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Foreword

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

The present document is part 6 of a multi-part deliverable. Full details of the entire series can be found in part 1 [i.1].

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).

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Introduction

The increasing interaction between the different elements of the Information Communication Technology (ICT) sector (hardware, middleware, software and services) supports the concept of convergence in which:

- multi-service packages can be delivered over a common infrastructure;
- a variety of infrastructures is able to deliver these packages;
- a single multi-service-package may be delivered over different infrastructures.

As a result of this convergence, the development of new services, applications and content has resulted in an increased demand for bandwidth, reliability, quality and performance, with a consequent increase in the demand for energy which has implications for cost and, in some cases, availability. It is therefore important to maximize the energy efficiency of all the network elements necessary to deliver the required services.

New technologies and infrastructure strategies are expected to enable operators to decrease the energy consumption, for a given level of service, of their existing and future infrastructures thus decreasing their costs. This requires a common understanding among market participants that only standards can produce.

The present document analyses the work on fixed broadband cable access networks whilst details of each of the other parts of the document set can be found in Part 1 [i.1]. It offers a contribution to the required standardization process by establishing an initial basis for determining the main energy consuming elements of the operators' broadband cable access network and defining indicators to measure their energy consumption and performance in terms of the work done by the network to transfer a volume of data.

Clearly the energy efficiencies of Operator Sites, Data Centres, the Core Networks and Customer Network Infrastructures are also important in maximizing the end-to-end energy efficiency of broadband communications and these issues will be covered in other parts of the document set. However, Access Networks differ from the other network components in that they are likely to include a very large number of locations each consuming a relatively low amount of energy. Not only do such small installations tend to be inefficient in their power utilization but when multiplied by their number, their total energy usage becomes considerable. Thus any energy saving which can be achieved becomes significant when the number of sites is taken into account.

The present document provides a basis for defining network key performance indicators as a bench mark that may assist network developers to measure energy metrics with progressive state of art., designs with the aim to reduce the overall energy consumption of the network. When complete, the documents will contain information to present principle metrics and approaches to calculate the broadband cable access network infrastructure energy performance. Innovative cable access architectures describe how these progress the broadband cable access network towards energy efficient infrastructures whilst continuing to meet year by year ever increasing demand for consumer multimedia services, voice, video and data.

Cable Operators across Europe and North America are defining metrics to measure the energy performance of their access network. In North America, the U.S. based SCTE [i.19] is in the process of defining the CAN in terms of energy consumption and metrics.

Through the cooperation agreement between ETSI TC CABLE and SCTE EMS-004 group [i.19], development of energy efficiency infrastructures for the broadband cable access network are expected to be defined along with metrics to support improvement measures in the energy consumption. Collaboration between the two organizations would ensure consistency and alignment as well as encourage sharing of information to optimize resources for standardization.

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1 Scope

The present document describes the cable access network, and progressive network access architectures that reduce the network energy consumption and the metrics required to benchmark the network and its components to support and enable the proper implementation of services, applications and content on an energy efficient infrastructure and describe measures that may improve the energy efficiency of cable access networks.

Within the present document:

- clause 4 presents the schematic for cable access network infrastructures, the evolution of the network architectures to meet consumer capacity demand and bandwidth growth and the main components of the cable access network energy consuming elements;
- clause 5 presents measurement key performance indicators to baseline and measure network energy performance;
- clause 6 explains power consumption metrics of the CAN;
- clause 7 describes and gives consideration to power metrics of field deployed access network elements;
- clause 8 describes the electrical powering of the CAN components and the distributed usage of the electrical power. This clause explains ways to improve the power consumption and benchmarking the HFC CAN plant;
- clause 9 considers the calculations to measure the data throughput of a CAN.

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.

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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] ETSI TR 105 174-1-1: "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".

[i.2] ETSI TR 102 881 (V1.1.1): "Access, Terminals, Transmission and Multiplexing (ATTM); Cable Network Handbook".

[i.3] ETSI EN 302 878-2: "Access, Terminals, Transmission and Multiplexing (ATTM); Third Generation Transmission Systems for Interactive Cable Television Services - IP Cable Modems; Part 2: Physical Layer; DOCSIS 3.0".

[i.4] ETSI TR 101 546: "Access, Terminals, Transmission and Multiplexing (ATTM); Integrated broadband Cable and Television Networks; Converged Cable Access Platform Architecture".

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

[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 TS 103 311 (all parts) (V1.1.1): "Integrated broadband cable telecommunication networks (CABLE); Fourth Generation Transmission Systems for Interactive Cable Television Services - IP Cable Modems".

[i.8] 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. European Commission, DG Enterprise and Industry".

[i.9] Coroama, Vlad C., Lorenz M. Hilty, Ernst Heiri, and Frank M. Horn. 2013. "The Direct Energy Demand of Internet Data Flows." Journal of Industrial Ecology, n/a-n/a. doi:10.1111/jiec.12048.

[i.10] Chan, Chien A., André F. Gygax, Elaine Wong, Christopher A. Leckie, Ampalavanapillai Nirmalathas, and Daniel C. Kilper. 2013: "Methodologies for Assessing the Use-Phase Power Consumption and Greenhouse Gas Emissions of Telecommunications Network Services." Environmental Science & Technology 47 (1): 485-92. doi:10.1021/es303384y.

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[i.12] Coroama, Vlad C., and Lorenz M. Hilty. 2014. "Assessing Internet Energy Intensity: A Review of Methods and Results." Environmental Impact Assessment Review 45 (February): 63-68. doi:10.1016/j.eiar.2013.12.004.

[i.13] Malmodin, Jens, Dag Lundén, Åsa Moberg, Greger Andersson, and Mikael Nilsson. 2014a. "Life Cycle Assessment of ICT." Journal of Industrial Ecology, May, n/a-n/a. doi:10.1111/jiec.12145.

[i.14] Schien, Daniel, Vlad C. Coroama, Lorenz M. Hilty, and Chris Preist. 2015. "The Energy Intensity of the Internet: Edge and Core Networks." In ICT Innovations for Sustainability, edited by Lorenz M. Hilty and Bernard Aebischer, 157-70. Advances in Intelligent Systems and Computing 310. Springer International Publishing.

NOTE: Available at http://link.springer.com/chapter/10.1007/978-3-319-09228-7_9.

[i.15] Coroama, Vlad C., Daniel Schien, Chris Preist, and Lorenz M. Hilty. 2015: "The Energy Intensity of the Internet: Home and Access Networks." In ICT Innovations for Sustainability, edited by Lorenz M. Hilty and Bernard Aebischer, 137-55. Advances in Intelligent Systems and Computing 310. Springer International Publishing.

NOTE: Available at http://link.springer.com/chapter/10.1007/978-3-319-09228-7_8.

[i.16] ETSI ES 205 200-2-4: "Integrated broadband cable telecommunication networks (CABLE); Energy management; Global KPIs; Operational infrastructures; Part 2: specific requirements; Sub-part 4: Cable Access Networks".

[i.17] 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.18] "Harmonizing Global Metrics for Data Centers Energy Efficiency, Global Taskforce Reaches Agreement Regarding Data Center Productivity," Green Grid, March 13, 2014.

NOTE: Available at http://www.thegreengrid.org/Global/Content/Regulatory-Activities/HarmonizingGlobalMetricsForDataCenterEnergyEfficiency_DCeP.

[i.19] Society of Cable Telecommunication Engineers (SCTE).

NOTE: Available at http://www.scte.org/.

3 Definitions, symbols and abbreviations

3.1 Definitions

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

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

fixed Cable Access Network: functional elements that enable wired (including optical fibre) communications to customer equipment

Hybrid Fibre Coax: 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

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

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
dB	decibel - a unit used to measure the intensity of the power level of an electrical signal by comparing it with a given level on a logarithmic scale
dBµV	decibel relative to one microvolt
dBmV	decibels relative to one millivolt
Gb	unit of Gigabyte (10^9 Byte)
GB	unit of Gigabyte (10^9 Byte)
KPI_{EP}	Global Key Performance Indicator of energy performance
KPI_{CMTSDS}	Key Performance Indicator metric for downstream CMTS ports
KPI_{CMTSUS}	Key Performance Indicator metric for upstream CMTS ports
KPI_{CMTS}	Key Performance Indicator metric for CMTS
KPI_{EQAM}	Key Performance Indicator metric for EQAM
KPI_{TXSA}	Key Performance Indicator metric for stand-alone optical transmitter
KPI_{CWDA}	Key Performance Indicator metric for CWDM based technology optical transmitter
KPI_{TXRX}	Key Performance Indicator metric for stand-alone optical receiver
KPI_{FN}	Key Performance Indicator metric for fibre node

KPI_{RFAMP}	Key Performance Indicator metric for RF Amplifier
KPI_{ANTOT}	Key Performance Indicator metric for the complete access network i.e. the total access network
KPI_{RFAMP}	Key Performance Indicator metric for RF Amplifier
$KPI_{EP_broadcast}$	Key Performance Indicator energy performance metric for broadcast data transmission
kWh	kilowatt hours
m	unit of measurement of length in meters
REF_{HE}	Reference point at the cable headend
REF_{NIU}	Reference point at the network interface unit

3.3 Abbreviations

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

AC	Alternating Current
ANA	Autonomic Network Architecture
CAN	Cable Access Network
CATV	Cable Television
CCAP	Converged Cable Access Platform
CMTS	Cable Modem Termination System
CM	Cable Modem
CPE	Customer Premises Equipment
CWDM	Course wavelength division multiplexing
DC	Direct Current
DEMUX	De-multiplexer
DEPI	Downstream External-PHY Interface
DOCSIS	Data over Cable Service Interface Specification
DTV	Digital Television
DPI	Deep Packet Insertion
DS	Downstream
DSL	Digital Subscriber Line
DVB-C	Digital Video Broadcast- Cable
EdgeQAM	Edge Quadrature Amplitude Modulator
EMS	Energy Management Subcommittee
EUI	Energy Unit Intensity
GW	Gateway
Fwd	Forward
HD	High Definition
HE	Headend
HFC	Hybrid Fibre Coax
HVAC	heating, ventilating, and air conditioning
ICT	Information Technology Equipment
IP	Internet Protocol
KPI	Key Performance Indicator
OFDM	Orthogonal Frequency Division Multiplexing
OS	Operator Site
OSP	Outside Plant
PBX	Private Branch Exchange
PC	Personal Computer
POS	Point of Sale
PS	Power Supply or Power Source
PUE	Power Usage Effectiveness
M-CMTS	Modular Cable Modem Termination System
MUX	Multiplexer
N+0	Node plus no amplifier
N+1	Node plus one amplifier
NC	Narrowcast
PHY	Physical
QAM	Quadrature Amplitude Modulator
Ret	Return
RF	Radio Frequency
ROI	Return on Investment
SC-QAM	Single Carrier-Quadrature Amplitude Modulation

SCTE	Society of Cable Telecommunication Engineers
SD	Standards Definition
SG	Signalling Group
STB	Set Top Box
TV	Television
US	Upstream
U.S	United States
VOD	Video on Demand
IT	Information Technology
LDPC	Low Density Parity Check
MAC	Medium Access Control
MPEG	Motion Pictures Experts Group
VA	Volt-Ampere (unit of apparent power)

4 Cable Access Network Infrastructure

4.1 Classical network, generic reference model

The HFC Cable Network is as described by ETSI Cable Handbook [i.2]. Figure 1 presents a schematic of a generic cable access network infrastructure.

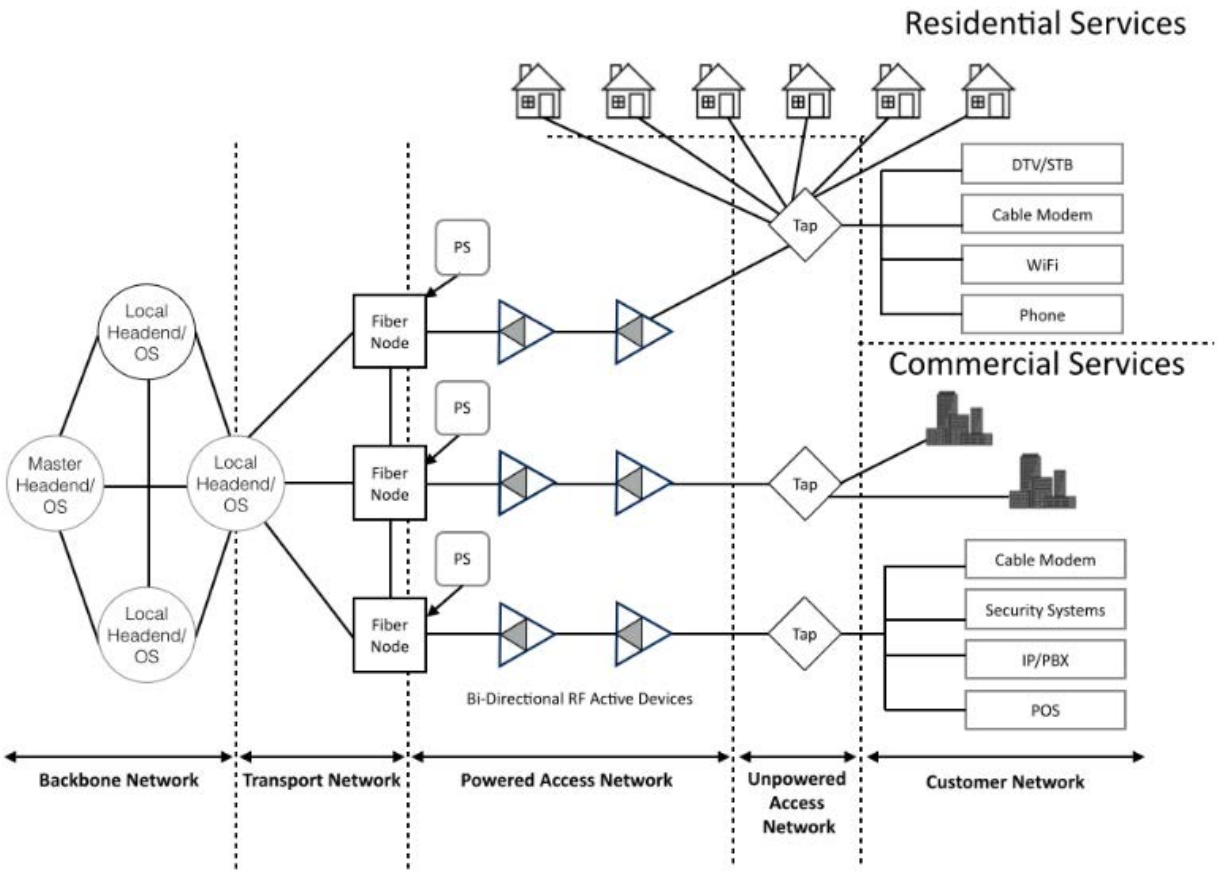

Figure 1: Schematic of HFC classical 'fixed' cable network infrastructures

The main energy consuming components of a Fixed Broadband HFC cable access network in no particular order are:

- The Power Supply - One supply will be dedicated to feed one node and the coaxial amplifiers the node feeds. The supply is the buffer between the power utility and the system components, regulating and grooming the AC output to active system devices. A power supply may have stand-by capability, which provides system power in the event of a power utility outage. This is done using batteries and an inverter module to convert DC to AC for the system components.

- Power Inserter - The power supply is interfaced on the coaxial system cables, using a fuse protected power inserter (a diplexer or dc) to combine AC with the coaxial system cable.

- The Fiber Node - The fiber optic node is a transceiver. Fed from the head-end via fiber cable, the node acts as the local head end, dedicated to serving up to 500 homes in a given area, over a coaxial distribution system. The node converts all upstream RF signals to light (return), and all downstream light signals (forward) to standard RF energy. This unit will receive power through one of the coaxial cables connected to the coaxial ports of the node.

- Trunk Amplifier - The Trunk amplifier is the workhorse of the RF system. It provides bi-directional amplification of the RF signals within the Access Network.

- Line Extenders - The line extender has one output port, which requires additional external splitters for multiple coaxial outputs. The device can be configured to pass or stop AC power as needed. This is a coaxial amplifier. The Line Extender will re-amplify system signals to their original power or designed amplitude level, and positive slope.

- Mini Bridgers - These are used where multiple coaxial feeds are required, as this unit can have up to four coaxial feeds active on dedicated ports. This provides configuration options for efficient signal distribution through a specific area. This is a coaxial amplifier. The Mini Bridger will re-amplify system signals to their original power or designed amplitude level, and positive slope.

- Coaxial Cable - Although a passive component of the HFC architecture the type of coaxial cable contributes to power usage in the node through fixed resistance within the cable length. This is usually mitigated through Impedance matching.

4.2 Fibre deep access network

A fibre deep cable access network topology is presented in Figure 2. A HFC cable access network that deploys fibre deeper in the network is a solution that significantly reduces the number of homes served per node from 500 - 1 000 that is typical in a traditional classical CAN architecture to 100 homes. Consequently there can be a significant reduction in energy consumption by the reduction in the line RF amplifiers.

The reduction in the energy consumption for a serving area can be determined. The present document only highlights the potential of energy saving with different network solutions. An in-depth study is required to provide specific data and comparisons with a classical HFC network.

Several equipment suppliers of fibre deep solutions have produced material that provide examples of the energy consumption within a classical and fibre deep CAN architecture solution. The present document does not reference the competitive data available from equipment manufacturers and suppliers. An in-depth study of the power consumption for a classical vs a fibre deep CAN is out of scope of the present document however if required it may be produced in revisions of the present document.

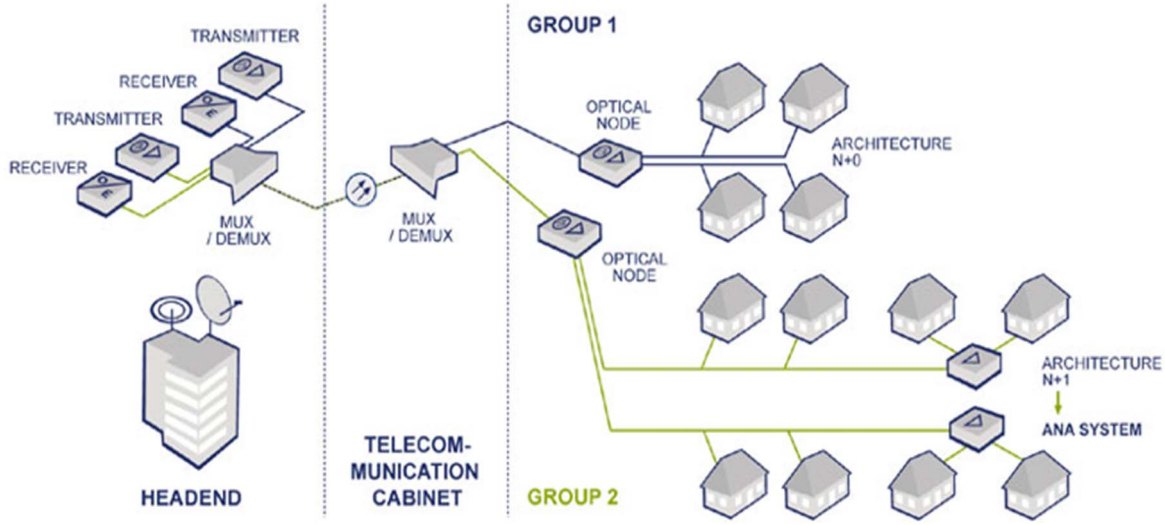

Figure 2: Schematic of HFC Fibre Deep 'fixed' cable network infrastructures

4.3 Network convergence with CCAP

The headend comprises data and video equipment. At the headend, the CMTS equipment supports data communications and the EdgeQAM equipment supports video communication. The cable network may be architected with modular or integrated designs of headend equipment. Detailed information is as given by ETSI DOCSIS 3.0 PHY layer specifications [i.3]. A converged cable access platform (CCAP) is headend equipment that converges both data and video communications. Detailed information is as given by ETSI TR 101 546 [i.4]. The platform increases the density of the QAM channels and has a reduced space and lower energy consumption footprint. The high speed internet streams flow through the CCAP as illustrated in Figure 5-4 of ETSI TR 101 546 [i.4] data reference architecture. The architecture of a CCAP platform achieves power savings with scalable port density, space savings and about 4 times more capacity as illustrated in Figure 3.

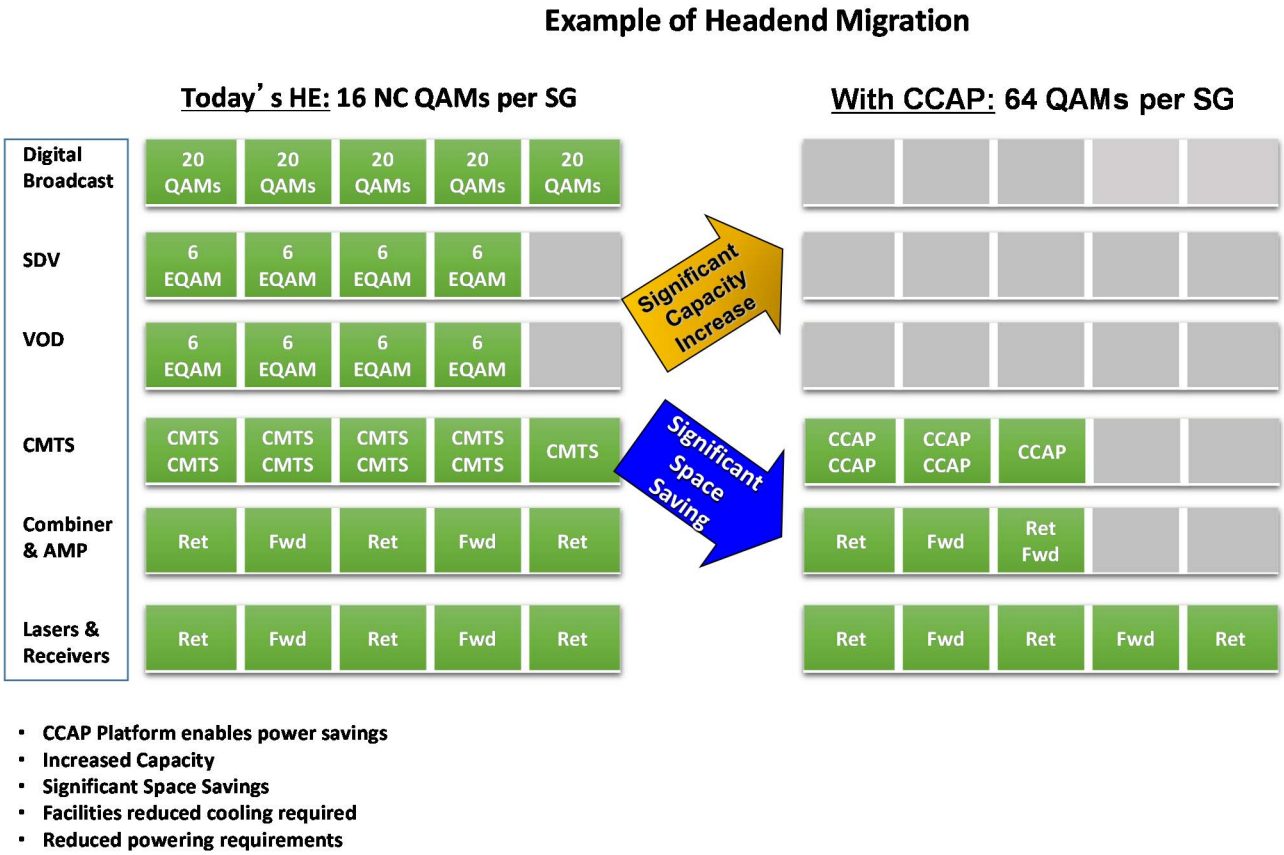

Figure 3: CCAP Platform Converged Data and Video Services

4.4 Network evolution

The CAN is constantly evolving to meet the ever increasing consumer demand for services resulting in a need for increased bandwidth. The evolution of the DOCSIS standards from 1.0 to 3.0 is given by the series of ETSI specifications [i.5] with data and video services converging at the headend by CCAP [i.4] standards based equipment. The cable networks continue to evolve with new technology solutions to meet the consumer demand for increased bandwidth both upstream and downstream. The architecture for cable services are migrating from the traditional DVB-C [i.6] based video services and DOCSIS based data/telephony services to be all IP based services which optimizes on spectral efficiency and bandwidth. The impact of these changes to the architecture and design of the broadband CAN is an increased efficiency of the network in delivering communication data between the subscribers terminal (e.g. CM, STB, GW) and the network headend termination (e.g. CCAP).

Further evolutions in moving either the MAC & PHY or just the PHY functions from the headend closer to the customer's premises located at the Fibre Node cabinet as illustrated in Figure 4, may further increase the efficiency of the broadband cable access network.

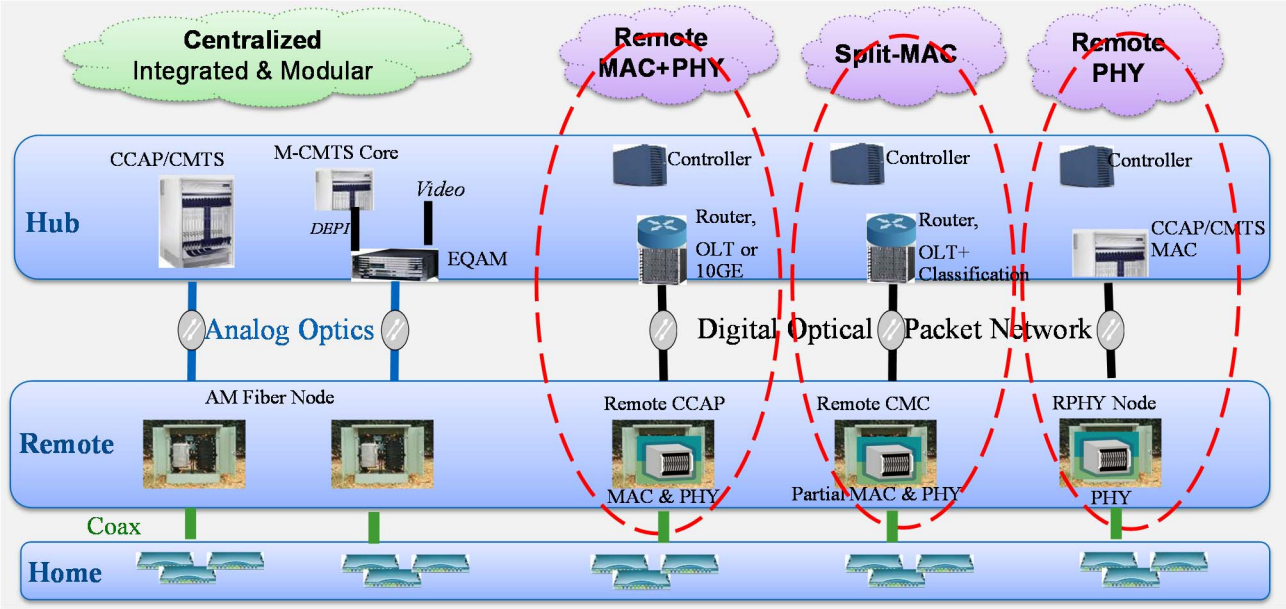

Figure 4: Evolution to distributed broadband cable network architectures

A fourth generation transmission technology, DOCSIS 3.1 [i.7], has been developed by stakeholders under a CableLabs project. The evolution from DOCSIS 3.0 to DOCSIS 3.1 transmission presents significant improvements by extending the upstream and downstream spectrum, optimizes on the RF spectrum density using OFDM and LDPC coding that enables speeds of 1 Gb/s in the upstream and 10Gb/s in the downstream. The technology minimizes on the re-engineering of the distribution equipment within the HFC network as it is backward compatible with DOCSIS 3.0 and can operate in existing HFC network plant. Whilst the new transmission technology enables significant increase in the modulation profiles achievable with increased spectral density, the increase in the power consumed is modest in comparison. Consequently DOCSIS 3.1 potentially enables a significant improvement in the energy performance of the access network. Figure 5 illustrates an idealized channel map with DOCSIS 3.1.

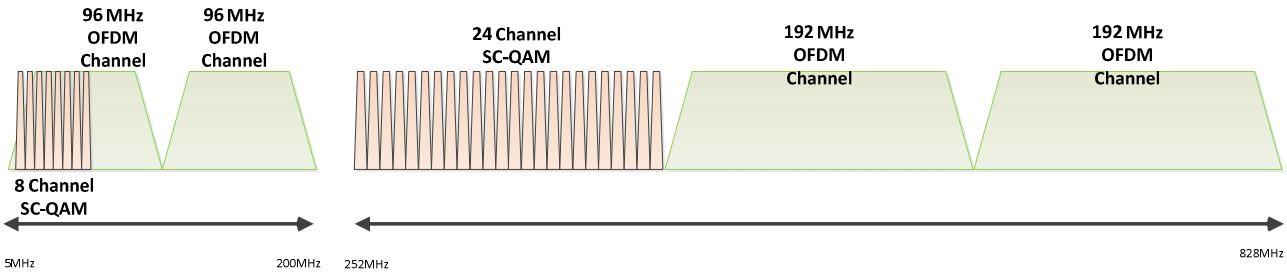

Figure 5: DOCSIS 3.1 idealized channel map

Next generation broadband CAN has to support growth in capacity whilst optimizing on the energy consumption to transfer data from the customer premises to the edge of the access network. Figure 6 illustrates the evolution of broadband cable network architectures to meet the continued consumer demand for higher product speeds and increased network data transmission capacity. An in-depth study of the power consumption for different CAN architecture scenarios is out of scope of the present document however if required it may be produced in revisions of the present document.

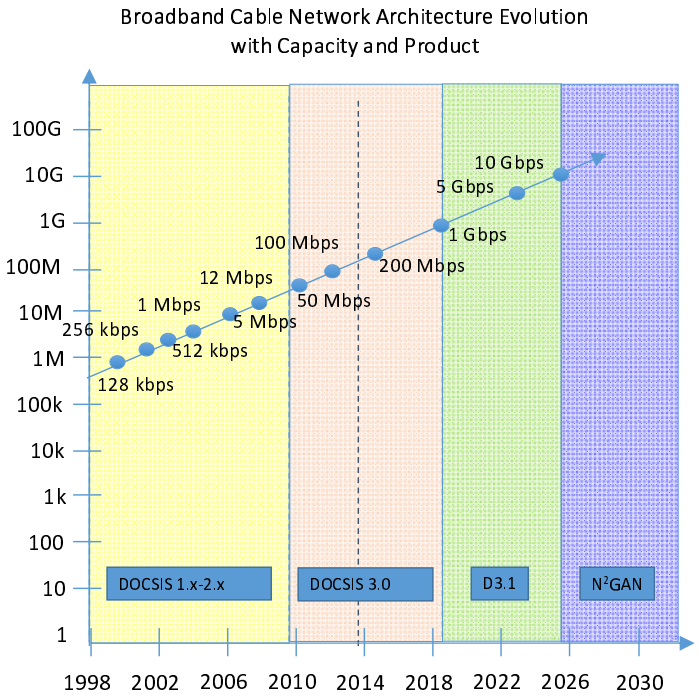

Figure 6: Evolution of Broadband CAN with increased product speed and network capacity

5 Measurement KPIs

5.1 Defining Energy Performance

Cable Operators across Europe and North America are defining metrics to measure the energy performance of their access network. In North America, the U.S. based SCTE [i.19] is in the process of defining the CAN in terms of energy consumption and metrics. ETSI has accepted a European Commission Standardisation Mandate M/462 [i.8] to develop energy metrics in the field of information and communication technologies to enable efficient energy use in fixed and mobile information and communication networks, and their associated applications/domains, facilities and infrastructures, at both network and subscriber level.

Through the cooperation agreement between ETSI and SCTE [i.19], development of energy efficiency infrastructures for the cable access network are expected to be defined along with metrics to support improvement measures in the energy consumption.

5.2 Energy Performance Global KPI

5.2.1 Definition

Cable Access Networks are primarily 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 usage, a metric is required that measures efficiency 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 a measure of its task efficiency KPI KPI_{TE} . The overall task efficiency of the network is predominately due to improvements in the effective use of the available spectral efficiency and from using increased modulation profiles to support substantially greater data throughput rates for relatively the same power consumption. The network task efficiency resulting from better spectrum utilization and modulation techniques is related to KPI_{EP} by calculating the ratio between the data volume transported across the Cable Access Network in Megabyte and the total energy consumption in kWh observed over the measurement interval *t*.

KPI_{EP} is a measure of the work done by the network which can be represented by a unit of work done by the network measured in Megabyte per kWh.

5.2.2 Impact of Plant Density on Energy Performance Global KPI

The distribution network portion of a CAN is generally characterized by its plant density. Plant density is usually numerically expressed as a number of homes/living units passed by the network, per kilometers of cabling in the network. Clause 8.2 on Benchmarking contains a more detailed discussion on plant density, and the metrics associated with it. Plant densities in distribution networks range from as low as 10 - 15 homes passed per kilometer of cabling for the most rural of networks, to 400 - 600 homes passed per kilometer for some of the most dense networks.

Powering requirements are heavily correlated with plant density. An OSP power supply in general feeds a few kilometers of coax, active, and passive cable plant, regardless of how many homes/customers are fed from that plant. With respect to KPI_{EP}, plant density will have an impact on the denominator of the metric, as if a plant is more rural and less dense, the same amount of power will feed fewer customers, and hence the Watts per customer will be higher. If the denominator is higher, then the metric would be worse (i.e. bytes/watt lower). Because of this, less dense plant starts at a dis-advantage with respect to efficiency.

Because of this density related impact to the metric, it is important that if the metric is used by operators to benchmark, judge, and/or compare CAN performance for this KPI, that plant density be factored in. One way to do this is by adjusting the metric in some way to properly compensate for density. If there were enough data points from real world examples of the relationship of plant density to watts/sub, another approach would be to create a mathematical equation from those data points that shows expected KPI performance as a function of plant density. Whichever approach is shown, users of KPI_{EP} should insure that they account for plant density as a part of their work with the KPI.

5.3 Comparable Work in Area of Energy Intensity of Data Transmission

Although there is no directly comparable work that has been performed in developing and/or defining specific metrics for access networks, and in particular CAN's, several studies have been undertaken, investigating the energy demand of internet infrastructure, excluding customer premises equipment (CPE) or end-user equipment (such as PCs, notebooks, mobile phones and television screens). These studies provide an interesting view of modern infrastructure, such as fibre optic submarine cables or satellite connections performing analogous functions to a CAN. As such, the literature provide viewpoints with respect to how to construct work based KPI's for networks, as well as a range of data indicating performance of networks in relation to the developed metric. The KPI published in the below mentioned scientific literature, use the reciprocal value of the KPI_{TE} used in this study. Generally efficiency is measured in energy consumed (in kWh, kilowatt hour) per transferred date volume (in GB, gigabyte).

Coroama [i.9] highlighted specific characteristics of worldwide fibre optical data transmission, showing that energy consumption occurs mainly at sender and recipient local nodes and not during long distance data transport through submarine cables (Coroama et al. 2013) [i.9]. A follow up study by the same authors conducted a literature review investigating the considerable range of the energy consumption of telecommunication sectors (Coroama and Hilty 2014) [i.12]. The authors classify the ten investigated studies according to the methodical approach chosen:

- "Top-down approach: According to (Chan et al. 2013) [i.10] top-down analyses are the ones taking into account the total electricity consumption estimated for the Internet and the Internet traffic for a region or a country within a defined time period. Dividing the former quantity by the latter yields the average energy consumption per data transferred.

- Model-based approach: By contrast, model-based approaches model parts of the Internet (i.e. deployed number of devices of each type) based on network design principles. Such a model combined with manufacturer's consumption data on typical network equipment leads to the overall energy consumption (Hinton et al. 2011) [i.11], which is then related to the corresponding data traffic.

- Bottom-up analysis: Finally, bottom-up analyses are based on direct observations made in one or more case studies, leading to energy intensity values for specific cases and a discussion of the generalizability of the results." (Coroama and Hilty 2014) [i.12].

Estimates from six different studies of the energy demand per data volume transferred diverge by up to two orders of magnitude from 0,057 kilowatt-hours per gigabyte (kWh/GB) to 1,8 kWh/GB. The lowest values published of 0,006 kWh/GB (Baliga et al. 2011) [i.11] were not included in the review. Other studies, which were taken into account in this review, included end-user devices such as desktop, notebook or tablet computers. The results show a higher energy demand per transferred data volume. Values range between 7 and 136 kWh/GB. The authors conclude that two factors are mainly responsible for the energy demand per data volume, these are:

1) **the year of the investigation** with a clear tendency towards energy efficiency increase over time;

2) **the system boundaries**, that is, whether or not end-user equipment, which is the main contributor to the kWh/GB consumed, is included in energy accounting or not.

Very recently Malmodin et al. published a life cycle assessment of the largest Swedish telecommunication provider. The investigated telecommunication system comprised the entire network including "*end user equipment via core network to international fiber connections and external data centers for e.g. search motors and social network.*" (Malmodin et al. 2014a) [i.13]. They included also G2 and G3 mobile networks and applied all three of the above mentioned approaches: The top-down approach and model based approach - to derive the amount of material and energy consumed by multiplying the end user equipment used in Sweden with the average energy consumption. Covered by this approach were consumer premises equipment (modem, routers, gateways, set-top boxes) and end user equipment (PCs, mobile phones, notebooks, televisions etc.). And the bottom up approach - by measuring the material and energy intensity of TeliaSonera' s network infrastructure (access network, operator activities and IP core network). Please see also supporting information (Malmodin et al. 2014b) [i.13].

Comparing characteristic data published in literature reviews, these values are at the lower end of the scale. They are near the values of 0,037 kWh/GB calculated by Coroama and Hilty (2014) or 0,057 kWh/GB (Schien et al. 2012; Schien et al. 2013) [i.14]. Nevertheless they are above the lowest value published of 0,006 kWh/GB (Baliga et al. 2011).

Coroma et al (2015) [i.12] and Schien et al. (2015) [i.14] conducted separate studies, first of the CPE and access network and secondly of the edge and core network. The first study assessed a large range of studies which partly included also end-user equipment. Their own case study an energy consumption < 0,2 kWh/GB was calculated. They strongly recommend to exclude end-user devices but include CPE and access network as they are part of the telecommunication network (Coroama et al. 2013 [i.9]; Coroama et al. 2015 [i.15]). The second study presents a bottom up approach with data collection on energy demand of specific devices and transmitted data volumes. They derive an energy consumption of 0,052 kWh/GB for the edge and core devices of a telecommunication network (Schien et al. 2015) [i.14]. Taking these two studies together an energy consumption of 0,252 kWh/GB can be deducted, from with roughly 80 % is caused by CPEs and access network and 20 % caused by edge and core networks.

5.4 Equipment KPIs

Indicators such as energy performance, KPI_{EP} is an energy efficiency metric that may be used to measure the work done by the network resources to deliver bytes of data between two points of the network. The equipment that makes up the network are important contributors to KPI_{EP}. As such, to aid in the selection and operation of the equipment making up the access network, metrics characterizing the energy efficiency of the individual pieces of equipment that make up the access network need to be defined. The intent of these metrics is to aid operators in evaluating equipment with respect to energy efficiency, as well as to be able to measure, benchmark, and evaluate equipment in operation with respect to its energy efficiency performance. Clause 6 of the present document provides a more detailed view of equipment KPI's specific to the CAN.

5.5 Hub and Data Centre Facility Sites

The data centers, hubs and headend facility physical structures that house the communications network equipment contribute to the energy performance of the access network as they consume energy in powering cooling, lighting, fault and monitoring equipment. The general engineering of these facilities and the interfaces for fault, management and monitoring equipment within the HFC distribution are factors that should be engineered such to optimize on power consumption to effect the overall energy performance of the access network.

With respect to the physical facilities themselves, the most common metric used to benchmark and assess energy efficiency in a facility is Power Usage Effectiveness (PUE). Mathematically, PUE is determined by dividing the amount of power entering a datacenter by the power used to run the computer infrastructure (defined as the equipment that is used to manage, process, store, or route data), with a perfect score being a 1, translated as 100 % efficiency or all power being used purely for computing activities.

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

Total Facility Power = the power measured at the utility meter - the power dedicated solely to the data site (and not offices). Includes cooling systems and power delivery units.

IT Equipment P*ower= the load associated with all of the IT equipment, such as compute, storage, and network equipment, along with supplemental equipment such as switches, monitors, and workstations used to monitor the datacenter.*

Although it can vary based on a number of factors, PUE for most data sites across various industries ranges between 1,5 - 2,5, meaning for every 1,5 - 2,5 watts of energy entering the facility, 1 watt is used to meet business computing needs, with the remaining 0,5 - 1,5 watts of energy used to provide for the cooling and lighting, as well as accommodate power supply inefficiencies, distribution losses, etc. It should be noted that in calculating KPI_{EP}, the non-IT equipment energy used to cool and light the facility is not included in the equation.

Use of PUE as a metric for critical facilities is well documented. KPI_{TE} as defined in ETSI ES 205 200-2-1 [i.17], if applied to an individual facility, is exactly the same as and would equal PUE for that facility. On a wider scale, the data center industry consortium Green Grid has published numerous papers on the subject of PUE, along with best practices for its measurement. The most recent of these publications not only added better definition to PUE, but also worked to harmonize and develop other data center metrics as noted in "Harmonizing Global Metrics for Data Centers Energy Efficiency, Global Taskforce Reaches Agreement Regarding Data Center Productivity," [i.18].

6 CAN Equipment Power Consumption Metrics

6.1 Usage of Power Consumption Metrics

As CMTS, E-QAM, and HE Optics equipment form the beginning of the Access Network PHY infrastructure, converting signals from the ethernet domain into bits that can be transported through the PHY layer of the access network, this clause will look specifically at those pieces of equipment. With respect to CMTS, E-QAM, and HE Optics, metrics currently being discussed for these devices focus on total amount of energy used in Watts per unit of functionality.

Use of such metrics is two-fold. Operators would like to develop standard metrics suppliers of this equipment will measure and publish as a part of their equipment specification. Publication of such metrics by suppliers would allow operators to compare and contrast suppliers equipment with respect to energy efficiency using standard energy metrics, just as they compare and contrast suppliers equipment with respect to cost, performance, etc. These metrics also can be used to measure energy efficiency of the equipment deployed in the field. In this sense, the metrics deployed equipment efficiencies that if summed with other deployed equipment efficiencies similarly defined and measured, could be added up to arrive at $KPI_{EP.}$

Following is a summary of current thinking with respect to these metrics.

6.2 CMTS Power Consumption Metrics

6.2.1 Metrics to Compare Supplier Equipment

The energy input into a CMTS is ultimately used to generate upstream and downstream DOCSIS channels which are connected to and transported thru the access network. The most widely and commonly deployed type of CMTS is the Integrated CMTS (I-CMTS). In this type of CMTS, the equipment is packaged in a single chassis located in a critical facility space. For this type of CMTS, the equipment energy efficiency metric is split into two parts, a metric for downstream channels, and a metric for upstream channels. Mathematically, the equation for this KPI would look like this:

$$KPI_{CMTSDS} = \frac{Total\ CMTS\ Chassis\ Power}{Maximum\ Number\ of\ DS\ Channels\ served\ from\ CMTS} = \frac{Watts}{Channel}$$

$$KPI_{CMTSUS} = \frac{Total\ CMTS\ Chassis\ Power}{Maximum\ Number\ of\ US\ Channels\ served\ from\ CMTS} = \frac{Watts}{Channel}$$

In both cases, Total Chassis Power represents the total power consumption of the I-CMTS chassis as determined by current and voltage measurements at the power entry point just outside the chassis, measured as part of the suppliers product testing.

Splitting the upstream and downstream for equipment energy metric is primarily done to help facilitate fair and proper comparison of supplier equipment, so that when comparisons are made, mix of channel types is not a variable in the metric. Use of maximum number of DS or US channels supported by the chassis is also done to facilitate comparison of supplier equipment, as it provides a common chassis fill for use in providing the metric. This combination of doing separate metrics of US and DS, each using the maximum number of channels to determine the metric, is considered the fairest way to make side-by-side comparison of different supplier CMTS equipment with respect to energy efficiency.

CMTS equipment has evolved over time, in particular separating out certain functions and distributing them to other parts of the network, as well as integrating those functions with other similar functions in the head-end. One evolution of the CMTS evolution focuses on separating the QAM's from the common elements in the CMTS. This type of CMTS is known as a Modular CMTS (M-CMTS). With respect to M-CMTS, block diagram of the structure is shown in Figure 7.

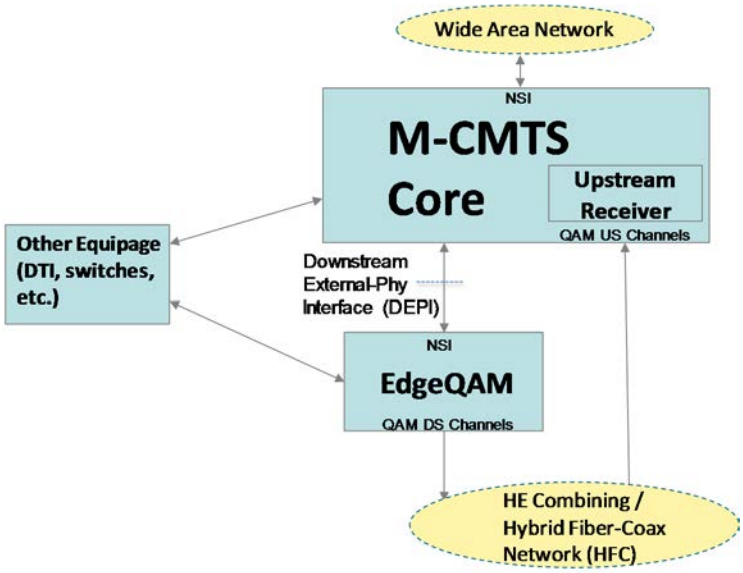

Figure 7: Structure of M-CMTS

The M-CMTS maintains a main chassis called a core module, but distributes functionality out of the core to separate other devices or "modules" which perform certain parts of the CMTS function. Because this structure of a CMTS looks different than the standard Integrated CMTS device, it only makes sense that M-CMTS should metrics specific to its own structure. M-CMTS metrics focus on an equipment KPI for each of the module types in an M-CMTS. Hence, there is a metric for upstream and downstream channels similar to the I-CMTS metric above, but only using the M-CMTS core power as the numerator. Metrics for the M-CMTS in essence are measured for each of the individual distributed elements which make up the M-CMTS, including the multi-purpose devices such as the Edge QAM (to be discussed later).

New and developing CMTS architectures continue on the theme of distributing parts of the CMTS as well as integrating CMTS QAM'S with other QAM's in the Head-end. One such new CMTS architecture, CCAP, has completed initial development and is in early stages of trial deployment. Energy equipment KPI's for CCAP are at this time still under development.

6.2.2 Metrics for Field Implementation

The above equipment metric focused on allowing operators to compare suppliers in a like-for-like manner with respect to energy efficiency. Simple extension of these concepts can produce metrics that work equally as well to characterize implementations in the field for potential benchmarking and comparison. Only difference is that instead of using "maximum" numbers of US/DS channels, metrics for field implementations would use actual number of US and DS ports deployed, and for simplicity sake add the US and DS together so that the metric looks at power per total number of ports. Mathematically, the field deployed metric would look like this:

$$KPI_{CMTS} = \frac{Total\ CMTS\ Chassis\ Power}{Sum\ of\ Deployed\ DS\ and\ US\ Channels\ served\ from\ CMTS} = \frac{Watts}{Channel}$$

For M-CMTS, similar metric would apply, just split between Core and Edge QAM as noted in clause above.

6.3 Edge-QAM Power Metrics

The energy input into an Edge-QAM is ultimately used to generate upstream and downstream MPEG Transport Streams as well as downstream DOCSIS channels, both of which are ultimately combined, connected to, and transported thru the access network. As such, the simplest energy metric for and Edge-QAM is the total power used by the Edge-QAM, divided by the downstream channels served by the by the Edge-QAM. In mathematical formation, the equation for this KPI would look like this:

$$KPI_{EQAM} = \frac{Total\ Edge{-}QAM\ Chassis\ Power}{Maximum\ Number\ of\ Downstream\ Ports\ served\ by\ the\ Edge{-}QAM} = \frac{Watts}{DS\ Port}$$

Similar to the I-CMTS metric, the above can be used to compare suppliers Edge-QAM devices. As with CMTS, if benchmarking and comparison of field implementations is desired, then "maximum" can be replaced with "deployed" in the denominator of the equation.

6.4 Head-end Optics - Transmitter Power Metrics

Optical transmitters in a head-end are either stand-alone devices mounted in racks, or modules placed in a chassis. The energy input is generally related to the number of transmitters being powered. As such, the simplest energy metric for and optical transmitters is the total power used by the stand-alone optical transmitters and/or the optical transmitter chassis, divided by total number of transmitters served by the chassis (if optical transmitter is stand-alone, then number served is one). With respect to transmitters, this is somewhat complicated by the fact that some transmitters now use CWDM technology to put multiple wavelengths down the same fibre from one transmitter device. To properly account for this, the metrics is split into two different metrics, one that deals specifically with single wavelength, 1 310 nm and 1 550 nm transmitters, and one that deals with CWDM based multi-wavelength transmitters. Mathematically, these two metrics look like this:

$$KPI_{TXSA} = \frac{Total\ Transmitter\ Chassis\ Power}{Maximimum\ Number\ of\ Transmitters\ Served\ from\ Chassis} = \frac{Watts}{Transmitter}$$

$$KPI_{TXCWDM} = \frac{Total\ Transmitter\ Chassis\ Power}{Maximimum\ Number\ of\ Wavelengths\ Served\ from\ Chassis} = \frac{Watts}{Wavelengths}$$

As with the other metrics, to use this with field implementations to benchmark and compare, one would replace "maximum" in the denominator with "deployed".

6.5 Head-end Optics - Receivers Power Metrics

Optical receivers in a head-end are either stand-alone devices mounted in racks, or modules placed in a chassis. The energy input is generally related to the number of receivers being powered. As such, the simplest energy metric for and Optical receivers is the total power used by the stand-alone optical receiver and/or the optical receiver chassis, divided by total number of receivers served by the chassis (if optical receiver is stand-alone, then number served is one). In mathematical formation, the equation for this KPI would look like this:

$$KPI_{RX} = \frac{Total\ Optical\ Receiver\ Chassis\ Power}{Maximum\ Number\ of\ Optical\ Receivers\ in\ Chassis} = \frac{Watts}{Receiver}$$

To use this with field implementations to benchmark and compare, one would replace "maximum" in the denominator with "deployed".

7 Power Metrics of Field Deployed Access Network Elements

7.1 Existing Energy Metrics for Field Deployed Equipment

Unlike the head-end elements of the access network, the field deployed equipment, there has been little development/discussion of specific energy related equipment KPI's for these devices. These elements have generally been out of scope for groups looking at energy efficiency in CAN's, and to date no other groups have taken up development of metrics specifically for this type of equipment. For their own purposes, individual operators have created ways to compare devices like these with respect to energy usage and energy efficiency. But by and large, standards bodies have not produced energy related KPI's for this type of equipment to date.

By extending energy metric concepts used for head-end standards work for related equipment (i.e. Head-end Optics, Head-end Launch Amplifiers, etc.) shown above, as well as accepted industry standards and practice in place for power suppliers, one can begin the process of defining equipment KPI's for energy efficiency for the field deployed devices. Following is a summary of the metric proposals surrounding this area.

7.2 OSP Power Supplies Power Metrics

With respect to power supplies, energy efficiency of power supplies has been well documented and generally made a part already of power supply specifications. Simply put, power supply efficiency is the ratio of power output from the supply for useful work, to the power input to the device. In mathematical terms, it looks like this:

$$KPI_{PS} = \frac{Output\ Power\ to\ Network}{Input\ Power\ from\ Grid} = Power\ Supply\ Efficiency\ in\ \%$$

Power supply efficiency is not a single number, but differs with load. As such, real comparison of efficiency between power supplies requires comparison of load curves, showing the efficiency of the power supply between no load and full load. A sample view of three different curves on a graph is shown in Figure 8.

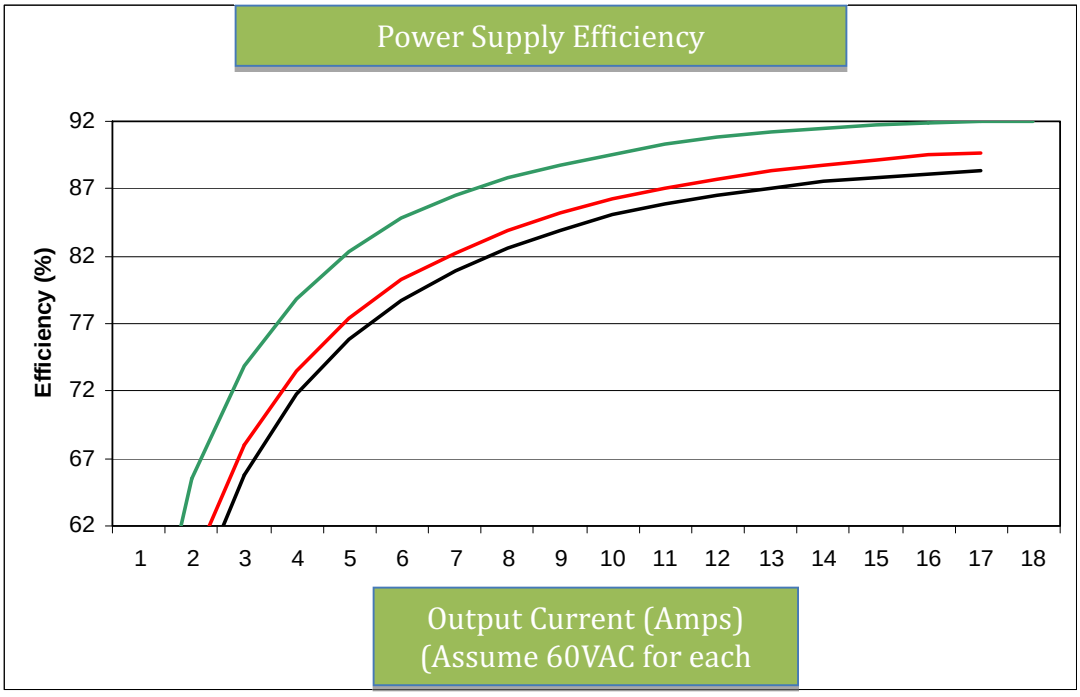

Figure 8: Power supply efficiency curves

The graph shows efficiency as a function of load current. Because in all three cases, the voltage for the supplies are the same (60VAC), efficiency as a function of current is the same as efficiency as a function true power load. As can be seen, comparison of these power supplies using this metric show that the PS represented by the green line is the most energy efficient, as it produces the best efficiency at each of the different output load (output current) levels.

As noted above, power supply efficiency is the common energy efficiency metric for power supplies, and comparison of efficiency curves the common way to determine device efficiency.

7.3 Fibre Node Power Metrics

As with the head-end optics, the energy input into a fibre node is ultimately used to power receiver inputs and transmitter outputs. Unlike the head-end, though, where transmitters and receivers are typically separate, the node physically combines transmitter and receiver. As such, an energy metric for the Fibre Node uses a combination of the total optical receivers and transmitter wavelengths as a reference. The simplest energy metric for the Fibre Node, then, is the total power use, divided by the sum of the receiver and transmitter wavelengths. In mathematical formation, the equation for this KPI would look like this:

$$KPI_{FN} = \frac{Total\ Fibre\ Node\ Power}{Total\ Number\ of\ Transmitter\ and\ Receiver\ Wavelengths} = \frac{Watts}{Wavelengths}$$

Although this equation is fairly straight-forward and a good starting point to work from, in some ways it does not fully characterize a Fibre Node with respect to power. This is because in addition to optical transmitters and receivers, fibre nodes differ in what other elements of the network they might include within the node case. In particular, nodes output RF (as well as pass AC power) to the HFC network, and differ as to how much power a node launches. This can impact total fibre node power by making it greater, making this metric worse. But because a higher launch RF power from a node can possibly eliminate an RF amplifier in the network, it is possible that it is the right thing to do from an access network energy efficiency point of view. Until future work on this metric can provide for accommodation of energy consuming parts of the node that are not transmitter or receiver related, one should take care to insure comparison of "like for like" when using this metric.

7.4 RF Amplifiers Power Metrics

The energy input taken in by an RF amplifier is ultimately used to drive output signals through output ports in the device. As such, the useful work of an amplifier can best be characterized by the total output power it launches into its output port(s). To calculate this, the maximum RF power per port is taken and multiplied by the total number of output ports in the device. Measurement of output power is typically in dBmV or dBµV (dBmV = dBµV - 60). In mathematical formation, the equation for this KPI would look like this:

$$KPI_{RFAMP} = \frac{Total\ Amplifier\ Power\ Dissipation}{Total\ Output\ Power\ Available\ from\ all\ Output\ ports\ (in\ dbmV)} = \frac{Watts}{dbmV}$$

Use of such a KPI can allow for proper comparison of RF amplifier devices with respect to energy efficiency.

7.5 Passives and Cable

The remaining access network elements are passive devices (i.e. splitter, couplers, taps, etc.) and coaxial cable. Because these devices are not "powered" devices, but simply create power loss in the path between REF_{HE} and REF_{NIU}, they are not looked at as candidates for energy efficiency equipment KPI's. Instead, one would suggest that for each of the elements, simple comparisons be made with respect to the loss created by like-for-like comparable devices. For coaxial cables, cable loss is generally defined at dB per meter (or per 100 m) of cable, at specific frequencies. The cable with the lower loss at relevant frequencies is the more energy efficient cable.

With respect to splitter and taps, they typically come with a defined loss (i.e. two-way splitter starts with 3 dB loss), so best thing to do is to make a like-for-like comparison between common split ratios and/or tap size. The device with the lowest lesser dB total loss is the more energy efficiency device.

8 Improving Energy Efficiency in the Access Network

8.1 Concept of Benchmarking

In the critical and non-critical facilities world, industry has for number of years been benchmarking energy efficiency for buildings. Metrics such as PUE in the critical facility realm, and EUI in the non-critical facility world, have been used to benchmark and measure energy efficiency. Companies use this benchmarking to help them target improvement projects to the worst performing facilities, as well as to measure and monitor improvement as those project progress and/or complete. The nature of energy efficiency projects in facilities, whilst still developing and improving, is generally well understood. Improving PUE in critical facilities is typically about improving the HVAC/cooling infrastructure. Improving EUI in non-critical facilities is a combination of infrastructure related projects (i.e. lighting, HVAC, sensors, etc.) and behavioural changes (turning off lights, devices not in use, etc.).

Probably the main reason facility energy efficiency benchmarking and improvement work is reasonably mature is that almost every industry across the business continuum have non-critical facility space, with many of them in today's world also having data centres and/or other types of critical facilities housing IT equipment. As such, a lot of people have been working on this issue over the last decade.

Being the domain generally of only telecom and CATV operators, the access network has had less attention with respect to energy efficiency. Partly that is because there has been little or no look and/or analysis of the access network with respect to how best to characterize and/or benchmark it, and partly because improvement actions associated with improving access network metrics are costly and long term in nature, and hence not worth spending time on. But with the growing OSP power bill for their networks, Operators are looking again at energy efficiency in the OSP network.

8.2 Plant Benchmarking

Access networks in HFC are built and designed to find the most economic and efficient way to lay the cable, active, and passive elements to get service to customers. HFC access networks are designed typically using the access network equipment discussed in clause 4 of the present document (i.e. fibre nodes, RF amplifiers, coaxial cable, taps and splitters, etc.).

Although all the equipment elements in the access network in some way drive power usage, the amount of power used by the devices is part of a careful design exercise, that ultimately places those devices as needed to support the lengths of fibre cable needed to appropriately locate a fibre node such that it feeds a pre-determined number of potential customers, as well as the lengths of coaxial cable needed to reach all the potential customers served by the node. As such, the most appropriate benchmark to characterize a complete access network is the total access network watts divided by the kilometres of fibre and coaxial cable in the access network. Mathematically, this looks like:

$$KPI_{ANTOT} = \frac{Total\ Watts\ used\ across\ a\ particular\ Access\ Network\ Geography}{Linear\ Kilometres\ of\ Fibre + Coaxial\ Cable\ in\ the\ Access\ Network\ Geography}$$

For historical reasons and from past practice, Operators generally characterize the density of their networks using a simple metric of Homes Passed/Serviceable by the network divided by the number of kilometres. Although not specifically an energy related KPI for the present document, mathematically this metrics looks like this:

$$Homes\ Passed/Kilomtre = \frac{Total\ Number\ of\ Homes\ Passed\ in\ an\ Access\ Network}{Linear\ Kilometres\ of\ Fibre + Coaxial\ Cable\ in\ the\ Access\ Network}$$

In theory, for a high level metric like this, plant geographies with equal plant densities should have similar plant characteristics and similar energy efficiency characteristics.

Benchmarking operator access network using this metric, and/or benchmarking geographic regions and/or operating areas within an operator can help operators understand at a very high level where their access network is performing well, and where it may be performing not as well. For the purpose of example and discussion, Table 1 shows a sample comparison of this metric between regions in an Operator.

Table 1: Sample Access Network Metric Comparison between Regions in an Operator

	Homes Passed per Km of fibre/coax	Access Network Power per Km of fibre/coax
Region A	57	144
Region B	53	150
Region C	44	131
Region D	76	168
Region E	38	141
Region F	49	112

Comparing one region to another, one can see that Region F performs quite well in comparison to it the other regions, utilizing 20 - 30 % less power per kilometre of plant, and ~50 % less power per kilometre of plant then Region D. Interestingly, Region B and Region F have the same density in Homes Passed per Kilometre, which would imply that their network should roughly close to the same with respect to power usage, but in fact there is almost a 30 % difference in the two regions with the same density.

Benchmarking in this way does not by itself improve energy efficiency. What it does do is start the process of an operator understanding where issues might exist, so that precious resources can be focused in the right areas where the most benefit can be attained. It may be quite possible that there are good explanations to the differences between these areas that an operator may have to live with, because access network energy efficiency is typically not either easy or inexpensive. But having these simple benchmark metrics for one's access network is a simple way of starting the process of moving forward smartly in evaluating and improving access network with respect to energy efficiency.

Once one has the metrics in place, and can see where opportunity might exist to make improvements in access network performance as it relates to energy efficiency, the next question is "what can be done about it?" The following clauses discuss methods operators can use to improve energy efficiency in access network.

8.3 Mechanisms for Improving Access Network Energy Efficiency

8.3.1 Power Supply Loading

When looking at a full access network in a geographic area or region, an important part of the analysis includes looking at the power supply loading of the OSP power supplies in the network. Because as noted in clause 4, power supplies work more efficiently the closer they are operated to full load, the efficiency of an access network can be positively or negatively affected depending on how fully loaded on average the power supplies are in the network, and the distribution of load between the power supplies.

For illustrative purposes, Figure 9 shows a sample power supply distribution by power supply load.

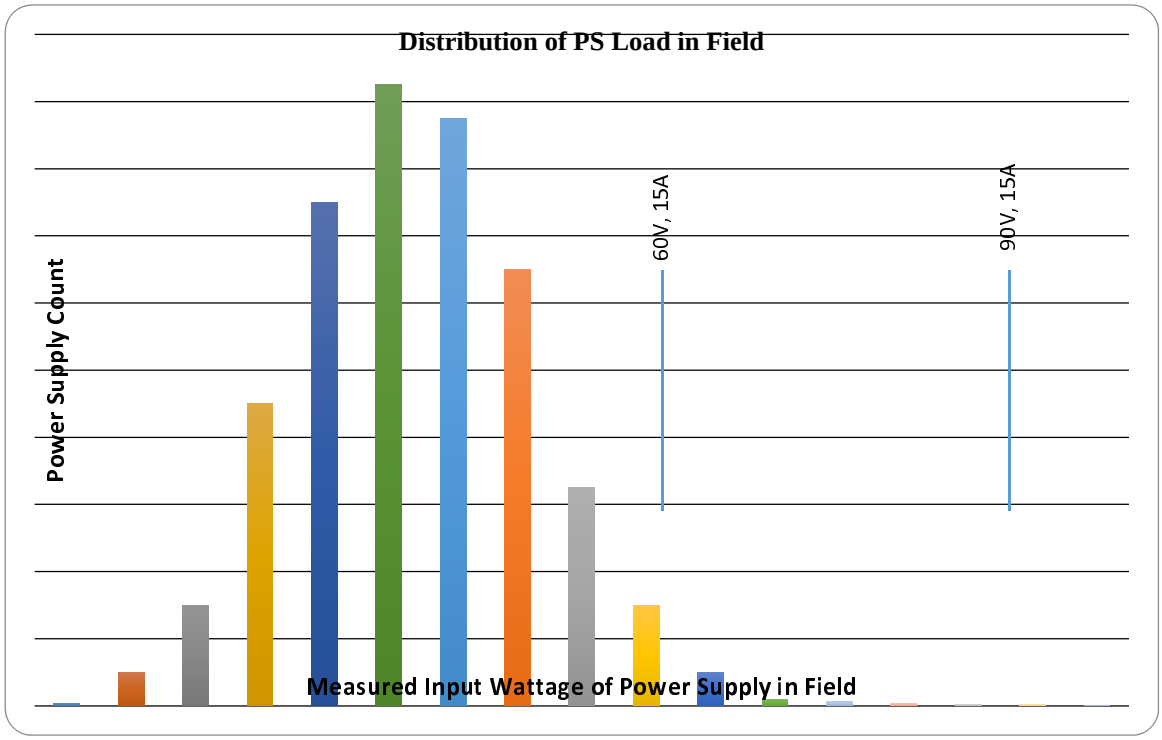

Figure 9: Power Supply Input Power Distribution

As can be seen, power supply distribution in an access network looks like a standard bell curve. Average input power (i.e. the median input power value) is 593 W, average output current is 7,1 A across all power supplies. Noted on the graph are full load amount for the two types of power supplies used in this illustrative operator example. These full load amounts represent:

- 60 V, 15 A for a nominal power of 900 W.
- 90 V, 15 A with nominal power of 1 350 W.

Referring back to the discussion of Power Supply efficiency as a function of load (clause 4), while power supply efficiency is relatively flat for higher load percentages, it drops off rapidly at the lower end. Ideally, power supplies for mature and stable systems should be operated at ~75 - 80 % of rated load to provide optimum efficiency with room for minor load growth, and in fact this is a target many operators aim for. In the illustrative example using the power supply distribution in Figure 9, the average power supply loading for this operator is 47 %. Using the curve in Figure 10, this places average supply efficiency across the whole of the plant at 82 %. At 10oads in excess of 75 % of rating, ferro-resonant power supplies achieve efficiencies of around 89 % to 90 %. Consequently, if efficiency was brought up to the nominal 89 %, the operator would save 7,9 % of all outside plant kWh power requirements.

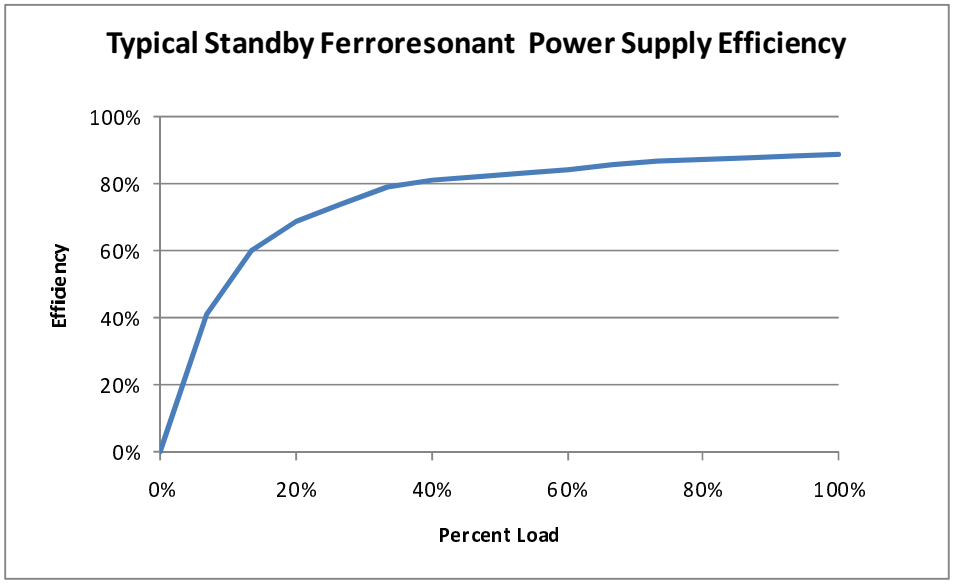

Figure 10: Ferro-resonant Power Supply Efficiency Characteristics

8.3.2 Improving Load with better Power Supply Selection

Power supply loading and efficiency are inexorably linked. Achieving a higher utilization can be achieved by substituting a lower rated supply for the given loading or by increasing the load on a given supply.

Selection of proper power supply size can have a significant impact on access network power supply efficiency. This typically can be an important consideration for operators considering regular replacements or new build purchases. As an example of the impact this can have for the illustrative power supply distribution shown in Figure 9, using a desired loading of 80 % of nameplate rating, Table 4 provides potential view of what could be done power supply distribution against and ideal distribution using the current 15 A supply and a fictitious 10 A power supply.

Table 2: Power Supply Distributions - Actual vs. Optimal

Power Supply Rating	Ideal Distribution	Actual Distribution
10 A	73 %	0 %
15 A	27 %	100 %

The installed capacity as summarized in Figure 9 indicates a significant overdesign, and that in fact, a large number of the power supplies could be smaller in size with no impact on access network service capability. Note that for a ferro-resonant power supply, operation at reduced load does not significantly (if at all) improve on the life span, as the power flow during normal operation is via the passive transformer stage only. Rather, overdesign manifests itself in higher purchasing cost and increased operating expense.

While it is advantageous to minimize the number of power supplies as much as practical and utilize the rating of the existing infrastructure as much as possible, the reality in today's plant environment is a trend to an increased number of supplies with lower output currents. Choices of lower rated supplies have been entering the market and several ratings below 15 A are available. Based on estimates summarized in Table 2, 73 % of the sample operator's plant could be covered with smaller 10 A power supplies running closer to full load.

Even though current in-service power supplies may have low operating efficiency, energy savings on their own may not produce a justifiable ROI for replacement of existing hardware. As new purchases are required for other reasons (e.g. failure replacement, build out, plant upgrade), lower rated devices can be phased in. Benefits are not only increased operating efficiency, but also lower procurement costs. Table 3 summarizes estimate of power supply manufacturing cost for various ratings.

Table 3: Power Supply Ratings and Manufacturing Cost Estimates

Power Supply Rating (A)	Cost
15	100 %
10	75 - 85 %
8	65 - 75 %

The combination of efficiency savings with proper loading (and the lower procurement cost for lower rated power supplies may provide sufficient ROI to accelerate future plant upgrade projects by one or more years.

Obviously, substituting a new power supply (say rated at 8 or 10 A) in the existing plant simply for efficiency's sake is only economical when an existing power supply requires a repair or is close to end of life. Otherwise, it is not economically viable given the level of annual savings noted above by the efficiency improvement. A load increase can be affected by changing the powering infrastructure such that each power supply covers a larger portion of the coax network and a larger number of actives. Options to achieve this include, but are not limited to, the use of power feeders, powering across nodes and, in voltage limited situations, the use of in-line booster supplies. This approach does not require significant capital outlay, if any, but is labour intensive from a design and implementation point of view.

While this discussion addresses existing plant, for any new installations or plant upgrades, one would recommend careful considerations of power supply loading to maximize operational efficiency.

8.3.3 Power Supply Consolidation

In addition to presenting an opportunity for potential replacement and right-sizing, lightly loaded supplies also present an opportunity for potential consolidation and elimination. In looking at the graph in Figure 9 showing input power distribution, 8 % of all supplies are loaded to less than approximately 2,5 A. Likely, only a portion of the 8 % of lightly loaded supplies will be candidates for consolidation and the resulting benefit is unlikely to nudge the efficiency of the plant much. Still, such a program also has the benefits of saving monthly utility connection fees and lowering operational expenses, such as maintenance visits and replacement battery purchases.

When consolidating a supply, in some cases, increased coax losses will negate some of the benefits. Given that the energy balance is entirely dependent on local characteristics and geography (power supply loading, distance between supplies, cable type employed), it is not possible to provide a simple scenario for energy savings when eliminating a power supply. Detailed design investigations have to be made for individual installations, beginning with the most lightly loaded supplies.

Implementing a power supply consolidation program will require operational investment and the utility based savings alone do not provide significant ROI. The viability of each case will need to be evaluated separately based on the surrounding circumstances of geography and plant architecture. However, reducing the number of power supplies yields other operational and capital benefits, including purchasing savings on replacement power supplies and batteries.

If a situation exists to potentially makes changes to the access network (for upgrade reasons, new build, etc.), a careful review of design guidelines should be performed going forward in order that the low utilization rate is not proliferated. Some recommendations in this regard are as follows:

- For mature areas, design the power supply load to 75 - 85 % of rating. Do not leave unnecessary safety margin.
- Review and calibrate design program outputs to ensure powering requirements are accurately portrayed.
- When splitting a node, avoid the installation of a second power supply and cross power the nodes. However, consider the number of exposed customers in the case of a power supply failure.
- In voltage limited, long distance situations, consider the use of a line extending, booster power supply rather than creating a new utility connection. This will save the annual fixed utility fee without overly impacting efficiency.
- Minimize utility connections and thus the number of power supplies (within the constraint of keeping coax losses reasonable).
- For new construction, consider efficiency when specifying coax to minimize DC loop resistance.
- For new construction or replacements, consider the efficiency of line equipment, such as amplifiers.

- Given that the ratings of the predominant 15 A power supply is not utilized (see Figure 9) consider substituting a lower rated supply (e.g. rated at 10 A) during future replacement cycles.

- Utilize status monitoring (where available) and utility data to periodically evaluate power supply loading and take appropriate action.

8.3.4 Plant Voltage and Distribution Losses

There will be an efficiency benefit in upgrading the remainder of the plant to 90 V. Operating at 60 V leads to relatively high line currents, leading to higher losses in the coax infrastructure. In a typical plant, the overall power supply and coax copper losses is approximately 50 % of the total outside plant energy requirement. If the remaining plant is upgraded to 90 V, the average line current will decrease, decreasing I^2R losses in the plant. By some estimates, moving a plant from 60 V to 90 V can achieve between 10 - 15 % savings in access network electricity.

From a powering perspective, capital outlay for a 90 V migration may be minimized by the fact that many of the newer power supplies observed in the plant likely are already capable of operating at 90 V. Most power supply manufacturers have moved away from dedicated 60 V units for the North American market and a large percentage of the installed power supply base likely is operated on a de-rated 60 V output tap, essentially not using 33 % of a unit's VA rating. A major consideration in the ROI calculation for an upgrade project will be the compatibility of the existing actives with a 90 V supply voltage.

8.3.5 Access Network Equipment Improvement

Power supply manufacturers have recently introduced high efficiency versions of the traditional ferro-resonant cable power supplies. These units incorporate a transformer which utilizes special magnetic materials and configurations to reduce losses in the magnetic circuit. Some of these magnetizing losses are fixed, i.e. not proportional to load. Consequently, these high efficiency supplies improve efficiencies not only at rated load, but proportionally even more at lower loading points. A typical high efficiency power supply improves efficiency by around 2 % for loads between 50 and 100 % and 3 % between 25 and 50 % load. This by itself does not typically warrant direct replacement of existing power supplies purely for operational cost savings associated with lower electricity costs, but should be taken into account when replacing defective and/or older supplies, as well as for new build.

Manufacturers of amplifiers have begun to pay more attention to equipment efficiency, lowering the input current requirement. As with high efficiency power supplies, amplifier replacement for efficiency purposes alone is not warranted. The information provided can be used to determine the maximum allowable purchasing premium for high efficiency amplifiers when considering a purchase for new builds or upgrades.

9 Calculation of data throughput

9.1 Parameters Impacting Data Throughput

Energy efficiency of telecommunication access network, no matter whether it is a fixed broadband DSL access network, mobile access network, or fixed broadband cable access network, can be measured with an energy performance indicators as introduced in ETSI ES 205 200-2-4 [i.16] and within the present document. The energy performance measures the data throughput per energy consumed. In literature an inverse indicator of energy consumption per data entity sometimes is also used.

Discrepancies in the "kind" of transmission technology are one of the difficulties when comparing different network technologies and architectures. Network technologies differ for example in:

- the capability of a true return channel allowing a bidirectional communication, which is not given for broadcast technology;

- or the necessity of being constantly online, which is e.g. necessary for telephone devices.

Industries have progressed in designing power saving modes particularly for mobile devices, as low energy demand expands the usage period before recharging - contributing for both energy savings as well as customer convenience.

For fixed broadband DSL access networks, the data throughput (up- and download) can be measured and put into relation with the energy consumption. For cable access networks this can be done as well for the IP based services. But the data delivery of broadband services needs to be adjusted. Reason for this is the fact that broadcast video bits are only defined as consumed if at least one CPE device connected to the REF_{NIU} is either displaying or recording the video bits. In order to compare the energy efficiency only the actually delivered or consumed bits should be accounted for whereas all the other "potentially" delivered TV signals should not be accounted.

To calculate the actually delivered data throughput of a broadcast signal three additional parameters have to be considered:

- Types of channels delivered to customers.
- Assumed bit rates for delivering those channels.
- Amount of viewing time a customer is watching the different types of channels.

9.2 Types of channels delivered to customers

Broadcast video in HFC is carried using three different types of channels, standard definition (SD) high definition (HD) and analogue channels. SD and HD channels will have bit rates based on a number of factors. This differentiation is important as the television channel types differ considerably in demand of bandwidth. Furthermore, in order to optimize their available spectrum, cable access network providers change the type of channel delivery (HD or SD, analogue channels are about to disappear) and optimize their channel distribution constantly.

9.3 Assumed bit rates for delivering those channels

It can be assumed that the average bit rate across all SD channels ranges typically between 3 - 5 Mb/s (BR_{SD}) and an average across all HD channels ranges typically between 12 - 13 Mb/s (BR_{HD}). With respect to analogue channels, as they deliver something similar to an SD quality signal to subscribers, for the purposes of these calculations, the bit rate assigned to an analogue channelBR_{ANA}, is the same as the average bit rate across all SD channels (i.e. $BR_{ANA} = BR_{SD}$.)

How many television channels can be bundled in a transmission channel depends on the QAM modulation as well as the bandwidth used. Taking the values for data rates for DOCSIS Upstream channels of Table 3 in ETSI ES 205 200-2-4 [i.16], the amount of SD and HD channels which can be transmitted under the actual modulation standard can be calculated. These standards differ from region to region.

Table 4 describe the amount of televisions channels which can be bundle in a transmission channel of a specific QAM modulation and bandwidth (it was assumed that 4 Mb/s is the bitrate for SD and Analogue channels and 12,5 Mb/s HD channels).

Table 4: Amount of televisions channels which can be bundle in a transmission channel of a specific QAM modulation and bandwidth

SD channel/ transmission channel		Bandwidth (MHz)				
		2	4	6	8	10
Modulation	16QAM	1,6	3,2	4,8	6,4	8,0
	32QAM	2,0	4,0	6,0	8,0	10,0
	64QAM	2,4	4,8	7,2	9,6	12,0
	128QAM	2,8	5,6	8,4	11,2	14,0
	256QAM	3,2	6,4	9,6	12,8	16,0

HD channel/ transmission channel		Bandwidth (MHz)				
		2	4	6	8	10
Modulation	16QAM	0,5	1,0	1,5	2,1	2,6
	32QAM	0,6	1,3	1,9	2,6	3,2
	64QAM	0,8	1,5	2,3	3,1	3,8
	128QAM	0,9	1,8	2,7	3,6	4,5
	256QAM	1,0	2,1	3,1	4,1	5,1

9.4 Amount of viewing time a customer is watching the different types of channels

The average television use per time is generally measured by surveys of national statistic offices, ministries of telecommunication or similar institutions. These consumptions patterns vary from region to region and are also expected to change considerably over time. Experts generally agree that traditional linear television consumption (as delivered by broadcast signals) will decrease whilst non-linear television demand (as VOD, video streaming, time shifted TV use etc.) will increase.

Network providers have generally a good knowledge of the viewing time of their customers. Hence, the average television use (in minutes or seconds) should be distributed over the television channels offered by the provider.

This leads to an effective data transmission rate of broadcast signals which can be calculated as follows:

$$Broadcast\ data\ transmission_{effective} = (data\ rate\ of\ an\ SD\ channel\ * viewing\ time\ SD) + (data\ rate\ of\ an\ HD\ channel\ * viewing\ time\ HD) + (data\ rate\ of\ an\ analogue\ channel\ * viewing\ time\ analogue)$$

The energy performance KPI of the broadcast services are calculated as indicated in clause 7.1.3 Energy Performance KPI of the ETSI Standard [i.16]. As a fraction of entire KPI, the energy performance KPI of the broadcast services can be calculated as follows:

$$KPI_{EP_broadcast} = \frac{Broadcast\ data\ transmission_{effective}}{total\ power\ per\ broadcast\ NIU\ connection\ during\ one\ hour} = \frac{GB}{kWh}$$

History

Document history		
V1.1.1	March 2015	Publication