ETSI TR 103 352 V1.1.1 (2016-06)

TECHNICAL REPORT

**Satellite Earth Stations and Systems (SES);
Energy efficiency of satellite broadband network**

Reference
DTR/SES-00344

Keywords
broadband, energy efficiency, environment, LCA, satellite

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Sous-Préfecture de Grasse (06) N° 7803/88

Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

Modal verbs terminology

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Introduction

Up until now, broadband services have mainly been provided using fixed (VDSL or optical) or mobile (3G or LTE) networks. However, satellite networks are now becoming able to provide broadband services of similar bandwidth and response times to those from terrestrial networks, especially with the introduction of new hybrid satellite networks where alternative paths can be selected depending on the bandwidth and response times required. It is therefore useful to be able to assess the energy efficiency of satellite networks and compare this on an equivalent basis to the energy efficiency of terrestrial networks.

Energy efficiency is also a growing concern in the design of satellite networks and there are increasing efforts to minimize the energy consumption of SatCom systems, especially in the ground segment where most terminals have been designed to operate on an always-on basis. By carrying out an assessment of the energy efficiency of a satellite network, the subsystems and components that have the most impact can be identified and attention paid to reducing their energy consumption. In particular, given the relatively large numbers of satellite terminals in operation, their impact can be identified compared with that of the other subsystems and appropriate measures taken to improve their energy efficiency.

1 Scope

The present document reviews the assessment of energy consumption during the operational phase of satellite networks, and identifies whether additions are required to the general assessment methodology developed in ETSI TS 103 199 [i.10]. It also reviews the energy efficiency related metrics developed for terrestrial wireless and mobile networks in ETSI TR 103 117 [i.7] and identifies any necessary adaptations to enable the methodologies to be applied to satellite networks.

Satellite Networks allow broadband services to be delivered to approaching 100 % of the population, even in remote areas, and can therefore be used to fill gaps in the coverage of other access technologies. Broadband services can be offered to residential or business customers via satellite in a cost effective manner compared to other methods of services provisioning. However, their energy consumption needs to be assessed and compared with other ways of delivering broadband services.

2 References

2.1 Normative references

As informative publications shall not contain normative references this clause shall remain empty.

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 referenced 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] Code of Conduct on Energy Consumption of Broadband Equipment, EC Joint Research Centre, Version 4, 10 February 2011.

[i.2] Code of Conduct on Energy Efficiency of Digital TV Service Systems, EC Joint Research Centre, Version 8, 15 July 2009.

[i.3] Code of Conduct on Energy Efficiency of External Power Supplies, EC Joint Research Centre, Version 4, 8 April 2009.

[i.4] The Green Grid Consortium.

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

[i.5] Data centre Metrics Task Force: "Recommendations for Measuring and Reporting Overall Data centre Efficiency", May 2011.

[i.6] The GreenTouch Consortium.

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

[i.7] ETSI TR 103 117: "Environmental Engineering (EE); Principles for Mobile Network level energy efficiency".

[i.8] ETSI ES 203 228: "Environmental Engineering (EE); Assessment of mobile network energy efficiency".

[i.9] EC FP7 ICT EARTH research project deliverable D2.3: "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown".

[i.10] ETSI TS 103 199: "Environmental Engineering [EE]; Life Cycle Assessment (LCA) of ICT equipment, networks and services; General methodology and common requirements".

[i.11] ISO 14044:2006: "Environmental management-life cycle assessment - requirements and guidelines".

[i.12] ETSI ES 202 336: "Environmental Engineering (EE); Monitoring and Control Interface for Infrastructure Equipment (Power, Cooling and Building Environment Systems used in Telecommunication Networks)".

[i.13] IEC 60038 Edition 6.2 2002-07: "IEC standard voltages".

[i.14] ANSI C84.1-2011: "American National Standard for Electric Power Systems and Equipment - Voltage Ratings (60 Hertz)".

[i.15] ETSI ES 201 554: "Environmental Engineering (EE); Measurement method for Energy efficiency of Mobile Core network and Radio Access Control equipment".

[i.16] EC FP7 Project BATS (Broadband Access via Integrated Terrestrial and Satellite Systems) Deliverable D5.2: "Cost Benefit Analysis".

NOTE: Available at http://www.batsproject.eu.

[i.17] EC FP7 Project BATS (Broadband Access via Integrated Terrestrial and Satellite Systems) Deliverable D5.3: "Energy Efficiency".

NOTE: Available at http://www.batsproject.eu/.

[i.18] Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council.

[i.19] 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.

[i.20] Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

[i.21] European Parliament COM(2009) 7604 2009/2228(INI): "Mobilising Information and Communication Technologies to facilitate the transition to an energy-efficient, low-carbon economy".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

cut-off: threshold below which part of a product, service or system can be considered insignificant and need not be considered by a LCA

energy consumption: amount of consumed energy

energy efficiency: relation between the useful output and energy consumption

3.2 Symbols

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

A_{SN}	Coverage Area of a Satellite Network
ECI	Energy Consumption Index
$ECI_{P/A}$	Energy Consumption Index (Power per Unit Area)
$ECI_{E/B}$	Energy Consumption Index (Energy per Bit)
N_{SG}	Number of Satellite Gateways
N_{ST}	Number of Satellite Terminals supported (by a satellite network)
P_{SG}	Power consumption of a Satellite Gateway
P_{SN}	Power consumption of a Satellite Network
P_{ST}	Power consumption of a Satellite Terminal
T_{SN}	Throughput of a Satellite Network

3.3 Abbreviations

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

3G	Third generation telecom networks
AC	Alternating Current
CoC	Code of Conduct
DC	Direct Current
EC	European Commission
EU	European Union
FP7	EC 7^{th} R&D Framework Programme
GHG	Green House Gas
ICT	Information and Communication Technology
ING	Intelligent Network Gateway
ISO	International Organisation for Standardization
IUG	Intelligent User Gateway
kbps	Kilobit (1 000 bits) per second
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LTE	Long Term Evolution
Mbps	Megabit (1 000 kilobits) per second
MW	Mega Watts
PUE	Power Usage Effectiveness
QoE	Quality of Experience
RF	Radio Frequency
SN	Satellite Network
STB	Set Top Box
Tbps	Terabit (1 000 Gigabit) per second
TV	TeleVision
US	United States
VDSL	Very-high-bit-rate Digital Subscriber Line

4 Requirements arising from relevant policies/legislation

European Member States have committed themselves to reducing GHG emissions by 20 %, increasing the share of renewables in the EU's energy mix to 20 %, and achieving a 20 % energy efficiency target by 2020. The European Roadmap for Moving to a Competitive Low Carbon Economy in 2050 notes that the EU is currently on track to meet two of those targets, but will not meet its energy efficiency target unless further efforts are made.

In COM(2009) 7604 [i.21], the EC notes that "*the use of ICT equipment in the delivery of services represents about 1,75 % of carbon emissions in Europe; a further 0,25 % of carbon emissions come from the production of ICT and consumer electronic equipment. As the range and penetration of ICTs increase, their overall energy use is growing*". The Communication went on to recommend the ICT sector set itself an energy reduction target.

In line with this policy landscape, the European Union has issued a number of directives to foster energy efficient design of products:

- Directive 2005/32/EC on 6th July 2005 [i.18] establishing a framework for the setting of eco-design requirements for energy-using products.
- Directive 2009/125/EC on 21st October 2009 [i.19] establishing a framework for the setting of eco-design requirements for energy-related products.
- Directive 2010/30/EU on 19th May 2010 [i.20] on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

In parallel with this, the EU have defined a series of voluntary Codes of Conduct (CoC) which specify annual targets for reductions in electricity consumption of different types of equipment. The CoCs relevant to satellite broadband networks are:

- CoC on Energy Consumption of Broadband Equipment [i.1]:

  This sets targets for reducing the energy consumption of equipment such as broadband modems and home gateways. Equipment on both the consumer side (end-use equipment) and the network side (network equipment) is covered for any service providing a two-way data rate of 144 kb/s or above. Several operational states are defined for each type of equipment (e.g. full load, low load and standby) with typical targets of 0,3 W for a fast ethernet port in the idle state, reducing to 0,2 W in 2013-2014.

- CoC for Digital TV Systems (Set-Top Boxes) [i.2]:

  This covers complex set top boxes (STBs) and similar equipment for the reception, decoding, recording and interactive processing of digital TV and related services accessible through a Conditional Access system. This gives targets for annual energy allowance of 60 kWh/year for a Satellite STB, falling to 53 kWh/year on 1 January 2013. There is pressure from regulators to reduce the target for power consumption of STBs to < 1 W in standby.

- CoC on Energy Efficiency of External Power Supplies [i.3]:

  This is referenced by the above CoCs in the case where the equipment has an external power supply, and targets for the energy consumption for these are set here. It covers single voltage external ac-dc and ac-ac power supplies, including AC adapters, battery chargers for mobile phones and IT equipment, in the output power range 0,3 W to 250 W.

Some parts of the ICT industry have already developed standardized energy related performance metrics.

- The data centre industry (for example through Green Grid [i.4] has defined Power Usage Effectiveness (PUE), an energy efficiency metric that measure the total energy of the data centre divided by the IT energy consumption. A typical legacy data centre would have a PUE of about 2. In this case for each Watt-hour consumed by the IT system, an additional Watt-hour is consumed to cool or distribute the electricity to the IT system. When all the energy is used for the IT system, then the PUE is close to 1 (see Green Grid consortium). There is now an agreement [i.5] between major data centre industry bodies and the US, EU and Japanese governments on the composition and measurement of PUE.
- The telecom industry has established a number of consortia such as GreenTouch [i.6] to reduce the carbon footprint of telecom devices, platforms and networks. ETSI have produced ETSI TR 103 117 [i.7] to define metrics for the energy efficiency of mobile broadband networks at both equipment and network level. Further work at ETSI has been recently published in ETSI ES 203 228 [i.8] based on the FP7 ICT Earth project results [i.9].

5 Energy Efficiency in context of Satellite Network

5.1 Scope and Boundaries

Only the power consumed during the operational lifetime of a satellite network is considered here.

Figure 1 shows the main components of a 2 way service satellite network architecture (e.g. broadband) with:

- The satellite composed of the payload and the platform.
- The satellite terminals composed of the antenna system (dish), the RF part (Power Amplifier, Low Noise Amplifier and filters) and the modem implementing the base band processing of the satellite radio interface.
- The satellite gateway that includes both a Network Control Centre to manage the in orbit radio resources and a Gateway with its antenna system, the RF part, a set of modems.

The Network Control Centre is not shown here and the power consumption is ignored under cut-off rules.

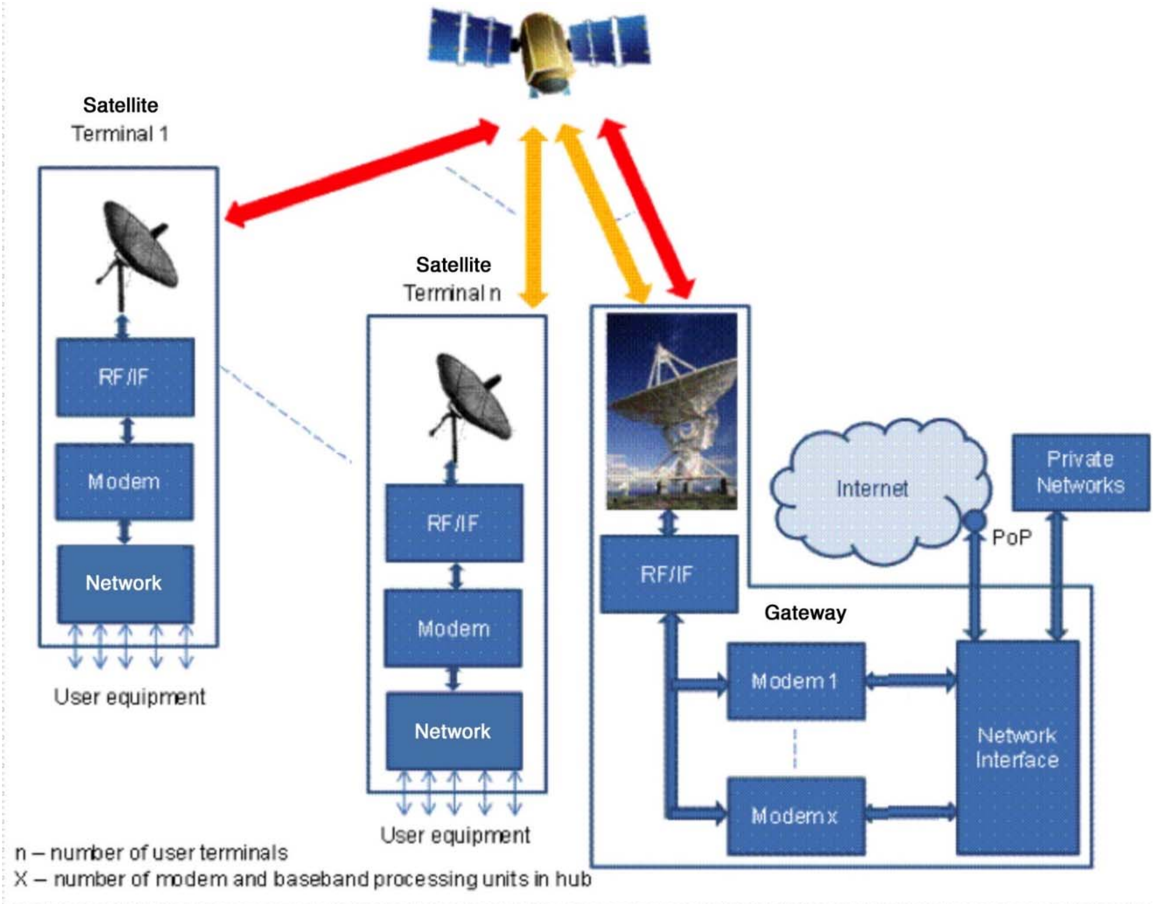

Figure 1: 2 way service satellite network architecture (e.g. Broadband)

The power consumption of a satellite network during its use is the sum of the power consumption of all subsystems and equipment included within the boundary of the system under investigation (figure 1). The network power consumption per operator is the sum of the power consumption of the satellites, satellite control centres, gateways and terminals under the control of the operator that are used to provide the service.

There are many ways to reduce the electricity consumption including energy saving mechanisms, energy efficiency technologies and energy efficient installation/set-up.

In order to foster the SatCom industry to research and develop energy saving features and technologies for satellite terminals, it is proposed to develop a standardized set of terminal modes and a Standardized measurement method to characterize the energy efficiency of satellite network, in priority geostationary satellite broadband network. The following modes are standardized for the satellite terminal so that comparable measurements of power consumption can be made in each:

- Full activity mode: Terminal transmission and reception at maximum service rate.
- Receive only mode: Terminal reception possible at maximum service rate but not transmission.
- Standby mode: Terminal is in low power state waiting to wake up.

5.2 Assumptions and approximations

The design operational lifetime of a satellite network is considered to be 15 years.

The approximations made during the environmental assessment will depend on the purpose of the assessment. Often a provisional assessment will provide sufficient results to allow optimization of a subsystem to provide significant energy savings without the need for a detailed analysis. Generally a more accurate model need only be developed if there is doubt about the validity of the application of a cut off rule.

During the operational lifetime of a satellite network, approximations should be made of:

- The number of terminals deployed.

  If the number of terminals deployed is lower than originally estimated, then the total power consumed by the terminals may be a less significant proportion of the total power consumed by the full hybrid satellite broadband system. This could mean that other energy use becomes significant according to the cut off rules.

- The average power used by an equipment or subsystem over the assessment period. For systems such as satellite earth stations or network control centres which are permanently powered up, the electricity consumed can be measured over a specific period and a rate of consumption determined. However, it is more difficult to estimate for user equipment such as satellite modems as the proportion of time the equipment will be switched on and used cannot be known in advance.

5.3 Cut-off rules

Cut-off is the process for the exclusion of insignificant items and activities from the analysis [i.10]. Invoking cut-off can simplify the assessment and reduce the cost by excluding items and activities that will not significantly change the overall conclusions of the study. This is valid as long as the intended purpose of the assessment is still met. Cut-offs should be avoided if possible, and are only acceptable if allowed according to guidance given in ISO 14044 [i.11] and an alternative to cut-off can be to model unavailable data based on known data.

6 Energy efficiency related metrics

Energy consumption should be measured in Wh or J over the period of the assessment including all subsystems.

Similarly to the cellular industry, a standard should be developed to calculate the energy efficiency of a satellite network and possibly its different component.

In ETSI TR 103 117 [i.7], there are general considerations about the design of mobile network which can be adapted to the satellite network context:

- The objective in the design of a mobile network is to maximize the number of bits that can be delivered over a certain time and in a given bandwidth; in this sense the throughput delivered in a given area and in such a bandwidth is deemed as an appropriate way to estimate the performance of the network.

- Energy is considered to be a scarce resource that should be carefully utilized. However, the spectrum efficiency and the quality aspects are also important, so the energy efficiency analysis should make explicit the service which is targeted (bit rate, coverage area, etc.) and the other scarce resources (e.g. spectrum) which are used to allow comparison between networks on an equivalent basis. This is for further study.

ETSI TR 103 117 [i.7] also suggests further possible metrics to characterize the energy efficiency of a network:

- successfully transferred data volume per unit time over consumed power (ε^I);
- area unit over consumed power (ε^A);
- number of users over consumed power (ε^S).

Power per area unit. The power per area unit metric is defined as the network average power usage (*P*) divided by the coverage area of the network (*A*) and is expressed in W per km^2:

- $ECI_{P/A} = P/A$ in [W/km^2]

Energy per bit. The energy per bit metric is defined as the network energy consumption (*E*) during the observation period (*T*) divided by the total number of bits (*B*) that were correctly delivered in the network during the same time period. Since the network energy consumption is simply the (average) power multiplied with the observation period, this metric could, equivalently, be described as the (average) network power (P) in relation to the (average) data rate (R) and expressed in W per kbps:

- $ECI_{E/B} = P/R$ in [W/kbps]

The case studies shown in annexes A and B demonstrate that the majority of the energy consumption is due to the Satellite Terminals. These account for nearly all of the total energy consumption of a satellite network.

7 Energy efficiency assessment methods

7.1 General requirements

7.1.0 Introduction

This clause describes the methods to measure the power consumption of satellite broadband network equipment and also gives the conditions under which these measurements should be performed.

The following general requirements apply to both the measurement of the energy consumption of the satellite gateway and the measurement of the energy consumption of the satellite terminal.

7.1.1 Traffic profile

Definition of Satellite Network traffic:

- Random variable packet size distribution from 64 octets to 1 518 octets (bytes).
- Traffic rates limited to 80 % of net activation rate (takes overhead into account).

Traffic flow in both directions (Upstream and Downstream) should be measured.

7.1.2 Measurement of data volume

The data volume (capacity) of the satellite network is considered as the overall amount of data transferred to and from the users accessing the satellite network under test. The data volume should be measured using network counters measuring the aggregated traffic in the satellite network under test.

7.2 Measurement method for energy consumption of satellite gateway

7.2.0 Introduction

The power consumption of the satellite gateway may be measured by means of metering information provided by utility suppliers or by network integrated measurement systems (ETSI ES 202 336 series [i.12]).

The satellite gateway should be allowed to stabilize to obtain stable power measurement. If power varies over the measurement interval time, an average of measurement should be calculated.

In a shared environment where power is provided to a gateway providing a number of separate services, a proportion of the power consumed by this equipment should be allocated to the satellite network. However, this is considered insignificant compared with the power consumed by the other subsystems and components of a satellite network, and can therefore be ignored under the cut-off rules.

7.2.1 Measurement conditions

All power measurements should be made on the gateway in normal operational use under the following conditions:

- Room Temperature: 25 °C ± 5 °C.
- Room Relative Humidity: 30 % to 75 %.
- Operating voltages: Nominal voltage of 230 V AC ± 10 % and frequency of 50 Hz ± 1 % [i.13].

  Nominal voltage of 120 V AC ± 5 % and frequency of 60 Hz [i.14].

7.2.2 Considered equipment

The following items are considered part of the satellite gateway and therefore their power consumption should be taken into account to calculate the total power consumption of the satellite gateway:

- RF/IF module.
- Gateway Cooling system.
- Normal operational power supply unit.

7.2.3 Not considered equipment

The following items are not considered part of the satellite gateway and therefore their power consumption should not be added to the power consumption of the satellite network:

- External rectifier (AC - DC converter).
- Room or outdoor Ventilation and Air Conditioning Unit (VAC Unit).
- Auxiliary or redundant power unit.
- Battery and battery charging equipment.
- Battery powered user equipment.

7.3 Measurement method for energy consumption of satellite terminal

7.3.0 Introduction

It is considered that there will typically be one satellite terminal per household or business premises and there may be more than one user accessing the network via the satellite terminal. The satellite terminal is assumed to include any associated terminal equipment that is necessary for communication such as an Intelligent User Gateway (IUG).

7.3.1 Measurement conditions

It is assumed that all satellite terminal will be AC powered (either by an internal or external power supply). The power measurements should be performed in a laboratory environment under the following conditions:

- Room Temperature: 25 °C ± 2 °C.
- Room Relative Humidity: 30 % to 75 %.
- Operating voltages: Nominal voltage of 230 V AC ± 10 % and frequency of 50 Hz ± 1 % [i.13].

  Nominal voltage of 120 V AC ± 5 % and frequency of 60 Hz [i.14].

7.3.2 Measurement instruments requirements

All measurement instruments used should be calibrated by counterpart national metrology institute and within calibration due date, and the measurement tolerance should be within ±1 %:

- Power Source: Power sources used to provide power to the equipment under test should be capable of providing a minimum of 1,5 times the power rating of the equipment under test.
- Power Measurement Instrument: Power measurement instrument (such as voltmeter and ammeter or power analyser) should have a resolution of 0,5 % or better. AC power measurement instrument should have the following minimum characteristics:

  1) A minimum digitizing sample rate of 40 kHz.
  2) Input circuitry with a minimum bandwidth of 80 kHz.
  3) It should be capable of accurate readings of waveforms having Crest Factor up to at least 5.

7.3.3 Considered equipment

The following equipment is considered part of the satellite terminal and therefore should be taken into account to calculate the total power consumption of the satellite terminal:

- satellite modem;
- antenna;
- intelligent user gateway (if used); and
- any external power supply required for the normal operation of the satellite terminal.

7.3.4 Measurement reference points

The system under test is considered to be a "black box", i.e. only the total power consumed by the network or terminal equipment is measured and not different parts of the network or terminal equipment [i.15]. A "black box" can be viewed solely in terms of its input, output and transfer characteristics without any knowledge of its internal workings.

Satellite terminal equipment is normally powered directly by AC mains voltage. In this case, the power consumption should be measured at the AC input as shown in figure 2.

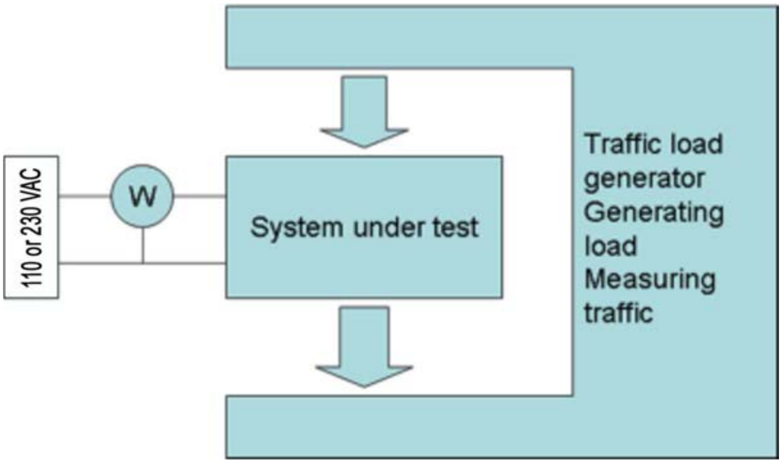

Figure 2: Measurement set-up of system under test

7.3.5 Minimum Measurement Duration

To ensure that behaviour in low power (standby) modes is fully taken into account, power consumption should be measured in each of the modes defined in clause 5.1, and an average measurement calculated according to the proportion of time the terminal is likely to spend in each mode.

In Full power and Receive only modes, wait 1 minute for the satellite modem to synchronize before starting measurement.

Comparison between satellite terminals of different systems should take into account the maximum service rate capabilities.

7.3.6 Measurement of Data Volume

The data volume (bit rate) of a satellite terminal should be measured using bit counters on the access links.

7.4 Assessment method for the energy efficiency of the satellite network

7.4.1 Assessment of total power consumption of the satellite network

The purpose of this clause is to estimate the number of terminals and the number of gateways that are active. The total power consumption of a satellite network is then calculated by summing the consumption of the individual subsystems, including the satellite gateways and the satellite terminals.

The total power consumption P_{SN} of the satellite network is calculated from:

$$P_{SN} = (P_{SG} \times N_{SG}) + (P_{ST} \times N_{ST})$$

where: P_{SG} is the average power consumption of a satellite gateway;

N_{SG} is the number of satellite gateways;

P_{ST} is the average power consumption of a satellite terminal (including any associated terminal equipment necessary for communication such as an IUG);

N_{ST} is the number of satellite terminals supported.

NOTE: The average power consumption per satellite terminal (P_{ST}) is computed over a 24 hour period and takes into account the average activity profile of the terminal as shown in table A.1.

Therefore:

$$P_{ST} = R_{full} \times P_{full} + R_{receiving} \times P_{receiving} + P_{standby} \times P_{standby}$$

where: R_{full} is the proportion of time the satellite terminal spends in full activity mode;

P_{full} is the power consumed by the satellite terminal in full activity mode;

$R_{receiving}$ is the proportion of time the satellite terminal spends in receive only mode;

$P_{receiving}$ is the power consumed by the satellite terminal in receive only mode;

$R_{standby}$ is the proportion of time the satellite terminal spends in standby mode;

$P_{standby}$ is the power consumed by the satellite terminal in standby mode;

where each is measured after the power consumption of the satellite terminal has stabilized after going into each state.

The number of satellite terminals that can be supported by a given satellite network can be derived from the average bandwidth required by each satellite terminal during the busy hour.

7.4.2 Assessment of energy efficiency of the satellite network

The required energy efficiency metric can be calculated from a knowledge of:

- T_{SN} satellite network throughput;
- A_{SN} satellite coverage area;
- P_{SN} satellite network consumption (including satellite terminals).

The energy per bit ECI $_{E/B}$ can be calculated by dividing the total power consumed by the satellite network (as calculated in clause 7.4.1) by the total throughput of the satellite (e.g. 0,5 Tbps).

$$ECI_{E/B} = P_{SN} / T_{SN} \quad [W/kbps]$$

The power per unit area ECI $_{P/A}$ can be calculated by dividing the total power consumed by the satellite network (as calculated in clause 7.4.1) by the total coverage area for the satellite network in km^2.

$$ECI_{P/A} = P_{SN} / A_{SN} \qquad [W/km^2]$$

7.4.3 Determination of Coverage Area

The coverage area under test is initially defined by an area served by (a subnetwork of) the satellite network. Coverage area is subject to satellite design. It varies according to an operators strategy and might therefore differ from operator to operator but also within the network of one operator for different geographical areas.

The geographic network coverage area is the total two dimensional area intentionally covered by the satellite network. This area is defined by an operator's defined network service plans (minimum granted data rate/typical data rate, etc.) for the selected area.

For an energy efficiency KPI it is not required to have knowledge of the actual coverage. From an energy efficiency point of view it is important to know how many users/sessions or served users/sessions experienced problems because of lack of coverage in relation to the total number of users/sessions or served users/sessions within the considered area.

8 Results and Recommendations for Future Work

In the present document a method of assessing the energy efficiency of satellite networks and terminal has been given. This can represent the basis for further detailed assessment procedures leading to a Technical Specification about satellite network energy efficiency assessment.

However, it is desirable to be able to assess the energy efficiency of a satellite network over the full life cycle and a methodology for this should be provided in a future document.

In Annexes A and B, the results of case studies on the assessment of the energy efficiency of Satellite Broadband and Hybrid Satellite Broadband are given.

Annex A (informative): Case Study on Satellite Broadband

A satellite broadband network is one where the satellite broadband link is used to provide the required service to users. From an energy efficiency perspective this has the implication that the satellite modem remains operational and ready to carry traffic 24 × 7.

The assessment of the power consumption of a satellite broadband network was derived the work done in the EU FP7 BATS project [i.17]. The power consumption was assessed in accordance with the methods described in clause 7 of the present document as illustrated below.

The total power consumed by a satellite network is calculated by summing the consumption of the individual subsystems, including the satellite gateways and the satellite terminals.

In this case, the total power consumption P_{SN} of the satellite network is calculated from:

$$P_{SN} = (P_{SG} \times N_{SG}) + (P_{ST} \times N_{ST})$$

where: P_{SG} is the average power consumption of a satellite gateway;

N_{SG} is the number of satellite gateways used;

P_{ST} is the average power consumption of a satellite terminal;

N_{ST} is the number of satellite terminals supported.

The average power consumption of a satellite terminal depends on the average activity profile of the terminal as shown below:

$$P_{ST} = R_{full} \times P_{full} + R_{receiving} \times P_{receiving} + P_{standby} \times P_{standby}$$

where: R_{full} is the proportion of time the satellite terminal spends in full activity mode;

P_{full} is the power consumed by the satellite terminal in full activity mode;

$R_{receiving}$ is the proportion of time the satellite terminal spends in receive only mode;

$P_{receiving}$ is the power consumed by the satellite terminal in receive only mode;

$R_{standby}$ is the proportion of time the satellite terminal spends in standby mode;

$P_{standby}$ is the power consumed by the satellite terminal in standby mode.

For this case study, it was observed that the satellite terminal spends the proportion of each day in the modes and with the power consumption shown in table A.1:

Table A.1: Proportion of time spent in each mode for measurement of power consumption

Mode	Description	% of typical day	Power Consumption (W)
Full	Two way data on satellite link	R_{full} = 30 %	P_{full} = 22 W
Receive Only	Receiving but not transmitting	$R_{receiving}$ = 70 %	$P_{receiving}$ = 7,5 W
Standby	Low power state	$R_{standby}$ = 0 %	$P_{standby}$ = 3,15 W

Therefore:

$$P_{ST} = 0,3 \times 22 + 0,7 \times 7,5 = 11,85 \text{ W (average power)}$$

The number of satellite terminals that can be supported by a given satellite network can be derived from the average bandwidth required by each satellite terminal during the busy hour. In this case study, a High Throughput Satellite with a capacity of 0,5 Tbps could support around 227 000 separate 30 Mbps links with a peak average busy hour requirement of 2,2 Mbps in 2020 [i.16].

In this case study, a High Throughput Satellite with a capacity of 0,5 Tbps required 26 satellite gateways in 2020 [i.16].

From these calculations, the peak power consumption during the operational lifetime of a satellite broadband system from European deployment of 15 years from 2020 to 2035 is shown in table A.2.

Table A.2: Power consumption during operation of a Satellite Broadband Network

Subsystem	Power Consumption per unit	Number of Units Peak deployment	Peak Power Consumption	Proportion of Peak Power Consumption
Satellite Gateways	4,605 kW	26	120 kW	4,3 %
Satellite Terminals (1 W RF)	11,85 W	227 000	2,69 MW	95,7 %
Peak Power Consumption			2,81 MW	100 %

The energy per bit $ECI_{E/B}$ was calculated by dividing the total power consumed by the satellite network by the total throughput of the satellite:

$$ECI_{E/B} = P_{SN} / T_{SN} \quad [W/kbps]$$

It was calculated in table A.2 that the peak power consumed by the satellite network was 2,81 MW. For this case study, the total throughput of the high throughput satellite used was 0,5 Tbps.

Therefore:

$$ECI_{E/B} = 2.81 \text{ MW} / 0{,}5\text{Tbps} = 5{,}62 \text{ mW/kbps}$$

The power per unit area $ECI_{P/A}$ was calculated by dividing the peak power consumed by the satellite network by the total coverage area for the satellite network in km^2:

$$ECI_{P/A} = P_{SN} / A_{SN} \quad [W/km^2]$$

It was calculated in table A.2 that the total power consumption of the satellite network was 2,81 MW. For practical purposes, a Terabit satellite is considered to be capable of covering an area typically equivalent to half of Europe (EU28) or US. This is taken to be an area of around 2,3 million km^2.

Therefore:

$$ECI_{P/A} = 2{,}81 \text{ MW} / 2{,}3 \text{ million km}^2 = 1{,}22 \text{ W/km}^2$$

Annex B (informative): Case Study on Hybrid Satellite broadband

B.1 General

A hybrid satellite broadband network is one where a combination of satellite broadband link and narrowband terrestrial link is provided in combination to provide the required QoE to users. From an energy efficiency perspective this has the advantage that the satellite modem can be put into a low power state for a larger proportion of the day. This means that the average power consumption of the satellite modem can be considerably lower than if continually in a high power state. However, it means that 2 extra pieces of equipment, the IUG (Intelligent User Gateway) and the ING (Intelligent Network Gateway), are also provided and accounted for in the analysis of power consumption.

The assessment of the power consumption of a hybrid satellite broadband network was based on the work done in the EU FP7 BATS project [i.17]. The power consumption was assessed in accordance with the methods described in clause 7 of the present document as illustrated below.

The total power consumed by a satellite network is calculated by summing the consumption of the individual subsystems, including the satellite gateways and the satellite terminals.

In this case, the total power consumption P_{SN} of the satellite network is calculated from:

$$P_{SN} = (P_{SG} \times N_{SG}) + (P_{ST} \times N_{ST})$$

where: P_{SG} is the average power consumption of a satellite gateway = 4,605 kW;

N_{SG} is the number of satellite gateways used = 26 [i.16];

P_{ST} is calculated below;

N_{ST} is the number of satellite terminals supported = 227 000 × 1,1 = 250 000.

The average power consumption of a satellite terminal depends on the average activity profile of the terminal as shown below:

$$P_{ST} = R_{full} \times P_{full} + R_{receiving} \times P_{receiving} + P_{standby} \times P_{standby}$$

For this case study, it was observed that the satellite terminal spends the proportion of each day in the modes and with the power consumption shown in table B.1. The power consumption of an IUG also has been added to the satellite.

Table B.1: Proportion of time spent in each mode for measurement of power consumption

Mode	Description	% of typical day	Power Consumption (W)
Full	Two way data on satellite link	R_{full} = 15 %	P_{full} = 27,7 W
Receive Only	Receiving but not transmitting	$R_{receiving}$ = 35 %	$P_{receiving}$ = 13,2 W
Standby	Low power state	$R_{standby}$ = 50 %	$P_{standby}$ = 8,85 W

Therefore:

$$P_{ST} = 0{,}15 \times 27{,}7 + 0{,}35 \times 13{,}2 + 0{,}5 \times 8{,}85 = 13{,}2\text{W (average power)}$$

The number of satellite terminals that can be supported by a given satellite network can be derived from the average bandwidth required by each satellite terminal during the busy hour. In this case study, a High Throughput Satellite with a capacity of 0,5 Tbps could support around 250 000 separate equivalent 30 Mbps links (in combination with the terrestrial link) with a peak average busy hour requirement of 2 Mbps via satellite in 2020 [i.16]. This is complemented by 0,2 Mbps that is carried terrestrially.

Using the values above the P_{SN} can be computed using the formula:

$$P_{SN} = (4{,}605 \text{ kW} \times 26) + (13{,}2 \text{ W} \times 250\,000) = 3{,}46 \text{ MW}$$

The energy per bit $ECI_{E/B}$ was calculated by dividing the peak power consumed by the satellite network by the total throughput of the satellite:

$$ECI_{E/B} = P_{SN} / T_{SN} \quad [W/kbps]$$

It was calculated above that the total power consumption of the satellite network was 3,46 MW. For this case study, the total throughput of the high throughput satellite used was 0,5 Tbps.

Therefore:

$$ECI_{E/B} = 3{,}46\ MW / 0{,}5Tbps = 6{,}92\ mW/kbps$$

The power per unit area $ECI_{P/A}$ was calculated by dividing the total power consumed by the satellite network by the total coverage area for the satellite network in km^2:

$$ECI_{P/A} = P_{SN} / A_{SN} \quad [W/km^2]$$

It was calculated above that the peak power consumption of the satellite network was 3,46 MW. For practical purposes, a Terabit satellite is considered to be capable of covering an area typically equivalent to half of Europe (EU28) or US. This is taken to be an area of around 2,3 million km^2.

Therefore:

$$ECI_{P/A} = 3{,}46\ MW / 2{,}3\ million\ km^2 = 1{,}5\ W/\ km^2$$

B.2 Power Consumption Breakdown

In addition it is interesting for information to compute the respective share of the power consumed by different components of the satellite network. The Power Consumption during the operational lifetime of a hybrid satellite broadband system from European deployment of 15 years from 2020 to 2035 is shown in table B.2. Table B.2 shows separate rows for the ING and IUG although the methodology in Section 7 states that these should be considered part of the satellite terminal for the calculation of power consumption.

Table B.2: Power consumption during operation of a Hybrid Satellite Broadband Network

Subsystem	Power Consumption per unit	Number of Units Peak deployment	Peak Power Consumption	Proportion of Peak Power Consumption
Satellite Gateways	4,605 kW	26	120 kW	3,5 %
Intelligent Network Gateways (INGs)	42 kW	1 (virtualised)	42 kW	1,2 %
Intelligent User Gateways (IUGs)	5,7 W	250 000	1,425 MW	41,2 %
Satellite Terminals	7,5 W	250 000	1,875 MW	54,2 %
Total Power Consumption of the satellite network (P_{SN})			3,46 MW	100 %

Table B.2 assumes there were 250 000 satellite terminals at peak deployment each combined with a 2 Mbit/s terrestrial link. The satellite boosted the peak throughput to 30 Mbit/s per user with a concentration factor of 192:

- The power consumed by the satellite terminals was the largest contributor to overall power consumption with 54 % of the total.
- The power consumed by the IUGs was also significant at 41 % of the total.

Note that at the expense of 23 % of more power consumed, the hybrid satellite network is able to serve 10 % more satellite terminals than the stand-alone satellite broadband system but with superior Quality of Experience (QoE).

It is expected that the power consumption of the IUG will be reduced further, possibly by integrating the function into the satellite terminal. Then the benefit in terms of QoE of the hybrid broadband network would have no impact on power consumption compared with the stand-alone satellite broadband network.

History

Document history		
V1.1.1	June 2016	Publication