INTERNATIONAL CONGRESS

EGG

ELECTRONICS GOES GREEN 2020+

The Story of Daisy, Alexa and Greta

September 1, 2020 | Berlin, Germany

Proceedings

The Going Green Partner Conferences

CARE Innovation
Austria

EcoDesign
Japan

ISSST
USA

Organized by Fraunhofer Institute for Reliability and Microintegration IZM, Berlin

in cooperation with Technische Universität Berlin

The power consumption of mobile and fixed network data services - The case of streaming video and downloading large files

Jens Malmodin, Ericsson Research, Ericsson AB, Stockholm, Sweden
jens.malmodin@ericsson.com, +46 730 311 785

Abstract

There are numerous claims in media about the electricity consumption of video streaming and data downloading over mobile and fixed networks. Reviewing these claims against recent data reveals many such claims to be inaccurate and out of range – often by orders of magnitude. Such claims are typically based on old *energy per data* figures for average use over time that cannot be applied to current very high data usages like video streaming and data downloading. Instead, as a more accurate and relevant method, this paper suggests that power models are used and suggests relevant parameter values for such models. Watching YouTube videos (~1 Mbps) on a smartphone including usage of networks and servers consume about 10 W on average. Streaming Netflix (4-5 Mbps) on fixed broadband add about 7 W, mainly from Netflix/partners data centers (servers), to the near constant 18 W power consumption of an average fixed broadband line including usage of higher order networks.

1 Introduction

Global GHG emissions need to be halved by 2030 to avoid the worst effects of global warming [1] and a halving is possible [2]. To identify accurate actions, it is necessary to get facts and figures straight to enable relevant decisions. This is especially true for media, policy makers and company executives with key roles and the power to influence many others.

At this point, there have been numerous claims about the energy consumption and GHG emissions related to downloading data or streaming video that are unreasonable when checked against relevant measurements and data. One example is the energy figure reported by French think tank *The Shift Project* [3] which translates to an unrealistic power consumption of up to 6 kW for streaming Netflix video, debunked by Kamiya at IEA [4], with a byte-to-bit correction from the think tank [5]. As shown in this study the corrected figure of 750 W is still completely out of range. *The Shift Project* based their claims on old hypothetical future scenarios [6] proven unrealistic (acknowledged by the author of [6] in [10]) by studies that uses up-to-date data from a large part of all networks globally [7-9].

Another such claim is that all downloads of a popular YouTube music video consume about 1 TWh electricity [11]. This energy figure translates to 2 to 10 kW depending on how many sec/min of the video that gets viewed and downloaded (not described by the source). But, as will be further outlined in this paper, viewing a YouTube music video on a smartphone (typical device used) consumes only about 10 W including usage of network and servers.

The common trait of such claims is that they rely on, often outdated, single *energy per data* figures (*kWh/GB*), sometimes based on real network averages, sometimes based on forecasts or future scenarios for which more recent assessments of actual conditions are available. This paper suggests the use of more accurate approaches based on power models considering that a user's average network use is typically represented by longer periods of *no data usage* split up by short periods of low data usage related to web browsing, social media, gaming etc. A very large error is made when such an average, is applied to specific high data usage services like video streaming and file downloading.

Energy per data figures are also associated with the impression that more data result in more energy. This has led to the belief that ICT's energy consumption is increasing fast, which is not the case according to studies of the sector´s actual energy usage [7-8]. More recently GSMA collected data from several large operators regarding their energy usage and data traffic development during the Corona pandemic and found minor changes in the former while the latter has increased a lot [9]: *"The GSMA surveyed several of its large operator members to ascertain the environmental impact of the surge in services such as videoconferencing and entertainment streaming. In most cases, network electricity usage has remained flat, even as voice and data traffic has spiked by 50% or more."*

This paper suggests a shift in how to model the energy consumption of network data services. Energy is a function of power over time and both these components need to be carefully studied and understood. This paper gives a broad understanding of how network equipment has evolved over time until today, how power models for each type of network equipment can be constructed based on real live network data, and show how the power consumption of mobile and fixed network data services can be estimated far more accurately.

2 Background

This section gives a short data background, introduces several important aspects and definitions, includes a short review of existing literature, and presents a short overview of the ICT sector.

2.1 A long history of real measured data

Ericsson has together with Swedish operator Telia measured the energy consumption in fixed and mobile networks since mid-90's and published several papers [7-8, 12-14] of importance for this study. In particular, since 2010 in a collaboration with ETNO (European Telecom Network Operators), detailed network operation data has been collected and analysed [7]. The data set has been expanded over the years and cover in 2018 about 15 operators with 60 operations in 45 countries.

In addition, a global data set that covers about 2/3 of all subscriptions globally 2015-2018 has been collected. This data collection started in 2005 with 10 operators [12] and has been expanded over the years to include 36 operators from 2015 [8]. The granularity of this data set is lower than the ETNO data set, but the larger sample size allows for more accurate global estimates.

All data used in this paper unless stated comes from these large data sets described above and from additional internal studies of other nation-wide networks.

2.2 Global ICT sector overview

Figure 1 show the ICT sector's electricity consumption and data traffic based on [8], and ongoing updates with 2018/2019 data.

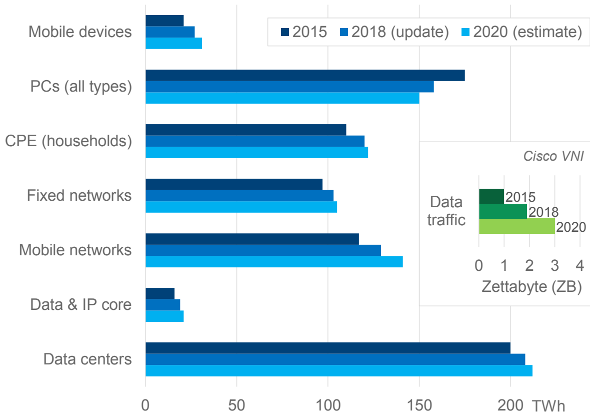


Figure 1: Global ICT sector electricity consumption and data traffic 2015-2020, based on [8]
Fixed networks include PSTNs, LANs and fixed broadband (BB) networks (WLAN/WiFi components included as fixed). Mobile networks include all standards, 2G/3G/4G/(5G).

Based on Figure 1, electricity consumption of networks increases with about +2.5%/year, data centers with +1.5%/year while user devices decrease with -1.5%/year. Number of subscriptions and data traffic increase faster, +3%/year and +25%/year respectively.

Figure 1 can be translated to average power values per subscription, line, user device or similar, also from [8], which gives a better "user" perspective, see Figure 2.

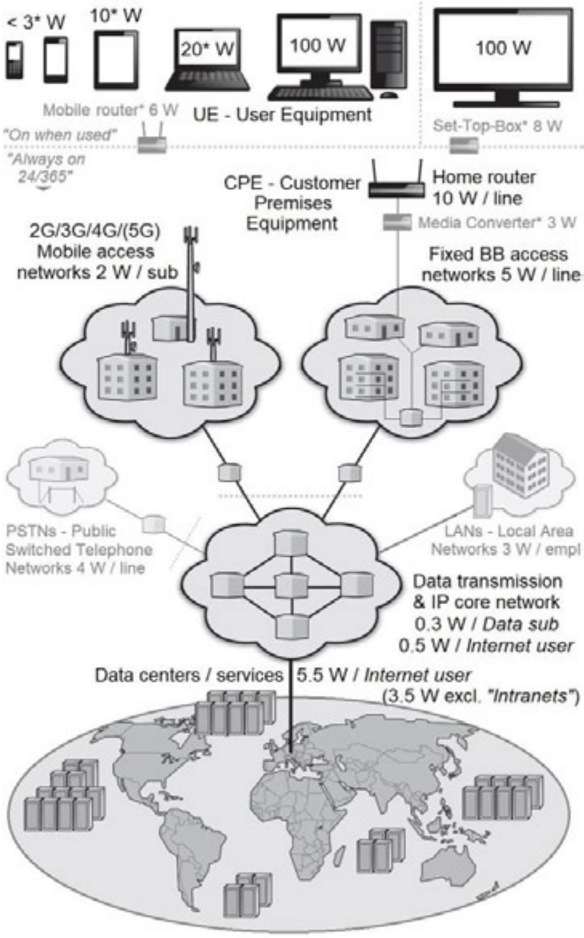


Figure 2: Global ICT sector average power values per subscription, line, user device or similar
* Portable user devices W-figures include charging losses, mobile routers, STBs and media converters are sometimes used (*optional*)

2.3 Low power per user, only a few Watt

The average power consumption per line/user (subscription) is relatively small, only about 2 Watt on average per mobile subscription globally.

The power consumption of the global data transmission and IP core network or the *Internet Backbone* is only about 0.3 Watt on average if the power consumption is split on 8.5 billion human mobile, fixed and LAN broadband subscriptions/users (not counting about 3 billion human "narrowband" users or any M2M/IoT subscriptions), or 0.5 W if split on *Internet users*.

For fixed broadband, the average power consumption is about 11.5 Watt for home routers and media converters and about 5 Watt for the average fixed broadband access network per line/household. A fixed broadband line is typically used by more than one person in a household and the average power per user is then about 4.5-6 W with an average of 3-4 users.

2.4 A reduction of power but an exponential increase of data

The average power consumption per line or user (subscription) of mobile and fixed network services has decreased over time from their introduction up to around 2010, after it has been stable [8]. This decrease has happened despite data rates and data traffic kept increasing exponentially [8]. The maximum possible data rate has increased from a low 10-60 kbps around 1995 in the order of 10 000 times to 100-1000 Mbps in mobile and fixed networks currently (2020).

2.5 Power is NOT proportional to data

The power consumption of network equipment is not proportional to data traffic or "usage" of the same equipment. This fundamental behaviour, seen in real measurements and described in more detail in section 4, is a key concept in this study. Only high output power mobile base stations show a limited proportionality power - data, but the average variation across base stations in a network is only in the +0% to +20% "window" with an average power typically <+10% from a quite high *idle* power consumption.

2.6 Existing literature

Table 1 list several previous studies that have estimated or measured electricity consumption and data traffic in networks, mainly based on a study by Aslan et al [15].

Reference and year to which data apply	kWh/GB CPE / *Network*	*Network* W/Mbps
Taylor & Koomey, 2000 [A]	# / 7	3182
Taylor & Koomey, 2006 [A]	# / 0.7	318
Weber et al, 2008 - 2010 [B]	(1.2) [C]	(545) [C]
Coroama et al, 2009 [AB]	# / 0.2	91
Baliga et al [16], 2008 - 2010	0.11 / 0.06 [D]	27 [D]
Malmodin et al [13], 2010 [AB]	0.3 / 0.16	73
Shehabi et al, 2011 [A]	0.18 / 0.11	50
Krug et al, 2012 [A]	# / 0.14	64
Suski et al [17], 2014 - 2020	# / 0.024	11
Krug et al, 2014 [A]	# / 0.06	27
Malmodin et al [8, 13], 2015 [A]	0.043 / 0.023	10
Priest et al [18], 2016	# / 0.08 [E]	36 [E]

Table 1: *Energy per data* figures (*kWh/GB*) for fixed CPE and the *network* from existing literature Note: This study does not recommend the use of these figures to quantify

[A] Figures have been obtained via Aslan et al [15] and…
[B] …Malmodin et al [13] unless stated
[C] Weber et al combines CPE and *network* into one single figure
[D] Swedish 2010 data used with Baliga et al model described in [13]
[E] Total figure for both fixed and mobile (3G/4G)

Figures in Table 1 are from or represent average network conditions. However, some of the studies have used these figures for specific high data use cases like video streaming that this paper does not recommend. But most claims in media come from 3rd party uses of these figures multiplied by today's video streaming data and that have led to large overestimations, e.g. [3].

The *network kWh/GB* figures in Table 1 can be translated to W/Mbps figures which indicates the figures are for average low data traffic not to be used for higher data bit rates as they result in power levels not possible (10 Mbps result in 100 W or more).

Baliga et al [16] recommended in their 2009-paper that some network components should be modeled based on use time rather than data in the future. But this recommendation seems to have gone under the radar like our own statement from 2014 about the use of *kWh/GB* figures [13]: *"Further, because those figures are based on average conditions, the results are not relevant for specific conditions, such as very high bit rates and data traffic, as in B2B data traffic, or high-end video conferencing or video streaming."*

Given the discussions above the popular energy intensity per data approach should be replaced with more accurate approaches. Ericsson published earlier this year a report that looked at the carbon footprints of digital services [19] based on more detailed power models. This study digs further into the details.

3 Generic power model

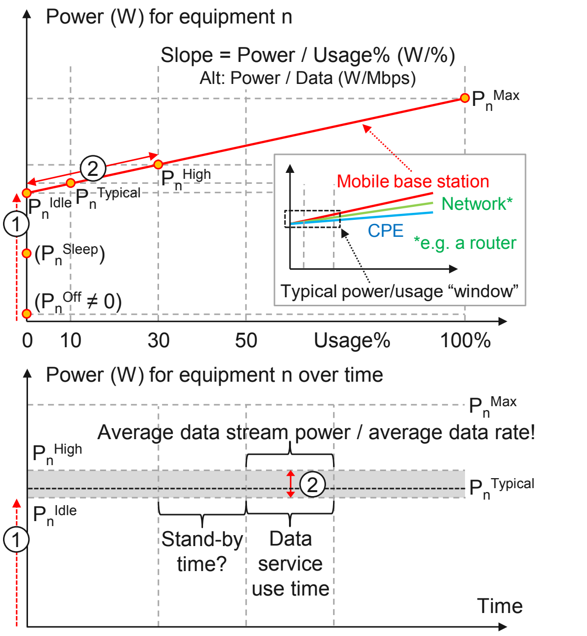
In this section a generic power model that can be used for any equipment or device is described, see Figure 3. Similar power models have been in use within Ericsson for over 10 years, see e.g. [20], and they are still in use, see e.g. [21]. The focus of the paper is network equipment including CPE, but the model can also be used for user devices and data center equipment (servers).

CPE and all network equipment are typically "always on" 24/7 all year round. Even when there is no user data to send or process, the equipment typically consume power at a level close to its average operation point. The power of any equipment can be modeled based on two components, an "idle" power component and a variable power component proportional to data use. The "idle" power component can be described as a basic connectivity data service that enables a user (or subscriber/subscription) to fast connect to and use any network data service or reach another user or be reached by any network data service or another user *at an instant (or close to) high data bit rate*. Just to enable this connectivity requires a lot of the network resulting in a high idle power consumption or *service power*.

The P^{Idle} point can be defined as *no load (no user data)* but including network/system data needed to operate the network/system, e.g. reference/system/sync data in 4G mobile networks [21]. This basic connectivity *service power* consumption is about 2 W per mobile (2G/3G/4G) subscriber, about 1 W for 4G mobile data only and about 6.5 W / 18 W for fixed broadband with and without CPE. These figures include a share of all higher order data transmission and IP core networks (see section 4.5). It is this basic connectivity service subscribers pay for, and data usage is often unlimited at no additional cost (but a small increase in power).

The variable power component of network equipment shows typically a linear proportionality from the P^{Idle} point between power and data usage (load) or can be approximated as such. It is possible to also include e.g. power supply (same proportionality) and cooling (little to no proportionality) so the power model can include the total equipment power which is done in this study. Impact of sleep and off modes (limited in today's networks) can be included in the model proposed. This is an area for improvements, both for real live networks and the model.

The upper part of Figure 3 shows a mobile base station to illustrate the power / usage better as mobile base stations show a larger variation in power consumption. The generic power model can also be used for CPE and fixed network equipment but has then less slope.



Alt: Power / Data (W/Mbps)

$$P_{Total} = \sum_{n=1}^{n} (\underbrace{P_n^{Idle} / \text{Users}}_{\text{Service power}} + \underbrace{\text{Usage\%} * (P_n^{Max} - P_n^{Idle}) / \text{DataUsers}}_{\text{Data stream power}})$$

$$E = P_{Total} * \text{DataServiceUseTime} \text{ [Wh]}$$

Figure 3: Power model and typical power over time for CPE and network equipment

A user's total data service power is simply the sum of all power shares, both the idle and variable component, for all equipment the data service uses along the network route. Total energy (electricity) E is simply: Total power * time (data service use time).

Additional *stand-by time* may be allocated to a data service, but it is then important to set the stand-by power = idle power, e.g. about 1 W per user for 4G mobile data. This is discussed more in the Discussion section.

4 Power models for all ICT parts

This section describes each ICT sector part with a focus on mobile and fixed broadband networks, how they have evolved over time and how a power model can be constructed based on real live network and individual network equipment data.

4.1 PSTN

PSTNs (Public Switched Telephone networks) is not in focus in this study but is described briefly. In the first measurements of PSTN by Swedish operator Telia in the early 90's, the average electricity consumption was about 40 kWh per active line for network sites and a further 25 kWh for "overhead" like offices, stores and other sites (including also some manufacturing sites at that time). The average today based on the ETNO data set [7] is about 36 kWh (~4 W) without overhead.

4.2 Mobile (broadband) access networks

The first network wide electricity measurement was carried out together with Swedish operator Telia in 1997 in the "08-area" (greater Stockholm area). The electricity consumption of the 2G (GSM) mobile network was about 33 kWh per subscription (sub) and the average for the whole of Sweden was estimated to about 40 kWh. In addition, about 8 kWh electricity per sub was consumed in offices, stores and other non-network sites [14]. The global average in 1997 was estimated to about 35 kWh with individual countries ranging from about 25 kWh to 65 kWh excluding overhead.

The electricity consumption per sub in mobile networks decreased relatively fast 1995 – 2005 as the increased number of subscribers used the same networks. The power consumption has since early 2000's been around 2 W, changing from slowly decreasing to slowly increasing around 2010, see Figure 4 and [8, 12]. At the same time, the increase in possible data rates and actual data traffic has been in the order of 10000 times [8].

The average power consumption currently (2020) in mobile access networks is in the range 1 to 4.5 W/sub for selected countries with a global average of around 2 Watt corresponding to an annual electricity consumption of about 17 kWh, see Table 2 and [7-8]. Most mobile networks include 2G, 3G and 4G services, some networks even 5G today. The power consumption of only the 4G part is around 1 W/sub but since not all networks offer 4G the global average is lower. 4G can be >50% of the power in built-out modernized networks. In sparsely populated countries like Finland and Sweden the 4G power per sub is about 2 W.

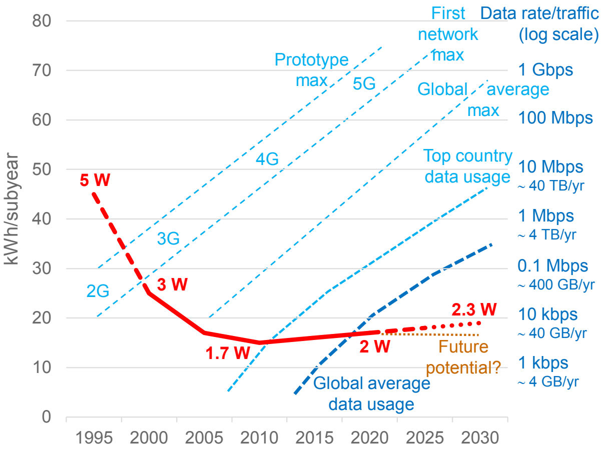


Figure 4: Average power, electricity use and data per mobile subscription over time, based on [7-8]

Year 2018	Capita /km²	Access network	Over-head [1]	Carbon footprint [2]
Finland	16	40 kWh	5 kWh	9 kg CO_2e
Sweden	23	35 kWh	5 kWh	2 kg CO_2e
US (excl. Alaska)	40	30 kWh	4 kWh	20 kg CO_2e
EU-28	110	25 kWh	4 kWh	12 kg CO_2e
China	150	20 kWh	3 kWh	18 kg CO_2e
World	**50**	**17 kWh**	**2.5 kWh**	**12 kg CO_2e**
Germany	240	14 kWh	2 kWh	13 kg CO_2e
India	400	13 kWh	1.5 kWh	17 kg CO_2e [3]
Bangladesh	1000+	9 kWh	<1 kWh	8 kg CO_2e [3]

Table 2: Electricity consumption and carbon foot-print per sub in selected countries, based on [7-8]

[1] Overhead = offices, stores, warehouses etc. (all non-network sites) Overhead is NOT included in the power model

[2] Using the country average electricity emission factor

[3] Including on-site diesel generator emissions

4G mobile BB access networks show a larger proportionality between power and usage compared to 3G and fixed BB. Still, 4G radio unit need a certain level of power, about 50% of its max power, to establish and maintain area coverage, keep track of and constantly broadcast reference/system/sync data to possibly thousands of mobile devices and be ready to instantly respond to any input from users and the network.

The additional power consumption is typically between 1 and 2 Watt per Mbps user data traffic. The power is typically lower in small cells with lower output power but can also be higher. New base stations typically operate more efficiently than older ones but can have higher output power. Figure 5 show the proposed power model and real measurements of a medium sized new 4G base station (part of a 2G/3G/4G base station) in a suburban environment. Note that also power for cooling, power conversion, baseband and data transmission is included in Figure 5 – *a whole base station site*.

Based on Figure 5 one could possibly allocate about 60 Watt to the 4 Mbps HD video stream based on the about 30% data share. However, that would be to ignore how a base station operates and what we can measure and see in Figure 5. The power before and after the added video stream is about 215 Watt, the additional power for the video stream is only about 6 Watt (P_{10} to P_{14}). A 4G radio unit can serve up to 1000 subscriptions and before, after and during the video stream, other active users are *served* with data and all subscriptions are constantly *served* with reference/system/sync data. Based on how a base station operates, it is not recommended to allocate any additional "stand-by-time" to any specific usage, especially not based on share of data.

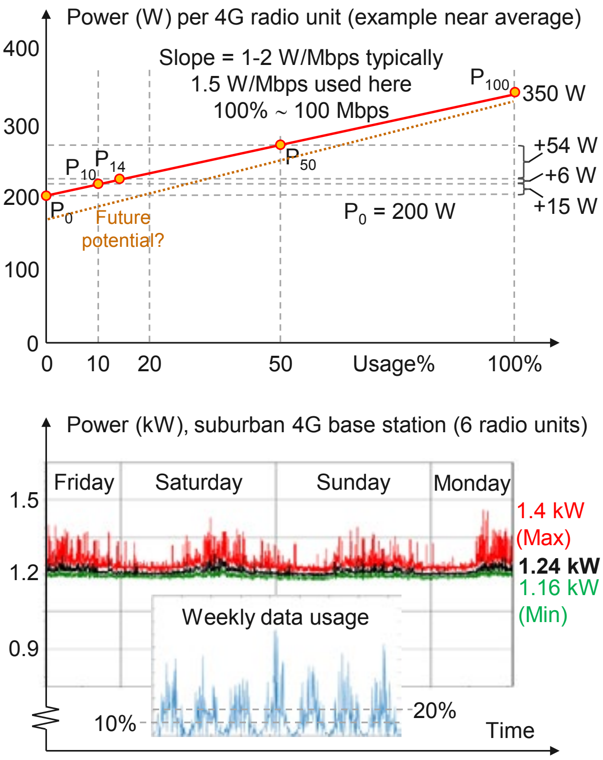


Figure 5: Power and data model for a suburban 4G radio unit / base station (based on real data)

Includes the whole base station (radio units, baseband, power and cooling) and its share of the data transmission and IP core network. P_{10}-P_{14}: 4 Mbps video stream, P_{10}-P_{50}: File download (40 Mbps)

Dedicated data transmission and control & core nodes typically make up about 5% of the electricity consumption of the access network. For the 4G base station in Figure 5 the power consumption of the additional higher order data transmission and IP core network is about 60 W (also about +5%), see section 4.5.

4.3 Fixed broadband access networks

The first generation of fixed BB access lines (ADSL) used existing PSTN lines (copper) and the electricity consumption per line was in the range 5 – 10 W and for the modem 10 – 15 W. The power consumption improved fast from >20 Watt to <15 Watt in a few years. For a short period of time, additional routers were needed to get more LAN and WiFi connections but that changed with modem/router combo products that also

ISBN 978-3-8396-1659-8

started to include IPTV and IP-telephony functionality. The average power consumption is about 11.5 Watt for the average mix of home routers and media converters with a wide range of about 6 – 30 W.

Year	CPE	Access network	Core network
2003	1st gen. modems: 12.5 W, 110 kWh	1st gen. ADSL: 7.5 W, 66 kWh	5 W, 44 kWh
2007 2010	Modems/routers: 13.5 W, 118 kWh	2nd gen. ADSL: 5 W, 70 kWh	3 W, 26 kWh
2015	Home router: 11 W, 96 kWh	Mix of all technologies: xDSL, fiber, cable-TV: 5 W, 44 kWh	1.5 W, 13 kWh
2018	Home router+*: 11.5 W, 101 kWh		
2018	Media converter: 3 W, 26 kWh	Used for fiber lines (about 50% share of lines 2020)	

Table 3: Average power and electricity use per line in fixed BB access networks, based on [7-8, 14]

* Includes also a share of media converters used for fiber lines

The power consumption per access line currently (2020), is in the range 2 W to 10 W with an average of 5 W for all main BB access technologies: xDSL, fiber and cable-TV [8, 14]. Older fiber and cable-TV lines typically consume more and new lines less.

Figure 6 show the power consumption of a typical fixed broadband line with an average share of the core network included (see section 4.5). The power per line have been reduced with about 25% 2000-2020. At the same time, the max data rate and average data traffic per line have increased >100 times [7-8].

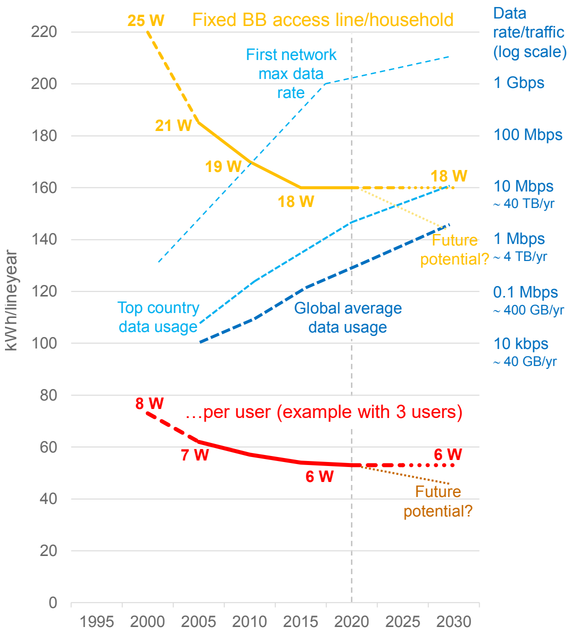


Figure 6: Average power, electricity use and data per fixed BB line over time, based on [7-8, 14]

Figure 7 show the proposed power model for an average fixed BB access line and how the power varies with different data uses and number of users, 3-4 users typically per line. As shown in Figure 7, an average *energy per data* figure over time cannot be used for high bit rate use cases like video streaming and file downloading as such numbers can be >100 times too high for those conditions, see Figure 7.

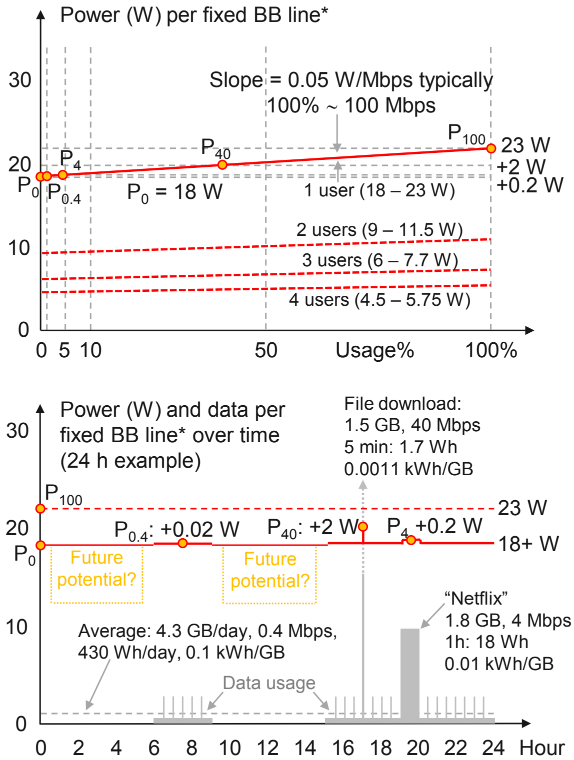


Figure7: Power/data and power/time (24 h) model for a fixed BB access line* (household)

* Includes CPE (home router) and all components of a fixed BB access network per line and its share of the data transmission and IP core network

The power consumption of a home router depends on first the model but then on services included in the subscription, how it is configured and the number of active connections/users in the household, but power variations are small, and after set-up/connections the power variation is even smaller. A fixed BB subscription and the home router can include IP-telephony (~1 W), IPTV (use of dedicated LAN-port), typically 4 LAN-ports (~1 W/port), WiFi (~2 W) and WAN connection and main module (~3 W). Several devices per user can be connected but this study recommend splitting the power on number of users as it is simple, and a user typically uses only one device at a time.

It must be noted that to allocate all power to one user in a household with e.g. 4 users is doing the impossible as one user only can use a share of the router, e.g. 1 LAN-port or share of WiFi. A more complicated split based on router component use would probably yield even lower power figures per user, but the simpler per user model is preferred here.

4.4 LANs - Local area (access) networks

LANs are not in focus in this study and are only described here briefly. The first measurement of LANs at

ISBN 978-3-8396-1659-8

Ericsson was carried out in Sweden in the mid 90's. It was difficult and not a primary goal to separate the LAN part from all other equipment like servers and storage that was mainly hosted locally at that time. The result indicated a power consumption of 10 Watt or more per active employee. New studies were done 2005-2010 "before and after" large IT modernizations and the LAN-part dropped from about 7 Watt in 2005 to about 3.5 Watt in 2010. The average power consumption in today's LANs have decreased further but due to the increase of WLAN equipment the average power is still about 3 Watt per active employee.

4.5 Data transmission and IP core network(s) (or just *core network*)

In the ICT network studies in Sweden 2010-2015 [14], the electricity consumption was constant in absolute terms, but there was a shift in electricity consumption from data transmission equipment to the IP core network, from link equipment to routers.

In 2009, Ericsson studied video conference data transmissions between offices in Sweden and the US including the Swedish core network and a high-capacity Atlantic optical submarine cable system (TAT-14) with help from operator Telia [22-23]. The average power consumption was estimated to about 2.5 W/Mbps (one direction), the Atlantic cable represented 0.5 W/Mbps. The hop count was 20 plus the Atlantic cable counted as only one. Today, 10+ years later, the same data transmission uses <1/10th of the power, see Table 4.

Today it is possible to have a data throughput of >1 Gbps per Watt in edge/metro routers and >3 Gbps per Watt in core routers and the variable power/data is only about 1/10th of that. Not to forget data transmission equipment with repeaters that are like routers in terms of power. Table 4 summarizes selected data for the core networks described in this section.

	Average per Data sub / Internet user	Split Fixed line / Mobile sub
Sweden 2010-2015 [12-13]	0.8 W / 1.5 W	3 W / 0.3 W
Europe/World 2015-2020 [7-8]	0.3 W / 0.5 W	1 W / 0.15 W
Typical router data	**Δ power**	**Total power**
Edge/Metro router [A]	0.1 W/Gbps	1 W/Gbps
Core router [A]	0.03 W/Gbps	0.3 W/Gbps
Ericsson 2009 study [21-22]	**2009**	**2020**
Routers (20)	0.7 W/Mbps	0.1 [B] W/Mbps
High capacity optical links with repeaters	1.3 W/Mbps	0.1 [B] W/Mbps
Atlantic optical submarine cable system including "data centers" at both ends [22]	0.5 W/Mbps	0.05 W/Mbps

Table 4: Data transmission & IP core network data

[A] These figures are similar to figures used by others [24-25]

[B] Proportions between routers and links modified based on [14]

The power model for the core network is the sum of the network route equipment (number of hops). Based on the data in Table 4, the following simple summary model with a fixed service power component and a variable power/data component is proposed:

Fixed BB power = 1.5 W + 0.03 W/Mbps
Mobile BB (4G) power = 0.2 W + 0.03 W/Mbps

The above model is a bit cautious and power is probably lower in real live networks as the ETNO Europe/World data suggest [7], (see section 2.1). Number of hops and an Atlantic hop is on the high side.

4.6 Data centers / services

Data centers / services show unique behaviours for each application. A global/regional/country average cannot be used to estimate a specific data service. Data traffic is not proportional to energy consumption. Netflix share of global data traffic was about 15% in 2018 but its share of data center electricity consumption was only about 0.2% [4].

Netflix global electricity consumption 2018/2019 including their use of other ICT companies' platforms (like Amazon and Google) divided by total video hours (about 50-65 billion h, about 250-300 EB), result in about 5-7 W per average video stream (4-5 Mbps) [4]. Note that non-streaming servers and other electricity consumption at Netflix (e.g. offices) related to production and other business activities is also included.

YouTube are here estimated to about 1 TWh (a lower estimate of <0.5 TWh can be found in [17]). With a much larger user base, less average use time and video quality, and much less overhead (own production) per video, the resulting power and electricity consumption are estimated to be less than half per video (time) compared to Netflix.

Table 5 shows key parameters for several well-known data services. Many of the well-known data center / services have a low power and energy consumption per user. Even if we sum FAMGA + Netflix and split their total electricity use on 3.5 billion Internet users (excluding some countries), the resulting power (1.1 W) and energy (9.4 kWh) is modest.

Year 2018 unless stated	AEC TWh	Users million	Use time (h/day)	Average W*/W*/kWh
FAMGA+N	33	3 500	na	1.1 / na / 9.4
Netflix	0.3	125	1 h 11 m	0.27 / 5 / 2.4
Netflix 2019	0.45	155	1 h 11 m	0.34 / 7 / 3
Facebook	3.4	2 400	40 m	0.16 / 6 / 1.4
Google	10.1	3 500	1 h	0.3 / 8 / 3
YouTube	1	2 000	11 min	0.1 / 2.7 / 0.5
Wikipedia	0.003	*Any stats result in low power/energy**		

Table 5: Examples of data center / services power/energy figures and use statistics

* Energy split on 24/7 all year round, next W-figure: energy split only on use time, Wikipedia user stats not known

ISBN 978-3-8396-1659-8

4.7 User devices (discussion)

User devices are not in focus of this paper. But for the sake of completeness their role in relation to data services (e.g. video streaming) is discussed briefly.

Desktop PCs and TVs consume in the order of 100 W in operation [8]. One simple rule is then: If an application or data service can be run on a smaller and more energy efficient device like a laptop, tablet or preferably a smartphone, power and energy consumption can be reduced substantially. Other studies have come to the same straight-forward conclusion, e.g. [16].

The additional power for streaming is mainly related to the data center / service as it mainly occurs over fixed BB (and WiFi) with low additional power. An optical disc player's stand-by consumption over a year is as large or larger (1/0.3 W before/today) than the average Netflix subscription (0.3 W, 3 kWh). The manufacturing of DVD's/BD's and the disc player, operation of the disc player and physical travels make the traditional physical way of watching a film more energy and material consuming. Streaming is a good example of dematerialization.

As video streaming has allowed watching e.g. TV-series and movies even on smartphones and tablets, there is probably a large hidden power and energy net saving effect of streaming. There are less TV's on in a household, also the primary TV is on less time, and PC usage show the same pattern of less use [8, 14]. Another probable positive effect of a high data bit rate is that user devices like TVs and PCs need to be on less time for upgrades and downloads of files (or file sharing). File sharing used to consume lots of power 10-20 years ago as primarily PCs were left on for hours to share files. To try to quantify this net power saving effects of streaming is an area for future research.

5 Total results - Conclusions

This study does not recommend using single *energy per data* figures (*kWh/GB*) as they are typically based on old average conditions and they lead to large overestimations for today's high data use cases like streaming video or downloading large files. The power consumption of mobile and fixed network data services can be calculated in a simple way according to Figure 8 based on the power models proposed in this paper.

In contrast to media reports [3,5,11], streaming YouTube and Netflix videos do not consume a lot of power. Watching a YouTube video (~1 Mbps) on a smartphone including network and server consume about 10 W and not >1000 W. Streaming Netflix adds about 7 W, mainly from Netflix/partners data centers (servers), to the near constant power consumption of a fixed broadband line of about 18 W.

Mobile BB (4G) data:

$$\underbrace{\overset{0.5\text{-}2\text{ W}}{1\text{ W}} + \overset{1\text{-}2\text{ W/Mbps}}{1.5\text{ W/Mbps}}}_{\text{"Base stations" Radio access network}} + \underbrace{\overset{0.05\text{-}0.5\text{ W}}{0.2\text{ W}} + 0.03\text{ W/Mbps}}_{\text{Data transmission \& IP core network}}$$

No data (inactive): 1.2 W
"Web surf" (0.4 Mbps): 1.8 W
"YouTube" (1.5 Mbps): 3.4 W
"Netflix" (4 Mbps): 7.3 W
File download (40 Mbps): 62 W

Fixed BB data (100%* = 100 Mbps*):

$$\underbrace{\overset{8\text{-}35\text{ W}}{16.5\text{ W}} + \overset{0.01\text{-}0.04\text{ W/\%}}{0.02\text{ W/\%*}}}_{\text{CPE and access network}} + \underbrace{\overset{0.5\text{-}3\text{ W}}{1.5\text{ W}} + 0.03\text{ W/Mbps}}_{\text{Data transmission \& IP core network}}$$

$$= \frac{18\text{ W}}{\text{Users}} + \frac{0.05\text{ W/Mbps}}{\text{DataUsers}}$$

Users = 1, 2, 3, 4…

No data (inactive): 18 W, 9 W, 6 W, 4.5 W
"Web surf" (0.4 Mbps): +0.02 W / DataUsers
"YouTube" (1.5 Mbps): +0.08 W / DataUsers
"Netflix" (4 Mbps): +0.2 W / DataUsers
File download (40 Mbps): +2 W / DataUsers
File download (100 Mbps): +5 W / DataUsers

Figure 8: Simplified power model for mobile and fixed data services with ranges and key results
* The data rate varies a lot between different fixed BB access subscriptions but the power variation with data rate is marginal

Number of users in a household and number of data service users, e.g. 2 data users watching Netflix in a household of 4, must be considered for fixed BB data. The last step to calculate Energy (E) is to integrate power (P) over time (t) which in the simplified form is:

$$E = P_{Use} * t_{Use} \ (+ P_{Stand\text{-}by} * t_{Stand\text{-}by}) \ [Wh]$$

Streaming saves energy and materials compared to e.g. traditional optical discs and as streaming let us use tablets (< 10 W) and smartphones (< 3 W) there is a large "hidden" net effect when we turn off our PCs and TVs (about 100 W) to be quantified by future research.

6 Discussion

This paper suggests more detailed modelling of energy consumption of network data services beyond often used energy intensities per byte which are mostly not representative and relevant for the purpose. Energy is a function of power over time and both these components need to be carefully considered and understood.

Energy per data figures (kWh/GB) are typically network wide metrics that can be used to understand a network and how it evolves, but further use is limited. Such figures should not be used to calculate an energy consumption related to a specific data service based on amounts of data. The reason is simple, power and electricity consumption show little to no proportionality to data due to the idling consumption of involved equipment. An average kWh/GB figure can be >100 times higher as an average vs in specific very high bit rate use cases like large file downloading, see Figure 7.

The use of the proposed power models in this paper instead of often used *energy per data* figures is supported by several strong arguments based on observations of real networks their behaviour over time:

- First, the power model is built on real live network data from a long period of time including up-to-date data from a large part of all networks globally.
- The proportionality between average power consumption and data for network equipment is very weak. Additional power consumption per additional data is very low.
- Subscriptions with unlimited data is becoming standard. The business model can be said to be aligned with the power model or vice versa.
- No connection between power consumption and data use is seen in history. Historic data shows data rates and data traffic have kept increasing exponentially (slowing down slowly) while power consumption has decreased per subscription or line.
- An instant high bit rate is wanted/needed for all data use, not only streaming and data downloading. For video streaming and file downloading a delay of a few sec can be accepted as they last much longer. Such delays are not accepted when we browse the web, social media use, gaming etc.
- "Network electricity usage has remained flat, even as voice and data traffic has spiked by 50% or more." GSMA studied the impact on networks from the recent lockdowns due to the Corona virus [9]. Again, no proportionality power - data.

One argument against the proposed power models is so-called *network stand-by time* are not considered. But stand-by time can easily be added by multiplying the *no data (inactive)* power with an appropriate stand-by time. But the real question is: Should any stand-by time be allocated to any use time at all?

A mobile base station serves in the order of 1000 subscriptions. Any allocation of stand-by time must be from times when the base station tracks up to 1000 users and serve up to 100 or more active users with data. For mobile, the stand-by power is in all cases marginal, and hard to justify. The same thinking can be applied to a fixed broadband line. Each person/user in a household and all devices are typically constantly connected. And to allocate all power to one user is physically impossible as a user use only one LAN-port or a share of the WiFi, main module and WAN-connection and so on. And for stand-by time it is the same as with base stations (WiFi ~ small base station), other users use the equipment and are connected to it. Any allocation of stand-by time becomes hard to justify.

An unintentional effect of using average *energy per data* figures for specific high data use cases is that the energy figure implies that a very long stand-by time have been added to the actual data use time. Real live network measurements show it is impossible to consume that amount of power. For every video hour typically >10 h stand-by time have been added and for file downloads this can be >100 times. This study does not recommend adding any stand-by time but if it is done, it must be carefully considered and quantified.

We need to learn that there is a certain power associated with being able to instantly be reached or reach most humans on the planet and get access to most knowledge and entertainment ever created, and an ever-increasing number of data services (*Internet*). The power consumption does not start when we use it, it is there all the time.

7 Acknowledgement

This study would not have been possible without the 20+ year-long collaboration with Dag Lundén and his colleagues at Swedish operator Telia. And thanks to Dag's colleagues at other ETNO operators, up-to-date detailed network operations data has been made available for our studies otherwise hard to come by.

8 Literature

[1] Rockström, J., Gaffney, O., Rogelj, J. et. al. "A roadmap for rapid decarbonization", 2017, Science, Volume 355 Issue 6331

[2] The Exponential Roadmap, "Scaling 36 solutions to halve emissions by 2030, version 1.5.1", March 2020, ISBN: 978-91-986090-1-1, https://exponentialroadmap.org/

[3] The Shift Project, "Climate crisis: The unsustainable use of online video", July 2019, https://theshiftproject.org/en/article/unsustainable-use-online-video/

[4] G. Kamiya (IEA), "Factcheck: What is the carbon footprint of streaming video on Netflix?", CarbonBrief, February 2020, https://www.carbonbrief.org/factcheck-what-is-the-carbon-footprint-of-streaming-video-on-netflix

[5] The Shift Project, "Did The Shift Project really overestimate the carbon footprint of online video?", June 2020, https://theshiftproject.org/en/article/shift-project-really-overestimate-carbon-footprint-video-analysis/

[6] A. Andrae, T. Edler, "On global electricity usage of communication technology: Trends to 2030", Challenges, 2015, Vol.6, No.1, pp. 117-157.

[7] J. Malmodin, D. Lundén, “The electricity consumption and operational carbon emissions of ICT network operators 2010-2015”, KTH Report 2018, ISBN: 978-91-7729-679-9, https://www.divaportal.org/smash/get/diva2:1177210/FULLTEXT01.pdf

[8] J. Malmodin, D. Lundén, “The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015”, Sustainability, 2018, 10, 3027; doi:10.3390/su10093027.

[9] GSMA Europe, “COVID-19 Network Traffic Surge Isn’t Impacting Environment Confirm Telecom Operators”, June 2020, https://www.gsma.com/gsmaeurope/latest-news-2/covid-19-network-traffic-surge-isnt-impacting-environment-confirm-telecom-operators/

[10] NyTeknik, “How much electricity do the world’s data centers consume really” (“Hur mycket el förbrukar världens datacenter egentligen?” in Swedish), May 2020, https://www.nyteknik.se/story/hur-mycket-el-forbrukar-varldens-datacenter-egentligen-6995233

[11] BBC News, “Climate change: Is your Netflix habit bad for the environment?”, October 2018, https://www.bbc.com/news/technology-45798523

[12] J. Malmodin, Å. Moberg, D. Lundén, G. Finnveden, N. Lövehagen, “Greenhouse gas emissions and operational electricity use in the ICT and Entertainment & media sectors”, Journal of Industrial Ecology, 2010, 14, 770–790.

[13] J. Malmodin, D. Lundén, Å. Moberg, G. Andersson, M. Nilsson, “Life Cycle Assessment of ICT - Carbon Footprint and Operational Electricity use from the Operator, National, and Subscriber Perspective in Sweden”, Journal of Industrial Ecology, 2014, 18(6), 829-845.

[14] J. Malmodin, D. Lundén, “The energy and carbon footprint of the ICT and E&M sector in Sweden 1990-2015 and beyond”, Paper presented at: ICT4S, Amsterdam, 2016, https://www.ericsson.com/assets/local/publications/conference-papers/energy-and-carbon-footprint-ict-em-sector-sweden-1990-2015.pdf

[15] J. Aslan, K. Mayers, J. G. Koomey, und C. France, “Electricity Intensity of Internet Data Transmission: Untangling the Estimates: Electricity Intensity of Data Transmission“, Journal of Industrial Ecology, 2017, doi: 10.1111/jiec.12630.

[16] Baliga, J., R. Ayre, K. Hinton, W. Sorin, and R. Tucker. 2009. Energy consumption in optical IP networks. Journal of Lightwave Technology 27(13): 2391–2403.

[17] P. Suski, J. Pohl, V. Frick, “All you can stream: Investigating the role of user behavior for greenhouse gas intensity of video streaming“, ICT4S, 2020, https://doi.org/10.1145/3401335.3401709

[18] C. Preist, D. Schien, und P. Shabajee, “Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube”, in Proceedings of the 2019 CHI Conference, Glasgow, 2019, S. 1–12, doi: 10.1145/3290605.3300627.

[19] Ericsson IndustryLab Report / Background Report, “A quick guide to your digital carbon footprint”, 2020, https://www.ericsson.com/en/reports-and-papers/industrylab/reports/a-quick-guide-to-your-digital-carbon-footprint

[20] G. Auer et. al., “Energy efficiency analysis of the reference systems, areas of improvements and target breakdown“, EARTH EU project work package 2 report, 2012 update, https://cordis.europa.eu/docs/projects/cnect/3/247733/080/deliverables/001-EARTHWP2D23v2.pdf

[21] P. Frenger, R. Tano, “A technical look at 5G energy consumption and performance“, Ericsson Blog, September 2019, https://www.ericsson.com/en/blog/2019/9/energy-consumption-5g-nr

[22] C. Donovan, “Twenty tousend leagues under the sea: A Life cycle assessment of fibre optic submarine cable systems, MSc Thesis, Degree project SoM Ex 2009:40, Department of urban planning and environment, Royal institute of technology, Stockholm, 2009

[23] J. Malmodin, D. Lundén, M. Nilsson, G. Andersson, ”LCA of data transmission and IP core networks“, Electronics Goes Green 2012+, http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6360437&contentType=Conference+Publications&sortType%3Dasc_p_Sequence%26filter%3DAND%28p_IS_Number%3A6360408%29%26rowsPerPage%3D75

[24] F. Jalali, K. Hinton, R. Ayre, T. Alpcan, R. Tucker, "Fog computing may help to save energy in cloud computing", IEEE Journal on selected Areas in Communications, Vol. 34, No. 5, May 2016, 1728-1739

[25] Yunbo Li, Anne-Cécile Orgerie, Ivan Rodero, Betsegaw Lemma Amersho, Manish Parashar, et al.. End-to-end Energy Models for Edge Cloud-based IoT Platforms: Application to Data Stream Analysis in IoT. Future Generation Computer Systems, Elsevier, 2018, 87, pp. 667-678, doi: 10.1016/j.future.2017.12.048