPIs. The global energy performance KPI (KPI_{EP}) is expressed in terms of the data volume transmitted by the CAN in MB and the energy consumed in kWh. The clause relates the task efficiency of the HFC distribution network equipment and the overall energy performance KPI_{EP}.
- Clause 6 maps the objective KPIs defined in ETSI ES 205 200-1 to the broadband Cable Access Network.
- Clause 7 gives a mathematical definition of the KPIs, with equations, calculations and use case examples.

NOTE 2: **DOCSIS**® is a registered Trade Mark of Cable Television Laboratories, Inc., and is used in the present document with permission.

1 Scope

The present document specifies Global Key Performance Indicators (KPIs) in terms of the performance of the fixed broadband Cable Access Network (CAN). The KPIs are expressed in terms of transmitted data volume in relation to the energy consumed by the distribution network between the in-home subscriber termination and network headend. The KPIs are taking into account the predominantly deployed HFC access network topologies by European cable network operators.

The present document addresses the objectives 1 to 4 as set out in ETSI ES 205 200-1 [1] to encourage:

- reduction in energy consumption;
- improvements in task efficiency;
- extension of energy re-use;
- application of renewable energy.

The definition of the Global KPIs is in accordance with requirements of ETSI ES 205 200-1 [1] in relation to:

- infrastructure scalability;
- infrastructure evolution;
- formulae and definition of terms;
- measurement points and procedures.

The present document refers to and introduces the Global KPI 'Energy Performance' in accordance with requirements of ETSI ES 205 200-1 [1] in relation to the above objectives.

With services trending towards exclusive use of digital transmission technologies, the present document considers only the network KPIs relevant for the support of digital services.

The contribution of all in-home equipment connecting to the customer premises network interface unit (NIU) such as the cable modem (CM), gateway (GW) and settop box (STB) to energy consumption as well as any other customer premises equipment connected to the in-home network are out of scope of the present document. The present document only considers components of the access network for the purpose of defining and measuring energy consumption key performance indicators.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] ETSI ES 205 200-1 (V1.2.1): "Access, Terminals, Transmission and Multiplexing (ATTM); Energy management; Global KPIs; Operational infrastructures; Part 1: General requirements".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] EC Mandate M/462 (May 2010): "Standardisation mandate addressed to CEN, CENELEC and ETSI in the field of Information and Communication Technologies to enable efficient energy use in fixed and mobile information and communication networks".

[i.2] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products ("Ecodesign Directive").

NOTE: Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035:en:PDF.

[i.3] Commission Regulation (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment.

NOTE: Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:339:0045:0052:en:PDF.

[i.4] Commission Regulation (EC) No 801/2013 of 22 August 2013 amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions.

NOTE: Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:225:0001:0012:en:PDF.

[i.5] Code of Conduct on Energy Consumption of Broadband Equipment - Version 5. European Commission, DG JRC, December 2013.

[i.6] ETSI EN 300 429 (V1.2.1): "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems".

[i.7] ETSI EN 302 878 (parts 1 to 5 - V1.1.1): "Access, Terminals, Transmission and Multiplexing (ATTM); Third Generation Transmission Systems for Interactive Cable Television Services - IP Cable Modems".

NOTE: Part 1: General; DOCSIS 3.0.
Part 2: Physical Layer; DOCSIS 3.0.
Part 3: Downstream Radio Frequency Interface; DOCSIS 3.0.
Part 4: MAC and Upper Layer Protocols; DOCSIS 3.0.
Part 5: Security Services; DOCSIS 3.0.

[i.8] ETSI TR 101 546 (V1.1.1): "Access, Terminals, Transmission and Multiplexing (ATTM); Integrated Broadband Cable and Television Networks; Converged Cable Access Platform Architecture".

[i.9] ETSI TR 102 881 (V1.1.1): "Access, Terminals, Transmission and Multiplexing (ATTM); Cable Network Handbook".

[i.10] ETSI TR 105 174-6 (V1.1.1): "CABLE; Broadband Deployment and Energy Management; Part 6: Cable Access Networks".

[i.11] CM-SP-EQAM-VSI-I01 (July 2011): "Edge QAM Video Stream Interface Specification. CableLabs".

[i.12] ETSI ES 205 200-2-1: "Access, Terminals, Transmission and Multiplexing (ATTM); Energy management; Global KPIs; Operational infrastructures; Part 2: Specific requirements; Sub-part 1: Data centres".

[i.13] ETSI ES 205 200-2-2: "Access, Terminals, Transmission and Multiplexing; Energy management; Global KPIs: Operational infrastructures: Fixed (excluding cable) access networks;".

[i.14] ETSI ES 205 200-2-3: "Access, Terminals, Transmission and Multiplexing (ATTM); Energy management; Global KPIs; Operational infrastructures; Part 2: Specific requirements; Sub-part 3: Mobile access networks".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

cable access network: functional elements that enable wired (including optical fibre) communications to customer equipment

EdgeQAM: head-end or hub device that receives packets of digital video or data from the operator network, re-packetizes the video or data into an MPEG transport stream and digitally modulates that transport stream onto a downstream RF carrier using QAM

energy consumption: total consumption of electrical energy by an operational infrastructure

energy management: combination of reduced energy consumption and increased task efficiency, re-use of energy and use of renewable energy

energy re-use: transfer or conversion of energy (typically in the form of heat) produced by the operational infrastructure to do other work

Hybrid Fibre Coax (HFC): broadband telecommunications network that combines optical fibre, coaxial cable and active and passive electronic components

information technology equipment: equipment providing data storage, processing and transport services for subsequent distribution by network telecommunications equipment

network telecommunications equipment: equipment dedicated to providing direct connection to core and/or access networks

objective KPI: KPI assessing one of the objectives of operational energy performance which is subsequently used to define a Global KPI for energy management (KPI_{EM})

operational infrastructure: combination of information technology equipment and/or network telecommunications equipment together with the power supply and environmental control systems necessary to ensure provision of service

operator site: premises accommodating network telecommunications equipment providing direct connection to the core and access networks and which may also accommodate information technology equipment

renewable energy: energy produced from dedicated generation systems using resources that are naturally replenished

task efficiency: measure of the work done (as a result of design and/or operational procedures) for a given amount of energy consumed

3.2 Symbols

For the purposes of the present document, the following symbols apply:

BR_{ANA} average data rate of an analog channel on the system in Mbps
BR_{CH} data rate of an RF channel in Mbps

BR_{HD}	average data rate of an HD channel on the system in Mbps
BR_{SD}	average data rate of an SD channel on the system in Mbps
C_{CMTS}	number of NIU connections fed by CMTS
C_{DS}	number of NIU connections fed by Downstream transport channels
C_{FAC}	number of NIU connections fed by HE broadcast equipment
C_{PS}	number of NIU connections to network PS feeds
C_{RX}	number of NIU connections fed by HE optical receiver on average
C_{TX}	number of NIU connections fed by HE optical transmitter on average
C_{US}	number of NIU connections fed by Upstream transport channels
D	volume of data transferred in MB
D_{BCEFF}	volume of broadcast data effectively transferred per NIU connection in MB
D_{BCTOT}	total volume of broadcast data transferred in MB
D_{DS}	volume of Downstream data transferred per NIU connection in MB
D_{NIU}	total volume of data transferred per NIU connection in MB
D_{US}	volume of Upstream data transferred per NIU connection in MB
E	energy consumed in *kWh*
k	weighing factor dependant on the type of communication, e.g. video, data, voice
k_{DS}	downstream channel utilisation co-efficient
k_{US}	upstream channel utilisation co-efficient
KPI_{EC}	Objective Key Performance Indicator of energy consumption
KPI_{EM}	Global Key Performance Indicator of energy management
KPI_{EP}	Global Key Performance Indicator of energy performance
KPI_{NP}	Global Key Performance Indicator of network performance
KPI_{REN}	Objective Key Performance Indicator of renewable energy usage
KPI_{REUSE}	Objective Key Performance Indicator of energy re-use
KPI_{TE}	Objective Key Performance Indicator of task efficiency
kWh	unit of Kilowatthour
L	distribution path between HE and NIU
Mbps	unit of Megabit per second
MB	unit of Megabyte (10^6 Byte)
N_{CH}	number of RF channels carried between REF_{HE} and REF_{NIU}
N_{DS}	number of Downstream channels carried between REF_{HE} and REF_{NIU}
N_{US}	number Upstream channels carried between REF_{HE} and REF_{NIU}
P_{CMTS}	total CMTS power
P_{CNIU}	CMTS power per NIU connection
P_{EQNIU}	EQAM power per NIU connection
P_{EQAM}	total power of all EQAMs required to provide broadcast feed
P_f	performance factor
P_{HENIU}	HE power per NIU connection
P_{NIU}	total power per NIU connection
P_{PS}	total power supply power
P_{PSNIU}	power supply power per NIU connection
P_{RX}	total power required to operate single HE optical receiver
P_{RXNIU}	optical receiver power per NIU connection
P_{TX}	total power required to power single HE optical transmitter
P_{TXNIU}	optical transmitter power per NIU connection
REF_{HE}	Reference point at the cable headend
REF_{NIU}	Reference point at the network interface unit
t	period of time over which KPIs are assessed
t_{ANA}	average time in minutes a customer watches analogue channels each hour
t_{HD}	average time in minutes a customer watches HD channels each hour
t_{SD}	average time in minutes a customer watches SD channels each hour
TE_{FA}	task efficiency of the final amplifier
TE_{FN}	task efficiency of the fibre node
TE_{GA}	task efficiency of the group amplifier
TE_{HE}	task efficiency of headend PHY equipment
TE_{NIU}	task efficiency of the network interface unit
TE_{PS}	task efficiency of the power supply
VAC	*unit of Volt with alternating current*
W	factor dependant on technology, architecture and design, e.g. modulation scheme, integrated HE, fibre deep

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AMP	Amplifier
BST	Base Station Transmitter
CAN	Cable Access Network
CCAP	Converged Cable Access Platform
CM	Cable Modem
CMTS	Cable Modem Termination System
CPE	Customer Premises Equipment
DOCSIS	Data Over Cable Service Interface Specification
DS	Downstream
DSL	Digital Subscriber Line
DTV	Digital Television
DVB-C	Digital Video Broadcast- Cable
EC	Energy Consumption
EC	European Commission
EM	Energy Management
EP	Energy Performance
EQAM	Edge Quadrature Amplitude Modulator
ERP	Energy Related Products
ESO	European Standards Organisation
FA	Final Amplifier
FAC	Facility
FN	Fibre Node
GA	Group Amplifier
GW	Gateway
HD	High Definition (digital video channel)
HE	Head End
HFC	Hybrid Fiber Coax
HSD	High Speed Data
IP	Internet Protocol
IP/PBX	Internet Protocol/ Public Branch Exchange
IT	Information Technology
KPI	Key Performance Indicator
LCR	Inductance, Capacitance, Resistance
LON	Local Operating Network
MAC	Media Access Control layer
MPEG	Motion Pictures Experts Group
NIU	Network Interface Unit
NP	Network Performance
ODC	Operator Data Centre
OS	Operator Site
OSP	Outside Plant
PF	Power Feed
PHY	Physical layer
POS	Point Of Sale
PS	Power Source or Power Supply
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
REN	RENewable Energy
REUSE	Energy RE-USE
RF	Radio Frequency
SC-QAM	Single Carrier-Quadrature Amplitude Modulation
SD	Standard Definition (digital video channel)
STB	Settop Box
TE	Task Efficiency (in the rest of the document)
TE	Terminal Equipment (in architecture figures)
TV	Television
US	Upstream

4 System Definition and Boundaries

4.1 Cable Access Network

The present document considers the cable network operational infrastructure whereby the Global Key Performance Indicator on Energy Performance KPI_{EP} is used as the measure of the overall ability of the network to use electrical energy efficiently in its operation. KPI_{EP} is expressed as a function of the total number of bytes of data transferred across the HFC distribution network against the overall power consumed. The data volume transferred across the network is registered between the cable modem (CM) measured at the in-home Network Interface Unit (NIU) reference point REF_{NIU} and the headend equipment reference point REF_{HE}.

NOTE: The headend comprises data and video equipment. At the headend, the CMTS equipment supports data communications and the EdgeQAM equipment supports video communication. A CCAP headend equipment is a platform that converges both data and video communication. For the purpose of the present clause, the volume of transferred data is presented in terms of the CMTS (data communication service) but the generic formulae and equations defined are applicable to EdgeQAM and CCAP headend equipment using a weighting factor k_v and k_c to represent an equivalent data throughput for video and converged data/video communications.

Figure 1 illustrates Energy Performance as a Global Key Performance Indicator in terms of the broadband CAN structure and how it makes use of the individual network components, systems and sub-assemblies to consume energy when transferring data. This indicator enables network managers to better manage the network resources in order to reduce the overall energy consumption of the broadband Cable Access Network.

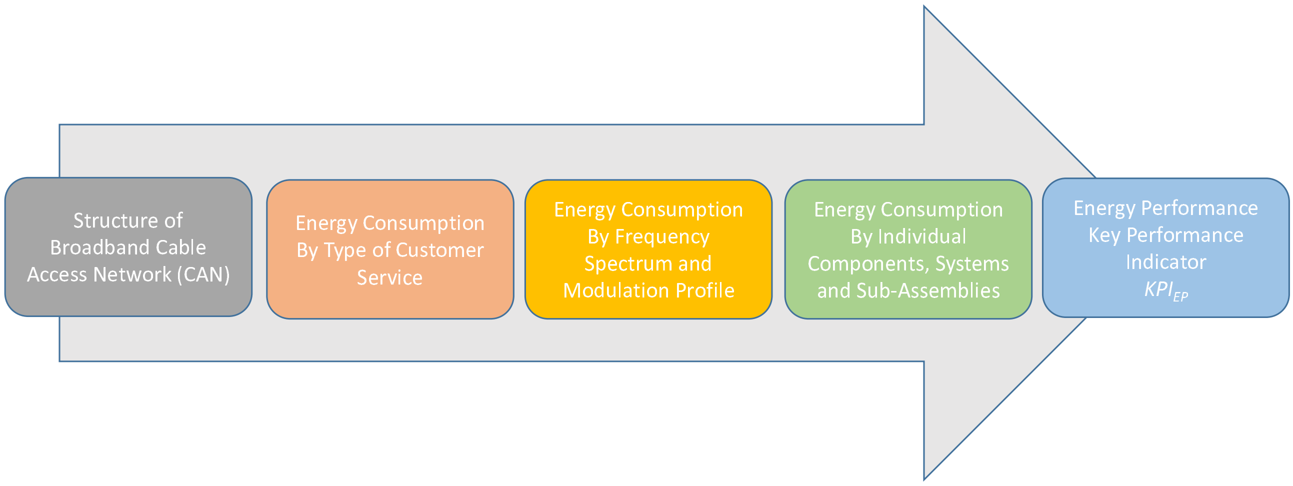

Figure 1: Illustration of Energy Performance as a Global Key Performance Indicator

A description of the Energy Performance KPI KPI_{EP} in relation to the definition of the Global Energy Management KPI KPI_{EM} and the Objective KPIs as defined in ETSI ES 205 200-1 [1] is given in clause 5.

Within an HFC distribution network, active components such as amplifiers, taps, couplers, fibre nodes and power distribution modules as well as passive elements such as taps, coaxial cable drops present the single value parameters in terms of each of their representative functions comprising the Objective KPIs.

Objective KPIs are:

- energy consumption (KPI_{EC});
- task efficiency (KPI_{TE});
- re-use of energy (KPI_{REUSE});
- use of renewable energy (KPI_{REN}).

Whereas there can be more than one KPI_{EM} with each KPI_{EM} being a function of a combination of the four separate Objective KPIs. The relationship between the Global KPI for Energy Management and the Objective KPIs is represented by Equation 1:

$$KPI_{EM} = f(KPI_{EC}, KPI_{TE}, KPI_{REUSE}, KPI_{REN}) \qquad \text{Equation 1}$$

and whereas the relationship of the Energy Performance KPI of the HFC distribution network between REF_{NIU} and REF_{HE} is represented by Equation 2, whereby KPI_{EM} of a specific path *L* weighted with *k* and *W* is summed over all *L*.

$$KPI_{EP} = f\left(\sum\nolimits_{L_{HE/NIU}} k * W * KPI_{EM}\right)\frac{D}{E}\ [MB/kWh] \qquad \text{Equation 2}$$

where:

L represents a specific distribution path between the HE and NIU;

k is a weighing factor dependant on the type of communication, e.g. video, data, voice;

W is a weighing factor dependant on technology, architecture and design, e.g. modulation scheme, integrated HE, fibre deep, etc.;

D is the volume of data transferred in MB;

E is the energy consumed in kWh.

The above formulae require measurement of the energy consumed by the HFC Distribution Network. For actual calculation of the volume of data transferred between REF_{HE} (CMTS/CCAP/EdgeQAM) and REF_{NIU} (CM) see defined equations given in clause 7.

KPI_{EP} is a measure of the energy performance in terms of the *work done* by the CAN between REF_{HE} and REF_{NIU} expressed as the volume of data transferred against the power consumed. The dependency on the amount of data that can be efficiently transferred by the individual network equipment components across the CAN explains the impact of their task efficiency on the Global KPI.

Figure 2 shows a generic schematic of the operational infrastructures of a broadband deployment as contained with the ESO response to the EC Mandate M/462 [i.1].

The relevant parts of figure 2 that relate to a broadband CAN is the 'Access network' between the OS and TE. The terms used and elements described do not correlate to the terms and elements comprising the broadband CAN. Figure 3 is the generic schematic representing a broadband CAN referred to by the subsequent clauses. Figure 2 is only included here as reference to the ESO response to the EC Mandate M/462 [i.1].

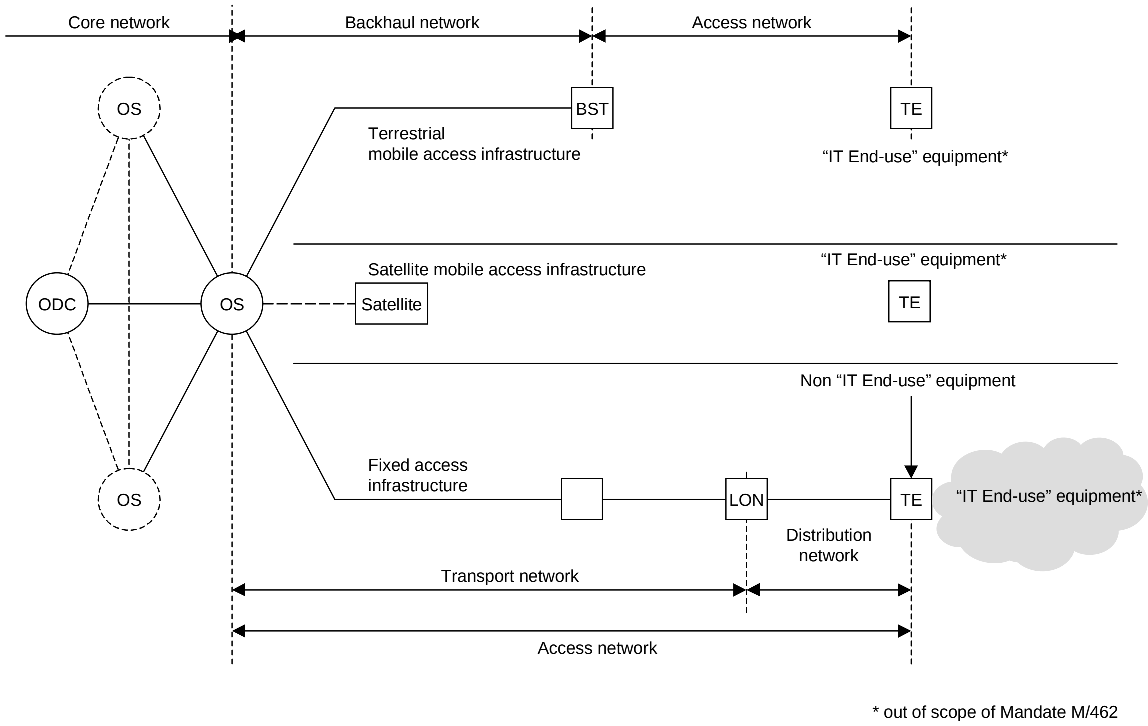

Figure 2: Schematic of core network together with fixed and mobile access infrastructures

Figure 3 is the schematic representing the HFC broadband Cable Access Network (CAN) infrastructure and its key energy consuming elements between the HE and NIU. The OS and TE in figure 2 correlate to the HE and NIU respectively.

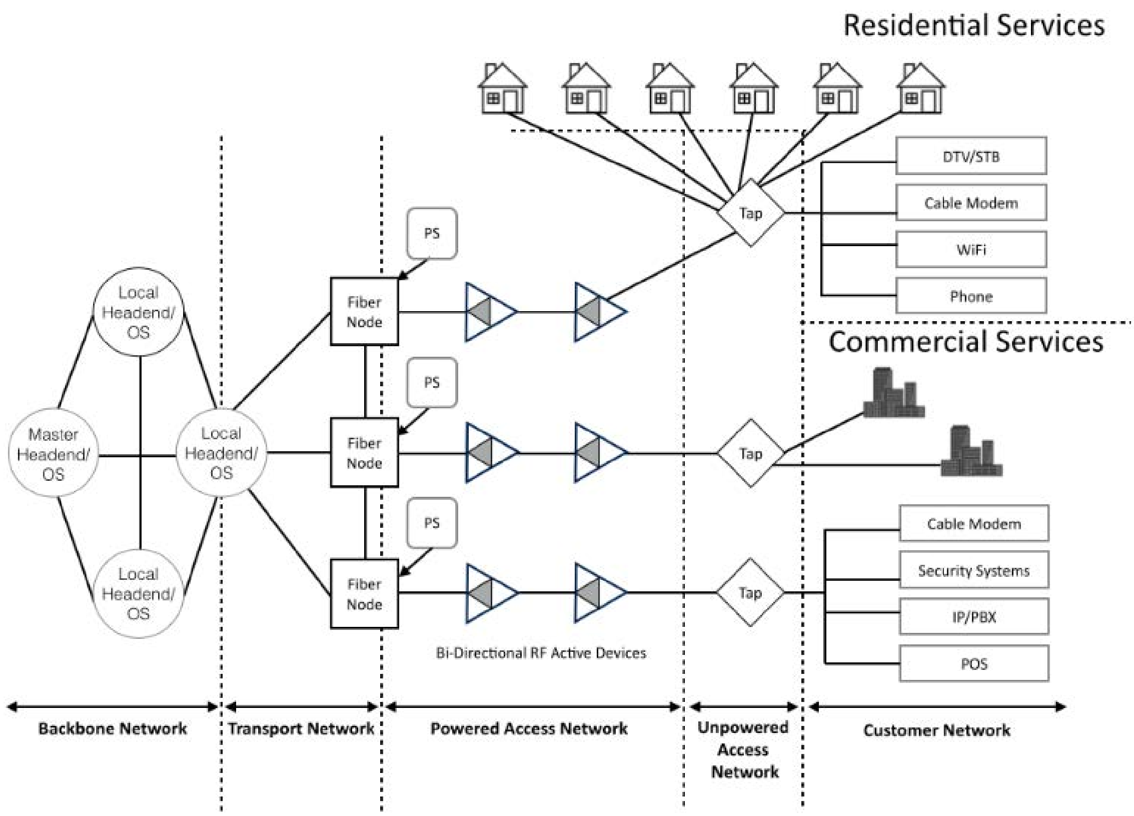

Figure 3: Schematic of HFC 'fixed' cable network infrastructures

With reference to figure 3, the present document considers:

- The Cable Access Network described is in its simplest form and consistent with typical network architecture deployments in Europe.
- Communications services are trending towards all digital services.
- The term OS in figure 2 represents the operator sites, and in terms of a broadband Cable Access Network (CAN) is depicted in figure 3 by the headend (HE) representing transmission equipment, such as CMTS, EdgeQAM and CCAP as referred to in the ETSI Cable Handbook [i.9].
- For the purposes of energy management, the fixed broadband CAN comprises all sites/elements between the headend (HE) and network interface unit (NIU) including all the elements of amplifiers, taps, couplers, drop cable, power distribution equipment, fibre nodes as shown in figure 3.
- The main energy consuming HFC distribution architecture components comprise:
  - Amplifiers.
  - Taps.
  - Drop cables.
  - Fibre nodes.
  - Power supplies.

4.2 Topology of Cable Access Networks

The broadband Cable Access Network and its distributed components are described in the ETSI Cable Handbook [i.9].

Figure 3 presents the schematic for a typical HFC Cable Access Network and its distribution equipment.

The volume of data that can be transferred between the HE and NIU has a dependency on the network topology, architecture and technology of the HFC distribution network. These dependencies influence the energy performance of the network and its relationship to the Global KPIs as presented in Equation 2 from clause 4.1.

The energy consumed is measured in kWh and is dependant on the volume of communication data (measured in MB (Megabyte)) transferred both Upstream (i.e. from the NIU to the HE) and Downstream (i.e. from the HE to the NIU) across the access network. The energy consumed is also dependant on the design choices of the deployed distribution equipment. For example a CCAP device [i.8] may consume less power than a CMTS [i.7] and EdgeQAM device [i.11]. The power consumed by the network amplifiers to do a unit of work will vary dependent on their design and the state of art, performance of the power distribution units (power supplies) that power the amplifiers and fibre nodes.

Energy performance of the broadband CAN is also dependant on the deployed transmission technology, i.e. DOCSIS 2.0 vs. DOCSIS 3.0 SC-QAM, the operational modulation profile, number of channel bonding groups, number of supported ports at the headend equipment, the spectrum optimisation profile used and type of supported subscriber communication service (analogue TV, digital TV, data, telephony, etc.). Efficient use of the available frequency spectrum and operating at increased spectral densities are network design measures that play a part in reducing the amount of energy required to be consumed by the network in order to transfer a given volume of data. Figure 4 illustrates by means of an example how the upstream and downstream spectrum is split to deliver services from the HE to the user equipment terminated at the NIU. Future deployments with the technology evolution to DOCSIS 3.1 may enable significant increases in the spectral efficiency and modulation profiles that can be used increasing the potential amount of work done by the broadband CAN to give a potential increase in the energy performance KPI_{EP}.

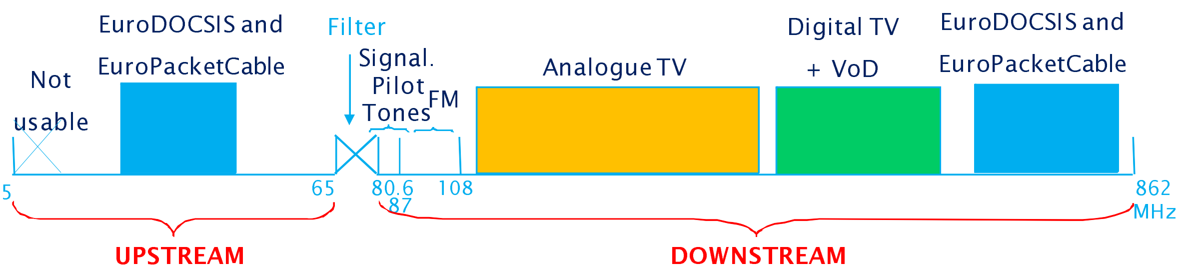

Figure 4: Downstream and Upstream spectrum in an HFC network

The equipment technology designs deployed in the HFC distribution network effect the resulting energy performance KPI_{EP} for the broadband CAN. The relationship of these technology dependencies are represented in Equation 2 by a weighing factor W as defined in clause 6.

Figure 5 illustrated the effect that low, medium and high Task Efficiency KPI of individual equipment, components, sub-assemblies and systems that represent the broadband CAN, has on network Energy Performance and Energy Consumption Key Performance Indicators.

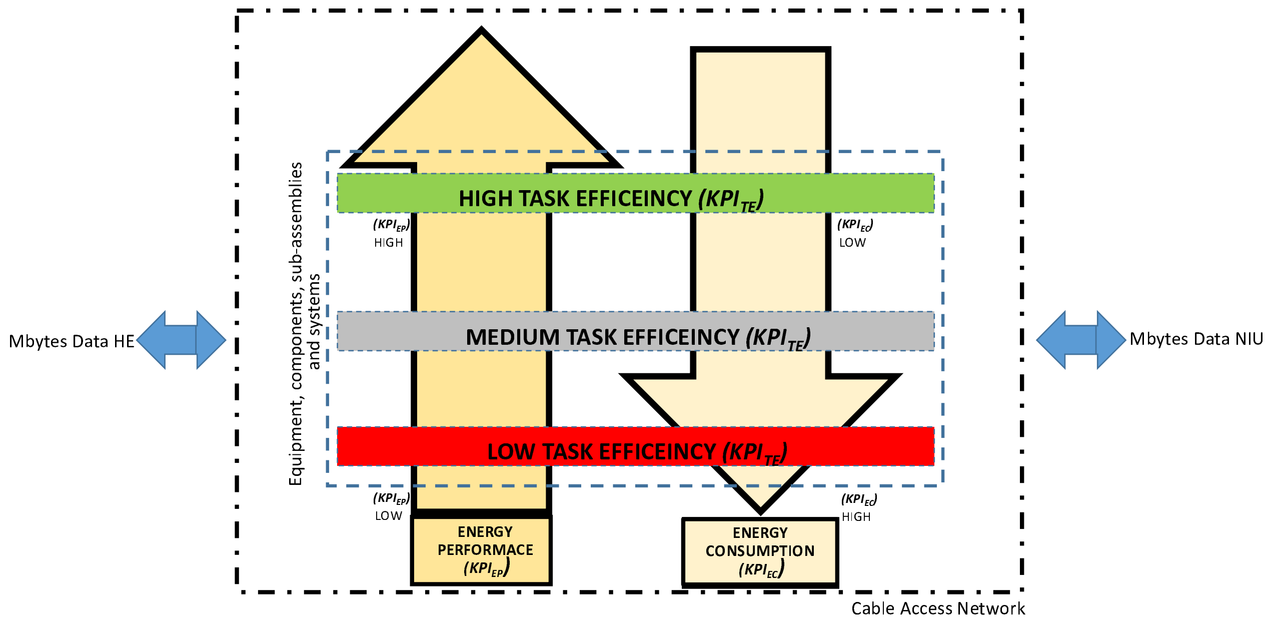

Figure 5: Illustration of impact of Task Efficiency on KPI_{EP} and KPI_{EC}

5 KPIs in Terms of the Cable Access Network

5.1 Objective and Global KPIs

Figure 6 shows the inter-relationship between Objective and Global KPIs. The Global KPI Energy Performance for the broadband CAN has a dependency on technical, operational and management KPIs.

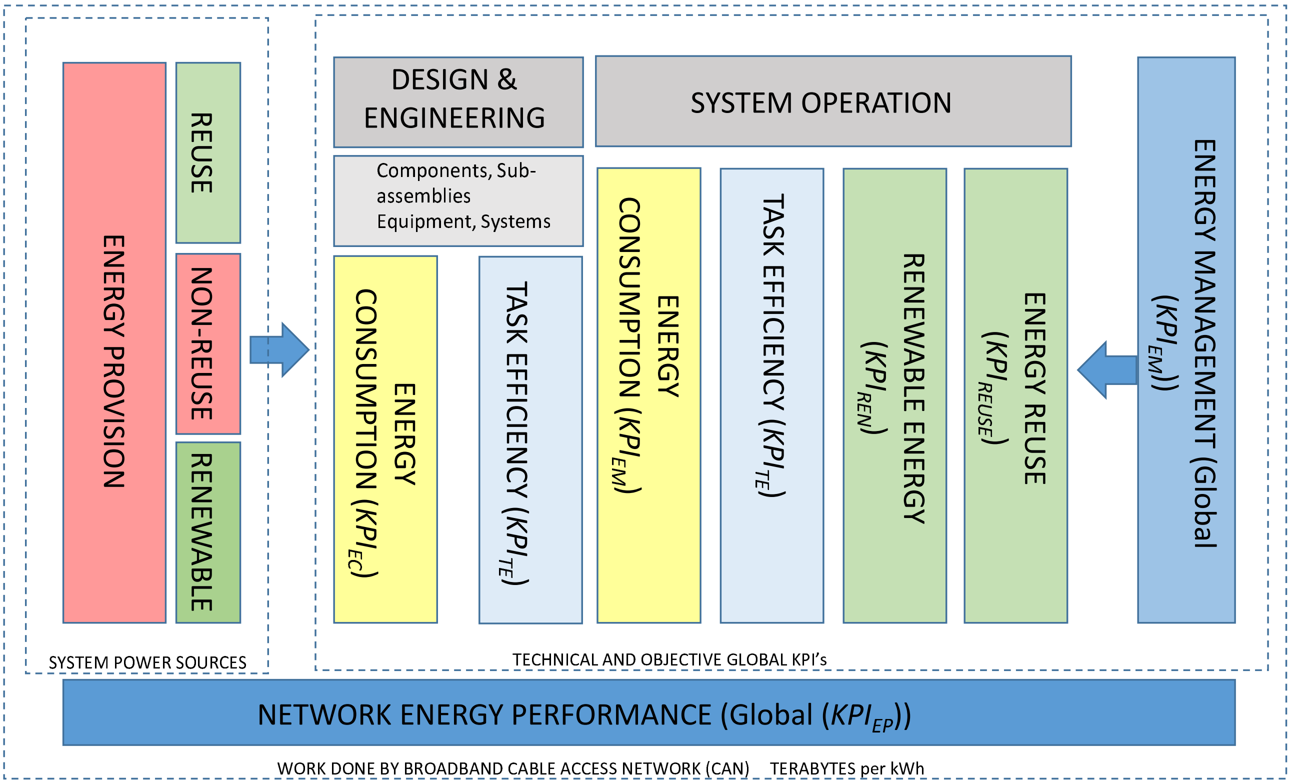

Figure 6: Inter-relationship between technical, objective and global KPIs

Figure 7 illustrates a communication path across the HFC access network and the key equipment components involved in the transfer of the data between the HE at REF_{HE} and NIU at REF_{NIU}. It also indicates the type of power feed for each individual equipment.

The network is dimensioned to support the desired capacity and throughput. A fibre node is architected to support a certain number of subscribers. There are too many network design parameters to cover within the present document that could optimise data throughput and consequently network performance. It is assumed for the purposes of defining the broadband CAN Energy Performance KPI that the network is largely optimised. However, development of advanced technology and innovation may further improve network performance in the future. This may apply to individual equipment, sub-assemblies, components and systems task efficiency as well as to the fundamental network architecture. Future development may require to adapt the definition of the Energy Performance KPI but are out of scope of the present document.

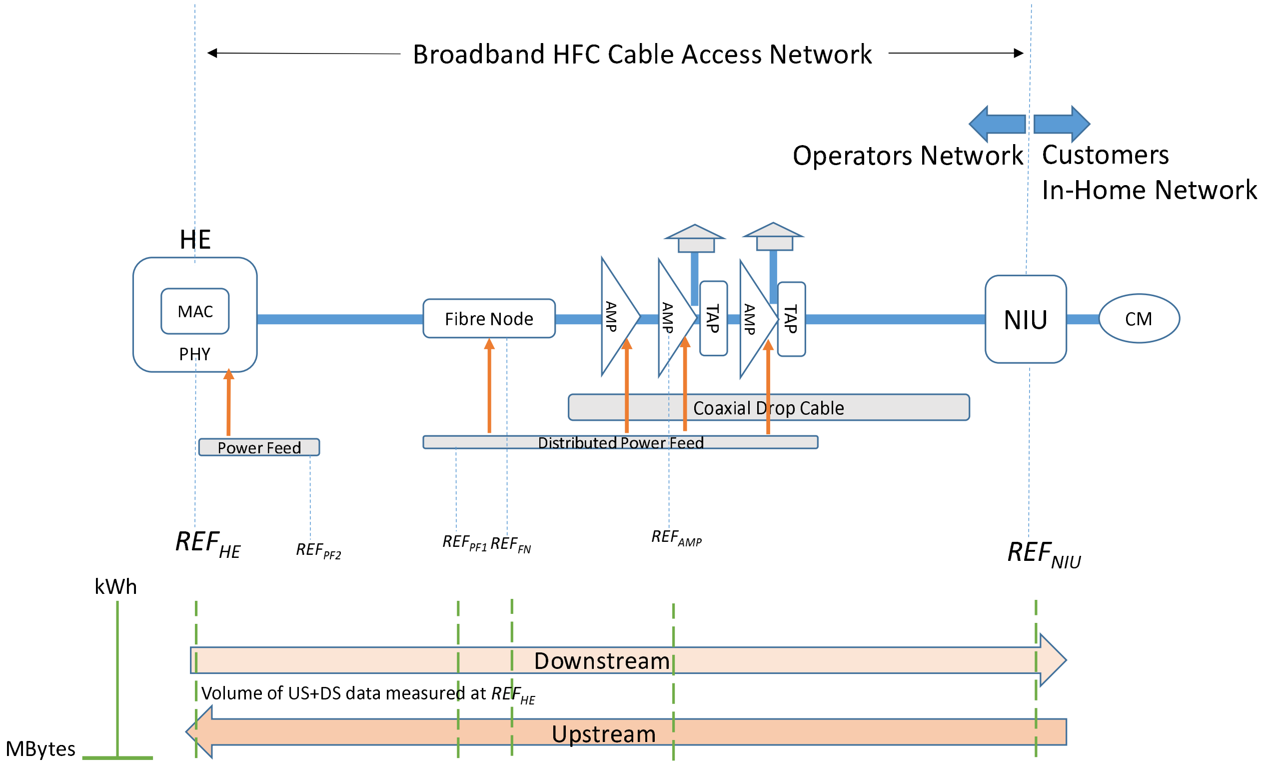

Figure 7: Illustration of communication path across HFC Cable Access Network

5.2 Energy Performance Global KPI

Cable Access Networks are predominatly deployed in residential environments but increasingly also in business environments characterized in both environments by continuous growth in many aspects (e.g. number of subscribers, demand on data transmission capacity, access speed, number of transactions). In such an environment, improvements in efficiency of energy usage when operating the network is typically outweighed by additional energy consumption caused by additional tasks that the network has to perform to satisfy customer demand. Therefore, in order to identify and evaluate improvements in energy efficiency, a metric is required that measures usage on a scale relative to the 'work' performed by the Cable Access Network rather than on an absolute scale of energy consumption.

The improvements in the performance of individual equipment is expressed as a variation of its Task Efficiency KPI KPI_{TE} . The overall task efficiency of the network is affected predominately by improvements in the effective use of the available frequency spectrum and from using modulation profiles of higher order to support substantially greater data throughput rates for a relatively limited increase in power consumption. The network task efficiency resulting from better spectrum utilisation and modulation techniques gives an improvement in the network's KPI_{TE} and - as given by clause 4 - this relates to KPI_{EP}. The improvement in the task efficiency of the individual equipment involved in the transfer of data may increase the overall volume of data that can be transported across the Cable Access Network with either a reduced, same or marginally increased total energy consumption measured over interval t.

5.3 Energy Management Global KPI

The KPI energy management KPI_{EM} is measured in kWh.

The dominant factor in the calculation of KPI_{EM} is the Objective KPI for energy consumption (KPI_{EC}).

The value of KPI_{EC} is mitigated by the weighted subtraction of any valid energy re-use (KPI_{REUSE}) and any energy contribution from locally generated renewable sources (KPI_{REN}).

This modified consumption value is multiplied by the Objective KPI for task efficiency (KPI_{TE}) which increases the value of the KPI_{EM} in direct proportion to the lack of task efficiency i.e. CAN sites with poor task efficiency will be adversely affected.

5.4 Energy Performance and Task Efficiency of a Cable Access Network

The energy performance of the network is dependent on the task efficiency KPI_{TE} of the individual HFC distribution equipment involved in the transport of the communication data as explained in the previous clause. The work done by the Cable Access Network is measured as how much data is transferred over a certain period of time such as one hour. If this is set in relation to the energy consumption assessed over the same amount of time, the resulting Energy Performance KPI KPI_{EP} is expressed in MB per kWh. The total consumed energy involved in the transfer of communication data required for services such as HSD, video, telephony for a specified communication path between the HE and NIU both in the US and DS is measured at the headend reference point REF_{HE}. It is measured by aggregating the power distribution feed at the reference points REF_{PF1}, REF_{PF2}, and REF_{AMP} as indicated in figure 7. This CAN energy performance meansurement is relevant to the specified communication path between the HE and NIU and is dependant on the number of connected subscribers. As an example, for a fibre node supporting 100 subscribers the Energy Performance KPI KPI_{EP} for the specified network path is equal to a hundred times the volume of data consumed by a single subscriber in relation to the energy consumed within the communication path including the fibre node.

The Task Efficiency KPI KPI_{TE} of each network equipment, component and sub-assembly directly relates to the performance of the network. It can, therefore, be a significant factor in determining and managing the energy performance of the broadband Cable Access Network, i.e. KPI_{EP} and KPI_{EM}. Improving the task efficiency of the individual HFC distribution component is the key measure to optimise Energy Performance KPI.

At the most basic level, individual components or sub-assemblies can be designed to have improved task efficiency i.e. less energy is consumed for a given output or task. Such components or sub-assemblies may be inherently more efficient in the way in which they use energy under specific operating conditions but are essentially unable to manage that consumption. An example of such a product would be a power supply unit which may be more efficient under higher load conditions.

Table 1 presents a list of the main energy consuming components and their task efficiency. The total task efficiency is dependant on the distribution path (L) between the HE and NIU and the task efficiency of the individual equipment along that path. The relationship between the Task Efficiency KPI KPI_{TE} in terms of the energy consumption of individual equipment to efficiently transfer data measured over a period of time t is represented by Equation 3.

$$KPI_{TE} = \sum_{L_{HE/NIU}} (TE_{HE} + TE_{FN} + TE_{GA} + TE_{FA} + TE_{PS} + TE_{NIU}) \ [MB/kWh] \qquad \text{Equation 3}$$

where:

TE_{HE} is the task efficiency of the headend PHY equipment;

TE_{FN} is the task efficiency of the fibre node;

TE_{GA} is the task efficiency of the group amplifier;

TE_{FA} is the task efficiency of the final amplifier;

TE_{PS} is the task efficiency of the power supply;

TE_{NIU} is the task efficiency of the network interface unit.

Equipment manufactures are constantly competing to increase the performance of their communications equipment, reducing energy consumption, increasing density, increasing throughput. One of their motivations is to improve on the overall network energy performance, Global KPI_{EP}.

The individual performance of the equipment (i.e. its task efficiency) is dependant on the technology used. A performance factor P_f with values between 1,0 and 2,0 is used in the calculation to accommodate that dependency. A value 1,0 represents existing equipment and a value 2,0 represents equipment built to minimise power consumption (future state of art). A value of 2,0 represents a performance improvement of 100 %.

NOTE: A P_f of 1 does not imply a poor performance of the equipment in question but simply indicates the current or typical performance of equipment as it is deployed at the time of the publication of the present document.

Table 1: Main energy consuming components of the Cable Access Network

Equipment*	Task Efficiency	Performance Factor P_f	Energy Consumption
Group Amplifier	TE_{GA}	1,1	kWh
Final Amplifier	TE_{FA}	1,1	kWh
Headend PHY - CMTS	TE_{HE}	1,0	kWh
Headend PHY - EdgeQAM	TE_{HE}	1,0	kWh
Headend PHY - CCAP	TE_{HE}	1,0	kWh
Power Supply	TE_{PS}	1,1	kWh
NIU	TE_{NIU}	1,0	kWh
NOTE: Refer to ETSI TR 105 174-6 [i.10] for more information about the equipment.			

6 Mapping the Objective KPIs

6.1 Energy Consumption

The energy consumption required to provide a given level of service will affect the energy performance of the Cable Access Network (CAN).

The KPI for energy consumption (KPI_{EC}) involves all the main energy consuming equipment of the broadband access network concerned in the transmission of data between the network interface unit REF_{UNI} located at the customer premises and the network headend equipment REF_{HE} located at the edge of the access network.

The KPI_{EC} is improved by actions including the following:

- Design of individual components or sub-assemblies with improved task efficiency such that less energy is consumed for a given output or task.
- Improve the way individual components or sub-assemblies use and manage energy under various operating conditions.
- Include control functions that automatically reduce energy consumption under certain operating conditions.
- Integrate platforms such as CMTS and EdgeQAMs, e.g. CCAP equipment.
- Increase the density of downstream and upstream ports.
- Reduce the number of active components such as amplifiers in the HFC distribution network, e.g. fibre deep architecture.
- Improve performance of distribution amplifiers in terms of power consumption and operating spectrum range.
- Improve performance of power distribution power supplies used to power amplifiers and fibre nodes.
- Minimise the LCR losses in the coax cable by optimising the operating power levels, e.g. amplifiers and fibre nodes powered at 90 VAC instead of 60 VAC reduces the current drawn as distributed over the coax power cable to power the equipment, thus minimising the LCR losses resulting in a reduction in power consumption.

Requirements or recommendations in relation to the reduction of the energy consumption within the fixed access network are not within the scope of the present document. Objectives for the reduction of energy consumption in the Cable Access Network (CAN) are included in the Broadband Code of Conduct [i.5]. It gives some target values relating to the headend equipment, CMTS and EdgeQAM.

Energy consumption improvement targets have also been defined under the European Commission's Ecodesign Directive 2009/125/EC [i.2] for improving the environmental performance of energy related products (ERPs) through ecodesign measures. The so called network standby Regulation 801/2013 [i.4] which amends Regulation 1275/2008 [i.3] is used to manage reduction in the energy consumption of CPE ERPs during periods when commuication data is not being consumed as determined by the network functions.

6.2 Task Efficiency

An improvement in task efficiency is a primary objective of the present document. See also clause 4.2.

The KPI_{TE}, while maintaining acceptable coverage and traffic capacity at all times, is improved by actions including the following:

- re-engineering of the HFC CAN distribution equipment, such as amplifiers, with increased spectrum range, lower power consuming components, power sources with lower losses, optimised optical transceivers;
- reducing node size, swapping headend PHY equipment from CMTS to CCAP or a change of transmission equipment from DOCSIS 3.0 to DOCSIS 3.1;
- optimisation of operational processes;
- automation of network management including energy efficiency constraints.

The KPI_{TE} applies to all HFC distribution equipment listed in table 1.

6.3 Energy Re-use

Energy re-use is considered to be the recovery of portions of the total energy consumption that would be dissipated into the environment otherwise (e.g. heat). Typically, energy re-use requires a self-contained environment to collect the portion of the energy consumption that is not required by the primary operation of the Cable Access Network. Due to the typical topologies this condition is not met by the Cable Access Networks. In general, Cable Access Network nodes and headend sites are geographically scattered which limits the possibility for merging any heat generated at each site. In addition to that, the main objective is on limiting the use of energy rather than re-using it. Therefore, KPI_{REUSE} is not considered in the present document.

6.4 Renewable Energy

The use of renewable energy is a secondary objective of the present document.

The energy provided to power the CAN distribution equipment comes from either utility (grid) or local sources (non-renewable or renewable).

The CAN may meet all their energy needs from local, renewable sources on a continuous basis.

The scope of the KPI for renewable energy use (KPI_{REN}) only takes locally generated renewable energy into account.

NOTE: This does not, as yet, take into consideration any proportion of utility supplies certified as "green" by nationally recognised schemes nor the carbon footprint of the energy source.

The KPI_{REN} applies to the HE equipment such as CMTS/CCAP or EdgeQAM and the HFC distribution equipment such as amplifiers and fibre nodes.

7 Mathematical Definition of KPIs

7.1 Calculating KPI_{EP}

7.1.1 Definition

With reference to clauses 4.1 and 4.2, formulae for the relationship between the Global KPIs KPI_{EM} and KPI_{EP} and the Objective KPIs are given in terms of a segment of the network path between the HE and NIU. This only presents a portion of the broadband CAN energy performance but may be extrapolated for a dimensioned network based on the supported number of subscribers.

When calculating the energy performance of the broadband CAN, the CAN architecture, design to optimise capacity and throughput in terms of modulation profile, frequency spectrum, amplifier performance, and the size of the fibre node are relevant factors to determine KPI_{EP} in addition to the performance of the power supply. See annex A for examples of typical power supply performance charts.

KPI_{EP} is defined as the measurement of the energy consumed, in units of kWh, by the HFC distribution network while transferring data between REF_{HE} (CMTS/CCAP/EdgeQAM) and REF_{NIU} (CM). The output of KPI_{EP} is given in MB/kWh after assessing the input parameters over a certain time interval of, usually, an hour.

To calculate KPI_{EP} it is recommended to use data gathered from measurement of power and data thru-put. When measurement data is not available, estimations of KPI_{EP} can still be made with the calculations in this clause, utilizing power ratings data given for individual components instead of measured data. In order to calculate energy from the power rating it is multiplied over time t over which the related KPI is assessed.

7.1.2 Power Between REF_{HE} and REF_{NIU}

The power between REF_{HE} and REF_{NIU} in an HFC network shall be a summation of the power needed to launch the signal from the headend, and drive it through the node, amplifiers, taps, couplers, coaxial and fibre cables. In the headend, the small portion of the total headend power required to operate the PHY portions of the CMTS and QAM modulators on a per customer basis, as well as the optical transmitters and receivers shall be accounted for.

NOTE 1: In the network, the Outside Plant (OSP) power supply is the single power source that provides power to the network to move the signal from the HE to the customer location.

Since CMTS, QAM modulators, optical equipment, and OSP power supplies all typically feed signal to varying numbers of customer NIUs in the field, then the measurement of the power per customer NIU for each shall be a function of measuring total power of the unit, divided by the number of customer NIUs it feeds.

NOTE 2: From an operational perspective, measurement of the energy used by the devices is the practical approach to assess energy performance or HFC design rules to design the network could be used.

Where measurements are not available with respect to the CMTS, QAM modulators, and optical equipment, then the manufacturer data sheets shall be used to best approximate the power required for the designed equipment load. In this manner, the power shall be calculated using manufacturer information to calculate load, and divided by the total number of customer NIU connections as specified for the equipment.

Considering the above, if the power for a CMTS is specified to be P_{CMTS} Watts, and the CMTS is specified to feed C_{CMTS} customer NIU connections, then the CMTS power per NIU connection is:

$$P_{CNIU} = \frac{P_{CMTS}}{C_{CMTS}} \qquad \text{Equation 4}$$

Where:

P_{CNIU} is the CMTS power per NIU connection;

P_{CMTS} is the total CMTS power;

C_{CMTS} is the number of NIU connections fed by the CMTS.

Similarly, power for the EQAM's feeding the broadcast portion of the network shall be found. Broadcast is used to feed the whole of the customers from the facility, therefore the EQAM power per customer NIU shall be the total power for the EQAM devices in the Head-end feeding broadcast content, divided by the total number of customers the EQAM broadcast equipment covers.

Considering the above, the EQAM's power required to supply the transport streams of broadcast content is P_{EQAM}, and the number of customers fed from the facility by the broadcast content is C_{FAC} customer NIU locations, then the EQAM power per NIU connection is:

$$P_{EQNIU} = \frac{P_{EQAM}}{C_{FAC}}$$ Equation 5

Where:

P_{EQNIU} is the EQAM power per NIU connection;

P_{EQAM} is the total power of all EQAMs required to provide broadcast feed;

C_{FAC} is the number of NIU connections fed by HE broadcast equipment.

Next, power of the optics used to move the data from the HE through the network to the NIUs shall be found.

Since the customer NIU connections fed from a transmitter in the HE are typically different from those fed by a receiver due to HFC design among other things, the power per customer NIU connection shall be calculated separately for HE transmitters and receivers.

Considering the above, the total power required to power a single HE optical transmitter is P_{TX} that feeds an average of C_{TX} customer NIUs, then the power for the transmitter per NIU connection is:

$$P_{TXNIU} = \frac{P_{TX}}{C_{TX}}$$ Equation 6

Where:

P_{TXNIU} is the total optical transmitter power per NIU connection;

P_{TX} is the total power required to power a single HE optical transmitter;

C_{TX} is the number of NIU connections fed by a HE optical transmitter on average.

Similarly, the return optical receiver is P_{RX} and feeds an average of C_{RX} number of customer NIU connections, then the power for the optical receiver in the HE per NIU connection is:

$$P_{RXNIU} = \frac{P_{RX}}{C_{RX}}$$ Equation 7

Where:

P_{RXNIU} is the total power for the optical receiver in the HE per NIU connection;

P_{RX} is the total power required to power a single HE optical receiver;

C_{RX} is the number of NIU connections fed by a HE optical receiver on average.

The power in the headend needed to provide network signal between REF_{HE} and REF_{NIU} is the sum of the individual HE power elements, namely:

$$P_{HENIU} = P_{RXNIU} + P_{TXNIU} + P_{EQNIU} + P_{CMTSNIU}$$ Equation 8

With respect to the OSP itself, the HFC network power for the portion of the network fed by the individual power supply as measured shall be used. In the event measurement data is not available, as with the Head-end component, an estimation of the power from HFC network design calculations shall be assumed to be used.

For illustration purposes figure 8 shows a sample design for one single power supply section.

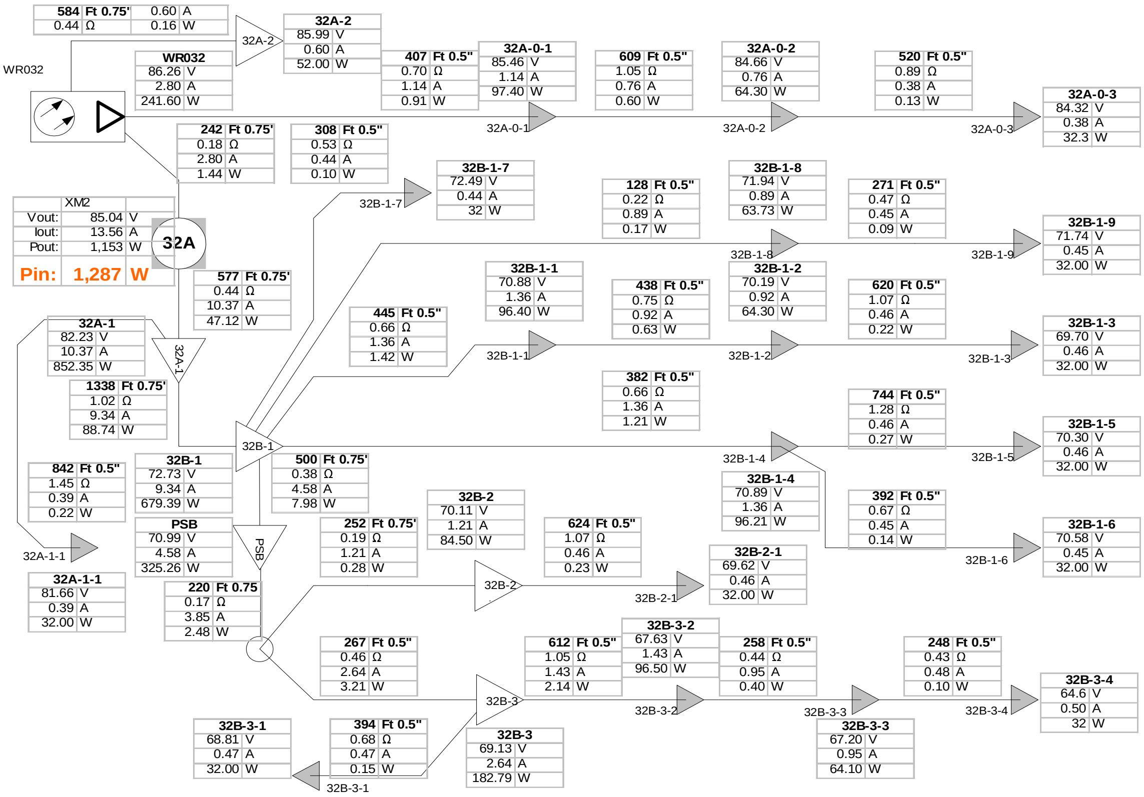

Figure 8: Illustration of a sample design for one single power supply

With the power used to feed all the customers connected to the power supply being P_{PS} Watts and the number of NIUs connected to the network fed by the power supply being C_{PS}, then the access network power per NIU connected is:

$$P_{PSNIU} = \frac{P_{PS}}{C_{PS}} \qquad \text{Equation 9}$$

Where:

P_{PSNIU} is the total access network power per NIU connection;

P_{PS} is the total power supply power;

C_{PS} is the number of NIU connections to the network fed by the power supply.

Considering the above equations then the total power per NIU connection is defined as:

$$P_{NIU} = P_{HENIU} + P_{PSNIU} \qquad \text{Equation 10}$$

7.1.3 Data Volume Transferred Between REF_{HE} and REF_{NIU}

To calculate the volume of data transferred, all the different types of data transport each customer receives shall be accumulated. In an HFC broadband network, the data stream transported to each customer is composed of three different elements:

1) Broadcast content sent from a central location but received by all customers.

2) Downstream broadband content directed at specific customers.

3) Upstream broadband content coming from specific customers.

Since the data volume will be considered in relation to the energy consumed, the same observation interval of one hour shall be used.

NOTE: The total volume of broadcast data transported is a function of, the number of transport streams carried on the network and the rate at which data is carried on each of those transport streams. In an HFC network, transport streams are carried using channels in the available RF spectrum. QAM modulation is used to create the signal that is transmitted across the network. The spectrum is divided into 8 MHz channels of frequency. Each 8 MHz channel in the spectrum is modulated using QAM. The data capacity of an RF channel is a function of the QAM modulation order.

Parameters for DVB-C [i.6] transport streams that are considered in this analysis are summarized in table 2.

Table 2: Available data rates for a DVB-C system (in Mbps)

Modulation	Bandwidth (MHz)				
	2	4	6	8	10
16QAM	6,41	12,82	19,23	25,64	32,05
32QAM	8,01	16,03	24,04	32,05	40,07
64QAM	9,62	19,23	28,85	38,47	48,08
128QAM	11,22	22,44	33,66	44,88	56,10
256QAM	12,82	25,64	38,47	51,29	64,11

The total volume of broadcast video data in MB transported between REF_{HE} and REF_{NIU} in an hour shall be calculated with the following equation:

$$D_{BCTOT} = N_{CH} * BR_{CH} * 3600\ s * \frac{1\ Byte}{8\ bit}$$ Equation 11

Where:

D_{BCTOT} is the total volume of broadcast video data in MB transported between REF_{HE} and REF_{NIU} in an hour;

N_{CH} is the number of RF channels carried between REF_{HE} and REF_{NIU};

BR_{CH} is the data rate of an RF channel in Mbps (see table 2).

Broadcast signals are unique in that they generate a data stream which is delivered within the entire Cable Access Network no matter whether end user equipment is connected. The energy which is needed for this service is likewise consumed - no matter whether end users demand e.g. a TV program. Fixed broadband DSL access networks, on the contrary, are an IP based network which per definition deliver the content only on request.

In order to compare data volumes of services delivered via broadcast and services delivered via unicast IP signals, the transported broadcast data shall be adjusted to the effective volume of broadcast data "consumed" by the end users.

Broadcast video data is defined as consumed if at least one CPE device connected to the REF_{NIU} is either displaying or recording the video content. To calculate this, the following three assumptions are given:

- Types of channels delivered to customers.
- Average bit rates for delivering those channels.
- Amount of viewing/recording (i.e. "consumption") time for the different types of channels.

Broadcast video in Cable Access Networks is carried using three different types of channels, standard definition (SD), high definition (HD) and analog channels. SD and HD channels will have data rates based on a number of factors. For this calculation, operators should use the average bit rate across all SD channels (BR_{SD}, typically between 3 - 5 Mbps) and the average across all HD channels (BR_{HD}, typically in the 12 - 13 Mbps range). With respect to analog channels, as they deliver something similar to an SD quality signal to subscribers, for the purposes of these calculations the data rate assigned to an analogue channel BR_{ANA} is assumed to be the same as the average bit rate across all SD channels (i.e. $BR_{ANA} = BR_{SD}$).

Finally, assumption with regard to average broadcast viewing time by customers are required. The average television usage is generally measured by surveys of national statistic offices, ministries of telecommunication or similar institutions. These consumption patterns vary from region to region and are expected to change considerably over time. Therefore, appropriate data should be drawn either from regional or national sources or from operators' own data, in order to make assumptions on the percentage of time on average each type of television channel (SD, HD, or analog) is being watched (i.e. consumed) by a device connected to the NIU.

With these assumptions, the effective volume of broadcast video data in MB transported in an hour between REF_{HE} and REF_{NIU} per NIU connection is:

$$D_{BCEFF} = \left((BR_{SD} * t_{SD}) + (BR_{HD} * t_{HD}) + (BR_{ANA} * t_{ANA})\right) * \frac{3600\ s}{60\ min} * \frac{1\ Byte}{8\ bit} \qquad \text{Equation 12}$$

Where:

- D_{BCEFF} is the effective volume of broadcast video data in MB transported in an hour between REF_{HE}; and
- REF_{NIU} per NIU connection;
- BR_{SD} is the average data rate of an SD channel on the system in Mbps;
- BR_{HD} is the average data rate of an HD channel on the system in Mbps;
- BR_{ANA} is the average data rate of an analog channel on the system in Mbps;
- t_{SD} is the average time in minutes a customer watches SD channels each hour;
- t_{HD} is the average time in minutes a customer watches HD channels each hour;
- t_{ANA} is the average time in minutes a customer watches analog channels each hour.

Upstream and Downstream broadband data is similarly transmitted on an HFC network as an RF signal using QAM modulation. Broadband data is delivered using the DOCSIS standard [i.7], where in Europe mainly the technology option based on a channel width of 8 MHz in Downstream is used. As with power, the first choice for data source for upstream and downstream data is via measurement. In the event measured data is not available, the calculations below can be used to estimate data transported in the upstream and downstream on a per NIU basis.

The data transmitted in Downstream direction is dedicated to a particular group of subscribers. To calculate the amount of Downstream data transported between REF_{HE} and REF_{NIU} for an individual NIU connection, the following equation applies:

$$D_{DS} = k_{DS} * N_{CH} * BR_{CH} * 3600\ s * \frac{1\ Byte}{8\ bit} * \frac{1}{C_{DS}} \qquad \text{Equation 13}$$

Where:

- D_{DS} is the broadband data transmitted downstream;
- N_{CH} is the number of Downstream RF channels carried between REF_{HE} and REF_{NIU};
- BR_{CH} is the data rate of an RF channel in Mbps (see table 2);
- C_{DS} is the number of NIU connections fed by Downstream transport channels;
- k_{DS} is the Downstream Channel utilisation co-efficienct, a number between 0 and 1 estimating equivalent percentage of time the channel is in use.

In the Upstream direction, spectrum is partitioned in 1,6 MHz, 3,2 MHz and 6,4 MHz channels. Table 3 details the data capacity for each bandwidth using different QAM modulation orders.

Table 3: Data rates for DOCSIS Upstream channels

Modulation	Bandwidth		
	1,6 MHz	**3,2 MHz**	**6,4 MHz**
QPSK	2,56M	5,12M	7,68M
16QAM	5,12M	10,24M	20,48M
32QAM	6,40M	12,80M	25,60M
64QAM	7,68M	15,36M	30,72M
128QAM	8,96M	17,92M	35,84M

As with the Downstream, the amount of Upstream data transported between REF_{HE} and REF_{NIU} for an individual NIU connection is given by the equation below:

$$D_{US} = N_{CH} * BR_{CH} * 3600\ s * \frac{1\ Byte}{8\ bit} * \frac{1}{C_{US}} \quad \text{Equation 14}$$

Where:

D_{US}	is the broadband data transmitted upstream;
N_{CH}	is the number of Upstream RF channels carried between REF_{HE} and REF_{NIU};
BR_{CH}	is the data rate of an RF channel in Mbps (see table 3);
C_{US}	is the number of NIU connections fed by Upstream transport channels;
k_{DS}	is the Downstream Channel utilisation co-efficienct, a number between 0 and 1 estimating equivalent percentage of time the channel is in use.

The total volume of data transported between REF_{HE} and REF_{NIU} per NIU connection is defined as:

$$D_{NIU} = D_{BCEFF} + D_{DS} + D_{US} \quad \text{Equation 15}$$

7.1.4 Energy Performance KPI

The Energy Performance KPI KPI_{EP} is given by the equation below:

$$KPI_{EP} = \frac{D_{NIU}}{P_{NIU} * t} \quad \text{Equation 16}$$

7.2 Use Case Sample Calculation of KPI_{EP}

This clause presents an example use case to illustrate the use of the equations from clause 7.1 to calculate the energy performance of the network.

In the use case example below, the following assumptions apply to the power calculation:

- Calculated power for all elements connected to the power supply (P_{PS}) is 1 271 W.
- Total number of NIU connections fed by the power supply (C_{PS}) is 250.
- Total Power for CMTS (P_{CMTS}) is assumed to be 1 000 W.
- Number of Customer equivalent NIU's served by the CMTS (C_{CMTS}) is assumed to be 5 000.
- Total Power for EQAM (P_{EQAM}) is assumed to be 1 500 W.
- Customer equivalent NIU's served by the Facility EQAM (C_{FAC}) is assumed to be 15 000.
- Total Power for one Optical Transmitter (P_{TX}) is assumed to be 16 W.
- Customer equivalent NIU's served by the Optical Transmitter (C_{TX}) is assumed to be 960.
- Total Power for one Optical Receiver (P_{RX}) is assumed to be 12 W.
- Customer equivalent NIU's served by the Optical Transmitter (C_{RX}) is assumed to be 240.

P_{RXNIU}, P_{TXNIU}, P_{EQNIU}, and P_{CNIU} are all as calculated using Equations 4-7 in clause 7.1.1.

$$P_{CNIU} = \frac{P_{CMTS}}{C_{CMTS}} = \frac{1000\ W}{5000} = 0{,}2\ W$$

$$P_{EQNIU} = \frac{P_{EQAM}}{C_{FAC}} = \frac{1500\ W}{15000} = 0{,}1\ W$$

$$P_{TXNIU} = \frac{P_{TX}}{C_{TX}} = \frac{16\ W}{960} = 0{,}02\ W$$

$$P_{RXNIU} = \frac{P_{RX}}{C_{RX}} = \frac{12\ W}{240} = 0{,}05\ W$$

Using Equation 8, the total power required by the headend per NIU connection amounts to:

$$\begin{aligned} P_{HENIU} &= P_{RXNIU} + P_{TXNIU} + P_{EQNIU} + P_{CNIU} \\ &= 0{,}05\ W + 0{,}02\ W + 0{,}1\ W + 0{,}2\ W \\ &= 0{,}37\ W \end{aligned}$$

From Equation 9, the power per NIU fed by the power supply is:

$$P_{PSNIU} = \frac{1\ 271\ W}{250} = 5{,}08\ W$$

and the total power per NIU connection follows from Equation 10:

$$\begin{aligned} P_{NIU} &= P_{PSNIU} + P_{HENIU} \\ &= 5{,}08\ W + 0{,}37\ W \\ &= 5{,}45\ W \end{aligned}$$

The following assumptions are made for the data throughput as:

- 63 digitally modulated RF channels are broadcast to all NIU connections.
- Each broadcast channel is 8 MHz wide, using 256QAM.
- Each HD Channel is transmitted with 12,82 Mbps.
- Each SD Channel is transmitted with 5,13 Mbps.
- Average time during a day a device in a subscriber home is connected to an NIU and consumes broadcast content (i.e. average viewing time of channels) by type of channel is:
  - SD content 31 min.
  - HD content 103 min.
  - Analog content 10 min.
- DOCSIS 3.0 uses 4 x 8 MHz in the Downstream at 256QAM, feeding a total of 960 subscribers (1 transmitter with same downstream).
- The Downstream utilisation co-efficients (k_{DS}) is assumed to be 0,75.
- DOCSIS 3.0 uses 3 x 6.4 MHz in the Upstream at 16QAM, feeding 240 subscribers.
- The Upstream utilisation co-efficient (k_{US}) is assumed to be 0,25.

From Equation 11, the total volume of broadcast data transported in an hour is calculated to be:

$$\begin{aligned} \mathrm{D_{BCTOT}} &= 63 * 51{,}29\ \mathrm{Mbps} * 3\ 600\ \mathrm{s} * \frac{1\ \mathrm{Byte}}{8\ \mathrm{bit}} \\ &= 1\ 454\ 072\ \mathrm{MB} \end{aligned}$$

For the effective volume of broadcast data per NIU connection, Equation 12 is used. Viewing times for each channel are assessed over one day (a very common way for that data to be measured). As the viewing time variables in the equation need to be assessed during an hour, the time reference is changed by dividing each value by 24 hours that are in one day.

$$\begin{aligned} \mathrm{D_{BCEFF}} &= \left(\left(5{,}13\ \mathrm{Mbps} * \frac{31}{24}\ \mathrm{min}\right) + \left(12{,}82\ \mathrm{Mbps} * \frac{103}{24}\ \mathrm{min}\right) + \left(5{,}13\ \mathrm{Mbps} * \frac{10}{24}\ \mathrm{min}\right)\right) * \frac{3\ 600\ \mathrm{s}}{60\ \mathrm{min}} * \frac{1\ \mathrm{Byte}}{8\ \mathrm{bit}} \\ &= 478\ \mathrm{MB} \end{aligned}$$

From Equation 13, the Downstream data per NIU connection is calculated to be:

$$\begin{aligned} D_{DS} &= 0{,}75 * 4 * 51{,}3\ Mbps * 3\ 600\ s * \frac{1\ Byte}{8\ bit} * \frac{1}{960} \\ &= 72\ MB \end{aligned}$$

and the Upstream data per NIU connection is calculated from Equation 14:

$$D_{US} = 0{,}25 * 3 * 20{,}5\ Mbps * 3\,600\ s * \frac{1\ Byte}{8\ bit} * \frac{1}{240}$$
$$= 29\ MB$$

From Equation 15, the total data volume transported between REF_{HE} and REF_{NIU} per NIU connection amounts to:

$$D_{NIU} = D_{BCEFF} + D_{DS} + D_{US}$$
$$= 478\ MB + 72\ MB + 29\ MB$$
$$= 579\ MB$$

and the Global Energy Performance key performance indicator KPI_{EP} results from Equation 16:

$$KPI_{EP} = \frac{D_{NIU}}{P_{NIU} * t}$$

$$= \frac{579\ MB}{0{,}00545\ kW * 1\ h} = 106238 \frac{MB}{kWh} \approx 106 \frac{GB}{kWh}$$

The Energy Performance of the Broadband CAN has a key performance indicator value of:

KPI_{EP} ≈ 106 GB per kWh

The above example does not infer energy performance values for an actual network operators CAN. To determine the network performance of an operators CAN the values and assumptions would need to be specified for a dimensioned portion of the actual CAN architecture in the same way as described in the example given in this clause, applying the equations from clause 7.1 to give an indication of the energy performance of the specified portion of the cable access network.

Annex A (informative): Power Supply Performance

The power that the HFC network requires between REF_{HE} and REF_{NIU} is a summation of the power needed to drive the signal through the node, amplifiers, taps, couplers, coaxial and fibre cables. The single power source in the network that provides power to the network is the OSP network power supply. The task efficiency of the power source is dependant on the load. Different materials present different efficiency curves. The typical graph for ferroresonant material is shown in figure A.1.

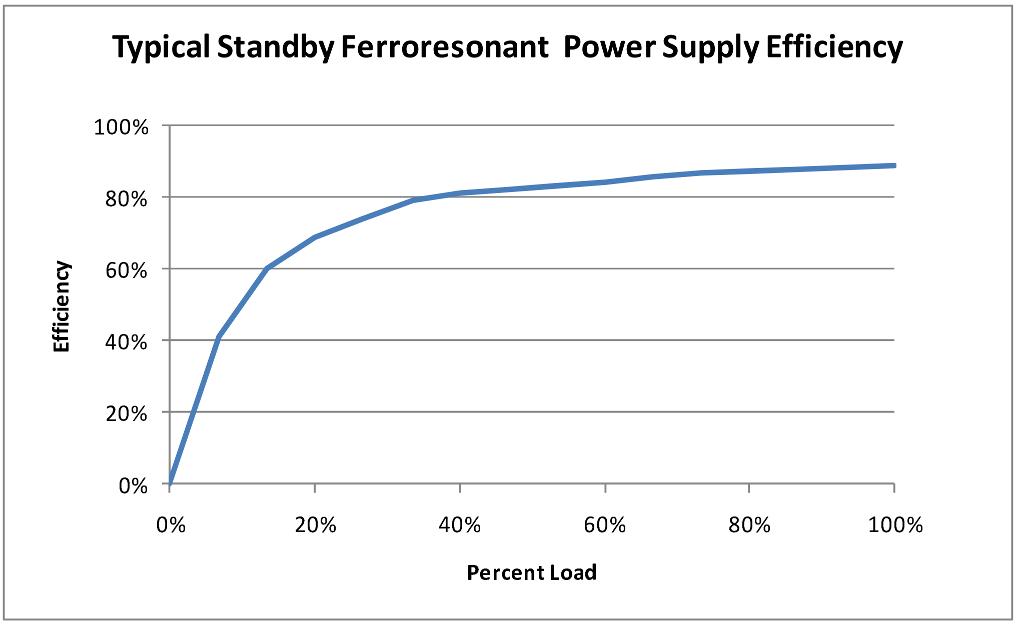

Figure A.1: Typical standby ferroresonant power supply efficiency

Annex B (informative): Bibliography

- Code of Conduct for Data Centre Energy Efficiency. European Commission, DG JRC.
- ETSI TR 105 174-1 (V1.2.1): "Access and Terminals (AT); Relationship between installations, cabling and communications systems; Standardization work published and in development; Part 1: Overview, common and generic aspects; Sub-part 1: Generalities, common view of the set of documents".
- Recommendation ITU-T L.1310 (August 2014): "Energy efficiency metrics and measurement methods for telecommunication equipment".
- ISO Guide 82: "Guide for addressing sustainability in standards".

History

Document history		
V1.1.1	March 2015	Membership Approval Procedure MV 20150524: 2015-03-25 to 2015-05-25
V1.1.1	June 2015	Publication