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PLANT

ITU-T L.1410 – Case study: The assessment of greenhouse gas emissions of a hybrid satellite broadband system over its life cycle

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ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Supplement 26 to ITU-T L-series Recommendations

ITU-T L.1410 – Case study: The assessment of greenhouse gas emissions of a hybrid satellite broadband system over its life cycle

Summary

Supplement 26 to ITU-T L-series Recommendations presents a case study of the application of Recommendation ITU-T L.1410 to the assessment of the greenhouse gas (GHG) emissions of a hybrid satellite and terrestrial broadband system over its life cycle. The goal of this assessment was to calculate the additional emissions of a hybrid satellite system assuming that an existing broadband system is present, which does not meet the European Digital Agenda rate of 30 Mb/s. The GHG emissions model that was developed for the assessment was then used to identify those parts of the Broadband Access via integrated Terrestrial and Satellite (BATS) system that would contribute the most to the GHG emissions, so that attention could be focused on mitigating those emissions. The network is the subject of research and development and is aimed at providing 30 Mb/s broadband services to rural or remote households in Europe. The proposed system lifetime is 2020–2035. The work was funded under the European Union 7th Framework Programme. This study was completed in 2014 by BATS project partners.

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Table of Contents

		Page
1	Scope.....	1
2	References.....	1
3	Abbreviations and acronyms	1
4	Background.....	2
5	General description.....	3
5.1	General requirements: Overview of satellite-based telecommunications services	3
5.2	Low-power modes	4
6	Methodological framework	7
6.1	General requirements.....	7
6.2	Goal and scope definition	7
6.3	Cut-offs.....	9
6.4	Data collection and quality	9
7	Life cycle stages	10
7.1	Raw material acquisition stage	10
7.2	Production stage	10
7.3	Use stage.....	10
7.4	End-of-life treatment stage	11
8	Life cycle inventory.....	11
8.1	Key input parameters.....	11
8.2	Estimating the number of terminals in operation	11
8.3	Delivery vehicles and their emissions trend.....	13
8.4	On grid electricity and emissions trends	13
8.5	Satellite launch vehicle and payload	14
8.6	Satellite gateway (ground segment) life cycle parameters	15
8.7	Life cycle parameters for the intelligent network gateway	16
8.8	Life cycle parameters for the user modem	16
8.9	Life cycle parameters for the intelligent user gateway.....	16
9	Life cycle impact assessment.....	17
9.1	Description of the model	17
10	Life cycle interpretation.....	18
10.1	Results of the life cycle impact assessment for a hybrid satellite system	18
10.2	Sensitivity analysis of major assumptions.....	20
10.3	Discussion.....	21
10.4	Compliance with [ITU-T L.1410]	21
10.5	Review.....	21

	Page
Appendix I – Compliance with [ITU-T L.1410].....	22
Bibliography.....	43

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Supplement 26 to ITU-T L-series Recommendations

ITU-T L.1410 – Case Study: The assessment of greenhouse gas emissions of a hybrid satellite broadband system over its life cycle

1 Scope

This Supplement presents a case study of the assessment of greenhouse gas (GHG) emissions of a hybrid satellite and terrestrial broadband network over its life cycle. The goal of this assessment was to calculate the additional emissions of a hybrid satellite system, assuming that an existing broadband system is present which does not meet the European Digital Agenda rate of 30 Mb/s. This was therefore not a comparative assessment. The GHG emissions model that was developed for the assessment was then used to identify those parts of the network that would contribute the most to the GHG emissions, so that attention can be focused on mitigating those emissions. This analysis only applies to geostationary satellites rather than low-Earth orbit satellites. This Supplement does not compare GHG emissions of satellite systems with terrestrial systems. The network is the subject of research and development and is aimed at providing broadband services to rural or remote households in Europe (EU28 plus Turkey). The assumed system lifetime is 2020-2035. Only the first order effects, the GHG emissions of information and communication technology (ICT) are assessed according to [ITU-T L.1410].

2 References

[ITU-T L.1410] Recommendation ITU-T L.1410 (2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services.*

3 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

ADSL	Asymmetric Digital Subscriber Line
BATS	Broadband Access via integrated Terrestrial and Satellite systems
CoC	Code of Conduct
EoLT	End-of-Life Treatment
GHG	Greenhouse Gas
GW	Gateway
HPA	High-Power Amplifier
ICT	Information and Communication Technology
ING	Intelligent Network Gateway
IUG	Intelligent User Gateway
LAN	Local Area Network
LCA	Life Cycle Analysis
LCIA	Life Cycle Impact Assessment
P	Production
PA	Power Amplifier

RF	Radio Frequency
RMA	Raw Material Acquisition
U	Use
WAN	Wide Area Network
WEEE	Waste Electrical and Electronic Equipment
WLAN	Wireless Local Area Network

4 Background

This case study followed a process sum approach to the GHG assessment of a hybrid satellite/terrestrial network with the overall objective to minimize greenhouse gas (GHG) emissions and energy consumption. The processes are the installation and operation of a hybrid terrestrial/satellite network. The steps followed included:

- Setting the objectives within the scope of the European Union (EU) Broadband Access via integrated Terrestrial and Satellite (BATS) project
- Defining the network under study including the network elements
- Identifying the processes which are likely to have significant GHG emission within the operational life cycle of the network. The operational life cycle is assumed to span the years 2020–2035 inclusive. The assumption was made that a terrestrial broadband network already exists, which can carry broadband data, and the satellite system adds additional capacity. It is the additional GHG emissions due to the satellite system which are the subject of this assessment
- Obtaining data for the time-varying global parameters, such as the future addressable market, number of households served, the future emission factors of the electricity grid over the life cycle and trends in the future energy consumption of vehicles used for transport. This formed part of the inventory
- Obtaining data for the carbon factors which were given by the GHG emission by mass or by energy used. This formed part of the inventory
- Totalling the GHG emissions for the life cycle stages of the network elements for each year of operation. This formed part of the assessment
- Totalling the GHG emissions over the assumed 16 year life cycle. This produced a figure for the overall GHG emissions in gigatonnes. This formed part of the assessment
- Performing a sensitivity analysis on the overall emissions by varying input parameters of the network elements to establish possible ways of reducing the GHG emissions
- Reporting key findings

This life cycle analysis (LCA) partially complies with [ITU-T L.1410] with the exceptions transparently listed and justified. These are given in Appendix A. As such it serves as an example of the application of the methodology described in [ITU-T L.1410] and can therefore help practitioners and organizations in their approach to the assessment of future GHG emissions of products or services based on information and communication technology (ICT).

The approach to this assessment was dependent on there being publicly available conversion factors such as those published by the European Union Joint Research Centre [b-EU/JRC EDGAR, undated] and the Department for Environment Food and Rural Affairs in the UK [b-Defra, 2016]. These conversion factors provide the GHG emission in CO₂ equivalent (CO₂e) per unit mass (for production and waste disposal stages) or per unit energy (for use stage). In some cases, conversion factors were not available from tables, so these were estimated from first principles. One example is the GHG emitted during the production of fuel used by rockets that launch satellites. More information about

how Defra derived its conversion factors can be obtained from [b-DECC, 2015], [b-UNU, 2007] and [b-U. Cambridge, 2014].

5 General description

5.1 General requirements: Overview of satellite-based telecommunications services

Satellite systems are one of several options to increase the coverage area of broadband communications to meet the target for next generation networks of 100% coverage at 30 Mb/s by 2020 [b-EC/DSM, 2016].

This case study reports a satellite-based system and does not make comparisons with terrestrial systems.

Figure 1 illustrates a conventional two-way satellite system. Geostationary satellites are characterized by round-trip signal delays of 240–280 ms that make them unsuitable for real time traffic for voice services or gaming.

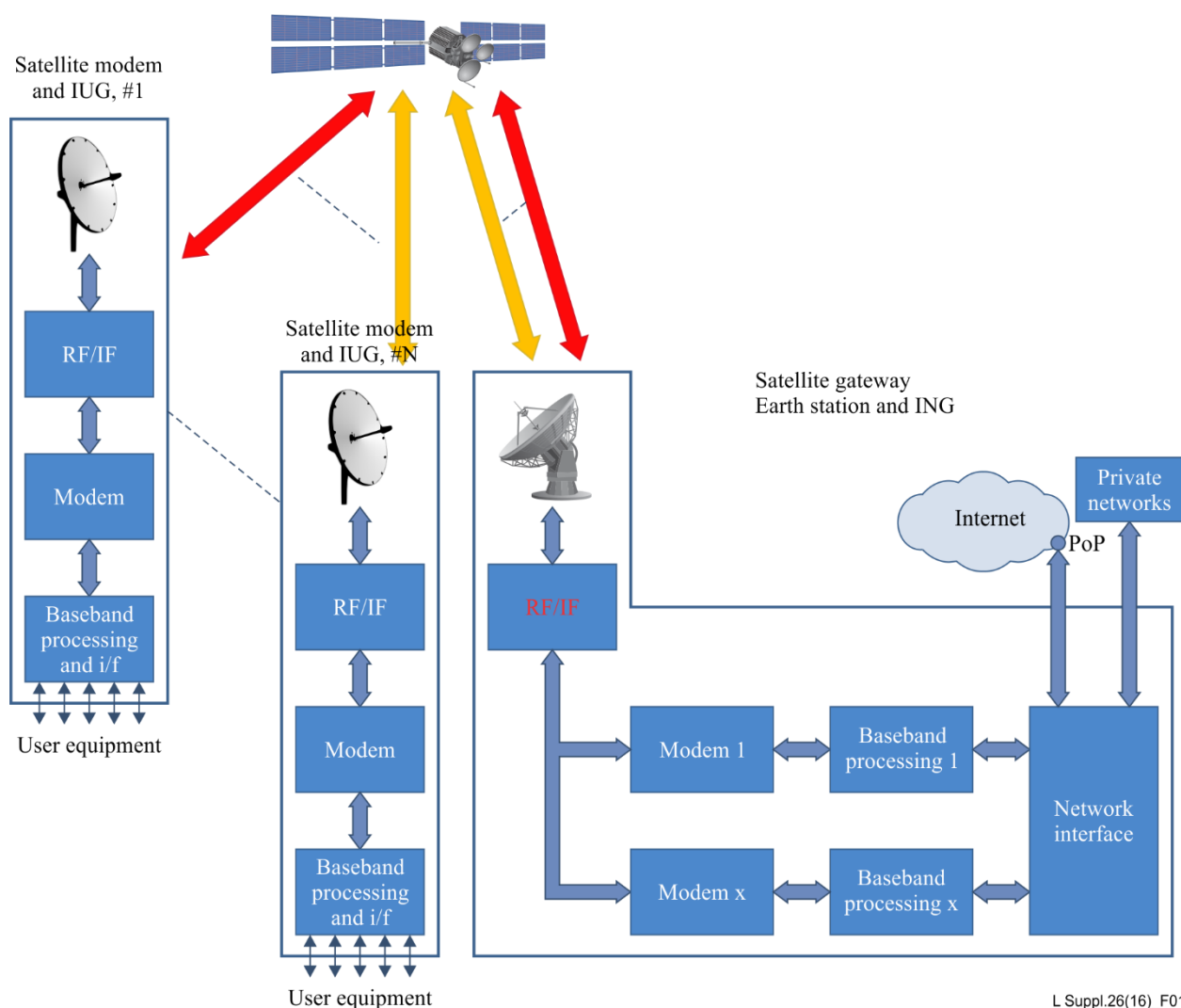


Figure 1 – Two way service satellite network architecture

A geostationary-based satellite access network is typically composed of the following parts:

- A space segment composed of one or more high-throughput satellites in geostationary orbit. The satellite relays bidirectional signals between the gateways (GWs) and user terminals.

- A ground segment, which includes a set of GWs that are in charge of transmitting and receiving data, control and management traffic to or from user terminals. This is part of the Earth station, which is assumed to be already operational serving existing satellite systems.
- A user segment that is composed of a set of user terminals.

Figure 2 illustrates a hybrid satellite system utilizing a combination of terrestrial and satellite paths to provide users with an interactive broadband service with an acceptable response time. Delay-sensitive traffic is routed via the terrestrial network whilst delay-insensitive traffic, often characterized by long packets, is routed via either network.

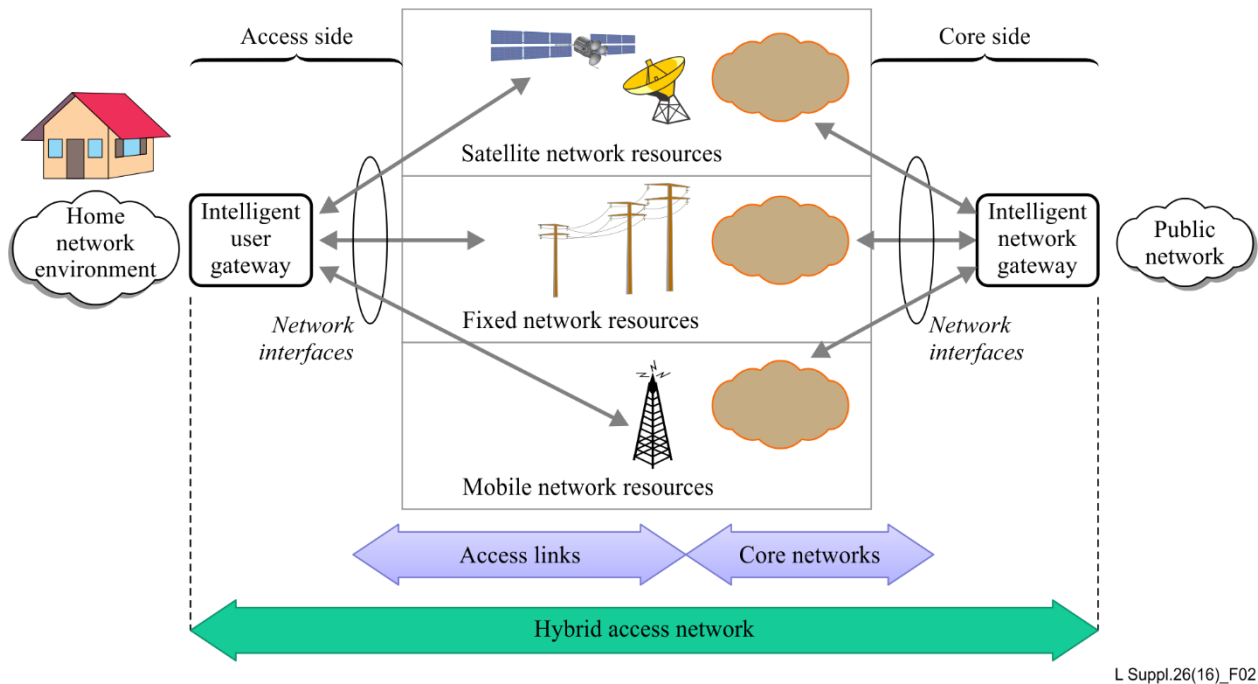


Figure 2 – Hybrid satellite/terrestrial system architecture

The routing of traffic is controlled by the intelligent network gateway (ING) shown at the right of Figure 2 and the intelligent user gateway (IUG) on the left. The energy challenge for this hybrid broadband access solution is to minimize the energy consumption and GHG emissions of a satellite system that supplements one or more terrestrial systems.

5.2 Low-power modes

At the outset of the BATS project, it was understood that the higher the energy efficiency of the network, the lower the GHG intensity is likely to be. An initial GHG assessment revealed that the in-use energy consumption of user satellite modems installed in possibly millions of household throughout Europe would make a strong contribution to the overall GHG emission of the network. Low-power modes were therefore considered for the user satellite modems.

Permanently installed two-way satellite systems are traditionally set to run at their full capacity at all times so that they are instantly available when required. However, with a hybrid system, the user satellite modem may be powered down to save energy according to the required duty cycle. The terrestrial network is assumed to be available to trigger the satellite into operation, e.g., when large quantities of data are to be transported.

The introduction of low-power modes provides a useful energy saving. The following operational modes are defined:

- full-speed transmit;

- B. idle, two-way ready;
- C. idle with power amplifier (PA) in mute;
- D. only receiving;
- E. not receiving;
- F. power-down [wake on local area network (LAN)].

Table 1 gives the time taken to return to full two-way operation from each mode, together with the power consumption in that mode. The current design does not use modes D, E and F.

Table 1 – Characteristics of satellite modem operational modes

Satellite communication modem mode	Mode	Delay for forward link connectivity (receive) s	Delay for return link connectivity (transmit) s	Return link packet latency s	Power consumption W
Full-speed transmit	A	0	0	~0	<22
Idle two-way ready	B	0	0	~0	<13
Idle with PA in mute	C	0	0	~0	<6
Only receiving	D	0	0	<5	<5
Not receiving	E	<10	0	<30	<4
Power-down (wake-on-LAN)	F	<70	<60	<30	<1

The amount of energy and the GHG emissions can be reduced by increasing the relative amount of time a satellite modem operates in states with the lowest power consumption. However, care must be taken, as use of the states with the lowest power consumption can affect the quality of service.

Figure 3 shows the state transitions that are required. The IUG will not normally have knowledge of the state of the satellite modem, nor will it be able to instruct the modem to change state. However, it may be required to manage power-up and power-down. The satellite modem determines which mode to adopt by responding to transmitted packets from the IUG. These packets will be buffered for the time taken to make the transition from the current mode to mode A.

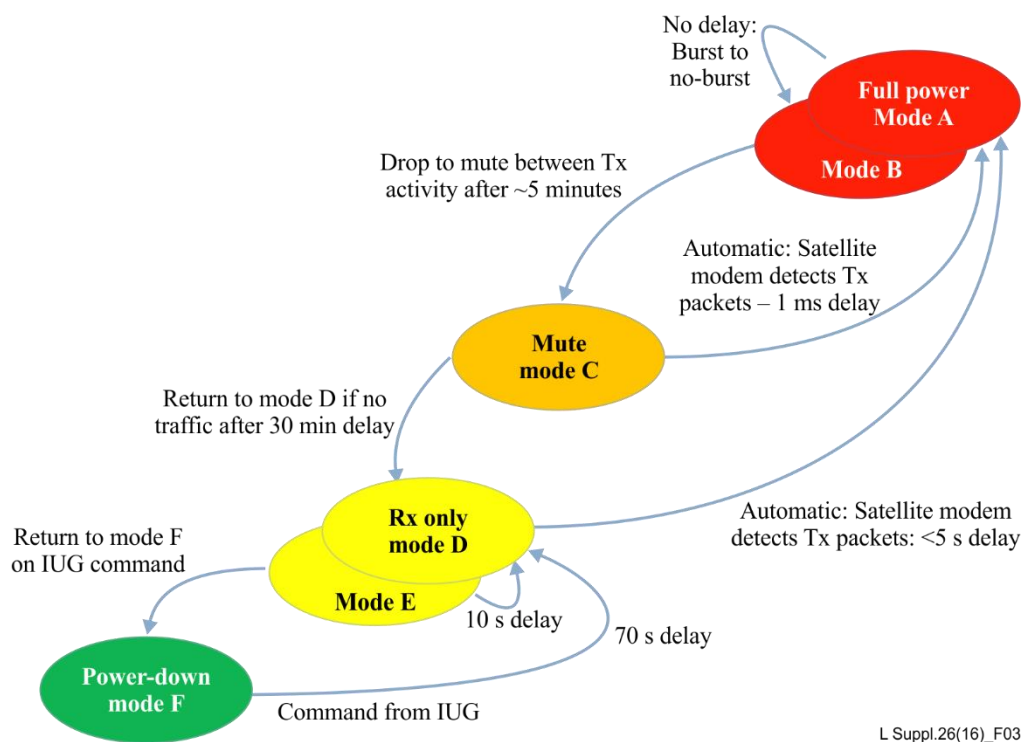


Figure 3 – Satellite modem mode transitions

Under typical usage patterns, it may be possible to reduce the average power consumption of the satellite modem by up to 70% without the user experiencing significant delays in the responsiveness of the system. This is because the IUG will send data traffic via the terrestrial communications channel until the satellite modem is returned to fully operational transmission mode. In the intervening time any packets passed to the satellite modem for transmission will be stored in the buffer. The worst case delay is 5 s, but the system will subsequently run with no further delay.

Table 2 introduces different power plans according to the amount of time that the satellite modem spends in each mode; from which the average duty cycle may be deduced. This ranges from 22 W when on full to 3.2 W under low usage.

Table 2 – Average power consumption using different power plans

Power plan	Satellite modem mode	F	D	C	B	A	Average W	GHG CO ₂ e EU Mt
		Power-down	Rx only	Mute	Ready	Full		
	power (W)	1	5	6	13	22		
0	PA always on					100%	22.0	5.39
1	Always on, with idle				90%	10%	13.9	3.71
2	Includes the use of muted mode			80%	10%	10%	8.3	2.54
3	Including Rx-only state,		78%	2%	10%	10%	7.5	2.37
3L	Low usage with plan 3		88%	2%	5%	5%	6.3	2.12
4	Including state F	63%	15%	2%	10%	10%	5.0	1.85
4L	Low usage with plan 4	78%	10%	2%	5%	5%	3.2	1.48

6 Methodological framework

6.1 General requirements

6.1.1 Handling of software

The network elements will contain software to ensure that the network can be managed remotely. This has yet to be designed in the form of a product. It was assumed that the GHG impact of this software is negligible compared with the traffic handled by the hardware, since it will not be required to change state rapidly. However, there will be hardware and software that control the routing of packets via the terrestrial or the satellite links. This is the primary function of the ING and IUG and these were therefore included in the GHG emissions model, including representative use cases. A sensitivity analysis was conducted to demonstrate the GHG impact of various use cases.

6.1.2 Operating lifetime

The operating lifetime of the system was estimated to be the lifetime of a geostationary satellite, which in this case is 16 years from 2020 to 2035. It is assumed that services are migrated on to other system platforms after the satellite service ceases.

6.2 Goal and scope definition

6.2.1 Goal and scope of the study

The goal of the assessment was to calculate the additional emissions of a hybrid satellite system, assuming that an existing broadband system is present that does not meet the European Digital Agenda rate of 30 Mb/s. The subject of this study is an ICT network which can provide ICT services. The GHG emissions model that was developed for the assessment was then used to identify those parts of the BATS system that would contribute the most to the GHG emission, so that attention could be focused on mitigating those emissions.

6.2.2 Functional unit

The function experienced by a user is the ability to send and receive data at up to 30 Mb/s in a rural or remote household, given that there is an existing broadband service operating at rates below 2 Mb/s.

The corresponding functional unit is the use of a broadband satellite system to provide an additional path to carry delay-insensitive information at rates of up to 30 Mb/s to a market peaking at 6.4 million households in Europe (EU28 plus Turkey) over an assumed life cycle of 16 years (2020–2035 inclusive).

The GHG emission of the network was estimated for each year of operation and summed to provide the life cycle GHG emission of the system.

6.2.3 System boundary

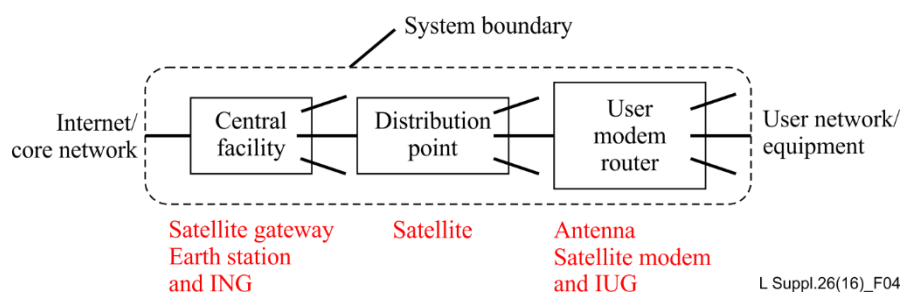


Figure 4 – System boundary

The boundary of the hybrid broadband satellite system is shown in Figure 4. Network elements for the satellite system include the following.

- The central facilities, also known as satellite GWs comprising: antenna, Earth station and ING.
- The distribution point, a geostationary satellite. Note that the launch vehicle and its fuel were included in the analysis.
- The user satellite modem, consisting of the antenna (dish), the radio frequency (RF) part consisting of a high-power amplifier (HPA) and a low-noise amplifier, baseband processor and the IUG.

The core network, data centres, user network and user equipment were assumed to be already present and are outside the scope of this assessment.

6.2.4 System boundary – Checklist of eight items

1) ICT hardware

This checklist item refers to the life cycle impact of ICT hardware. The hardware items were:

- IUG;
- Earth station GW upgrade for hybrid satellite;
- satellite (and launch vehicle plus fuel);
- user satellite modem;
- ING.

For each of these network elements, data values were gathered for the following life cycle stages included in the assessment:

- production: including raw material extraction and transport to installation site;
- use: including electricity or fuel;
- end of life treatment (EoLT): including disposal of network elements;

2) ICT software.

Only pre-production software was available at this stage of the project. More significant will be the software used to activate the expected use cases, which will vary dynamically according to the traffic presented. Handling of the future software needed to control this functionality and network configuration and management was not assessed. A sensitivity analysis was performed on a user satellite modem to highlight the GHG emission of various use cases as described later.

3) Consumables and other supportive products

Packaging was included in the calculation of production emissions of the user equipment.

4) Site infrastructure

The Earth station buildings and customer premises were assumed to be already in place, including air-conditioning units.

5) Transport (movement of goods)

Transportation of the ICT hardware to the location of installation was included.

6) Travel (movement of people)

This was considered to be out-of-scope for a calculation of the impact of ICT alone. Only first order effects were included.

7) Storage of goods

This was not accounted for.

8) Working environment

This was not accounted for.

6.3 Cut-offs

The following cut-offs were applied.

- Second order and other effects were not included (e.g., changes in user behaviour).
- The system boundary (see Figure 4) was assumed to be the IUG and ING in the case of hybrid broadband satellite technology. End user devices, such as television sets and personal computers, were not included because these were assumed to be existing devices. The core network was not included.
- The Earth station buildings and customer premises were assumed to be already in place, including air-conditioning units. Changes in building structure required for the upgrade of Earth stations, etc. were not included.
- Emissions from maintenance work was not included.
- Support activities were not included,
- Storage, disassembly, dismantling and shredding were not included.

6.4 Data collection and quality

Wherever possible, referenced sources of data were used, thus reducing the need for estimates by the project team. Secondary data used in the assessment was for the future network.

Global parameters, such as: the future addressable market, the number of households served and the future emission factors of the electricity grid are described in clause 8.

Clause 8 also describes how the network element parameters, such as the GHG emission by mass or by energy, were obtained.

For the European model, priority was given to emission factors obtained from the *Emissions database for global atmospheric research* [b-EU/JRC EDGAR, undated]. This database includes values for chemicals emitted, including CO₂ per unit mass. However, some tables date from 2006. When no figure was available, the most recent Defra spreadsheet was used [b-Defra, 2016]. It is not known what the trends will be in the future. Defra tables of carbon factors are updated annually. The most recent set of tables were used at the time of assessment (2014). No attempt was made to predict future values for these tables.

In some cases, no conversion factor was available from tables, so estimates were made from first principles. One example is the GHG emitted during the production of the fuel used by the rockets that launch satellites.

Where a parameter was considered to be important and could be estimated well into the future, publications were used to provide forward estimates. These included the number of households in a country, the emission factor for electricity (dependent on the energy mix), the addressable market and market share and the emissions of delivery vehicles. Future values for the power of broadband equipment were available from [b-EU/JRC CoC, 2013] up to 2016. More information on this is given in clause 8.

The data quality is difficult to assess for this case study, which requires parameters to be estimated for the future time period 2020–2035. In some cases, e.g., electricity and transport, future estimates were made from publications from the best available sources.

The JRC database [b-EU/JRC EDGAR, undated] is relevant to Europe, the geographical area of the study, but this is incomplete, as it focuses on chemical and materials rather than products (such as electrical goods). The data is older data than that of Defra [b-Defra, 2016], which is updated annually.

Whilst the Defra database is up-to-date, and includes the production (material use) of electrical goods by mass, it is focused on the UK. The estimate required for this case study should be an average for the whole of Europe, but in many cases only the Defra figure was available.

For waste electrical and electronic equipment (WEEE) the tables of [b-Defra, 2016] employed assume that raw materials rather than open loop recycling is used. However, recycling is being introduced in the UK for WEEE. Therefore the materials use for WEEE products may be an overestimate.

7 Life cycle stages

7.1 Raw material acquisition stage

Figures for the launch vehicle (rocket) and its fuel were derived from first principles using published data from [b-EU/JRC EDGAR, undated]. The derivation included values for elements such as iron, aluminium and hydrogen.

7.2 Production stage

Tables, such as those published for the UK [b-Defra, 2016], were used to provide carbon factors by mass for network elements that were used to construct the network. These are categorized as: WEEE – large; WEEE – mixed; and WEEE – small. (The same classification is used for EoLT. See clause 7.4). The generic tables available from [b-Defra, 2016] for electronic goods were used as a detailed inventory of the raw materials used in electronic products, such as a satellite modem. The proportions of raw materials in electronic products are not declared by Defra.

The production stage included the following processes:

- production of network elements and interconnections;
- transport of products to site;
- installation process.

The mass of a network element and its packaging was obtained from representative products already available.

7.3 Use stage

The energy consumption of a hybrid broadband satellite network during the use (operational) stage is the sum of the energy consumption of all subsystems and equipment included within the boundary of the network under investigation.

The energy consumption was assessed in kilowatt hours over the period of the assessment, including all subsystems. The energy consumption was estimated with reference to the EU JRC codes of conduct [b-EU/JRC CoC, 2013] or, if not available there, from representative products.

To convert in-use electricity into GHG emissions, the emission factor for the electricity supply was estimated, as described in clause 8. This will vary from year to year over the period 2020–2035. The variation of conversion factors for electricity in the EU can be found in [b-EC/DGE Energy, 2010]. It should be noted that the CO_{2e} conversion factor is expected to drop from 0.357 kg/kWh in 2020 to 0.275 kg/kWh in 2035.

A first approximation of the energy consumption of a hybrid broadband satellite network was derived from a typical satellite broadband network operating in the Ka band via a state-of-the-art geostationary high-throughput satellite, addressing both Earth station (GW) and user terminals. The satellite itself was not considered to consume any energy from sources on Earth while in orbit and therefore does not need to be accounted for in the use stage. However, the embodied carbon arising from the production of the satellite (including any electricity-generating sources, such as solar panels) was included.