Making smart devices really smart - A design guideline for networked household products with reduced standby energy consumption.

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ABSTRACT

The proliferation of "smart technologies" becomes visible with more network connected devices in modern households. Such devices require a network connection, which demands the network modules to be active at all times, leading to additional energy consumption even during periods of inactivity - so called "network standby". This research investigated the network standby power consumption of connected products in Austrian households, by selectively conducting power measurements and comparing the results with the regulatory requirements of the EU Ecodesign Directive for Network standby. Modems, game consoles, network printers, home gateways, smart lights, smart plugs, and home (audio) assistants, were investigated. The results show that there is potential to optimize the EU regulatory framework, as well as for product improvements. Therefore, a guideline for the design of networked devices with reduced standby energy consumption was developed.

1. INTRODUCTION

Network connected devices are becoming ubiquitous (see Figure 1). It is estimated that 100 billion network connected devices will be in use worldwide by 2030, reaching up to 500 billion connected devices over the following decades.

On the one hand these connected devices have the potential for improving energy use and energy management, but on the other hand, the devices themselves have associated power consumption in active and standby modes. In 2013, network connected devices consumed about 616 TWh of electricity. By 2025 it is projected that energy consumption of devices could reach 1140 TWh, corresponding to 6% of current total final global electricity consumption (IEA, 2014). Recent estimates indicate that the network standby energy consumption of all devices would double from 2018 to 2030, reaching almost 300 TWh by 2030 (EDNA, 2019).

2. FEATURES OF NETWORK CONNECTED DEVICES

Devices connected to networks include a wide range of technologies and equipment, such as televisions, mobile phones, lighting, sensors, thermostats, voice assistants, speakers, etc. Some of these are new technologies, while many are existing appliances and equipment gaining a network connection. Through the network connectivity these household devices are able to receive and transmit digital signals, allowing for remote control and the execution of functions.

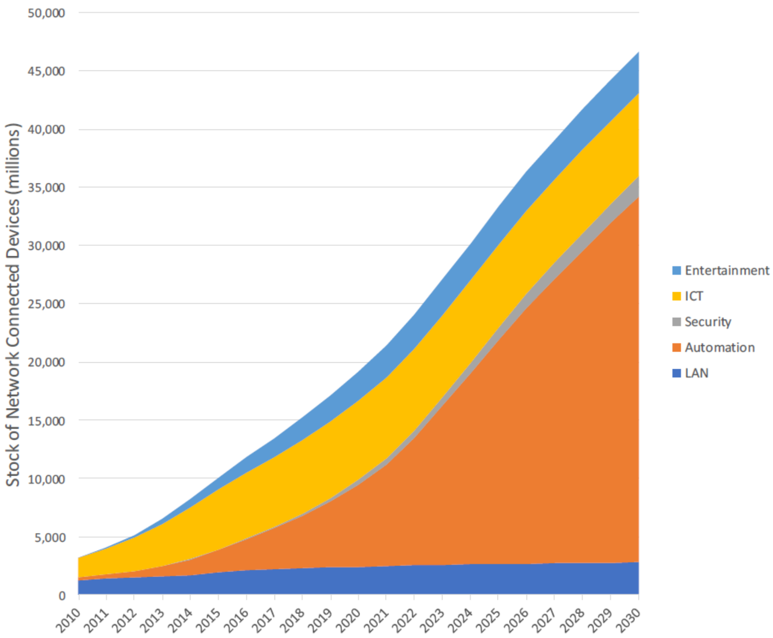

Figure 1: Stock of network connected devices by category 2010 to 2030 (EDNA, 2019).

The network active condition includes any state in which a device performs some function that requires interaction with a network. The network standby condition is a low power mode with network connectivity. This refers to states in which a device is not delivering its primary or secondary functions, but retains the capability to resume applications via a network connection (EDNA, 2019).

Network connected devices can be switched into different standby modes. For example, in networked standby mode, the device is connected to *all* possible networks, and can be reactivated via commands from other devices connected to the same networks, from a control unit, or by directly operating the device. In partial network standby the device is connected to *at least one* of several possible networks and can be reactivated via commands from other devices connected to the same network, from a control unit, or by directly operating the device. In not connected standby mode the device is not connected to any network. It can be reactivated via commands of a control unit, or directly by operating the device. Additional functions might exist (e.g., quick start option). In the Off mode the device is not connected to any network. It can be reactivated via commands of a control unit, or by directly operating the device. The only active feature is waiting for the reactivation.

The European Ecodesign Regulation (EC) No 801/2013 introduced requirements for networked standby to the Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and to Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions (EC, 2014). These specific requirements introduced for networked equipment are based on the concept of "network availability" - the capability of the equipment to resume functions after a remotely initiated trigger has been detected by a network port (EC, 2013). The following types of network availability are considered:

- "Networked equipment with high network availability", or "HiNA equipment", means equipment with one or more of the following functionalities, but no other, as the main function(s): router, network switch, wireless network access point, hub, modem, VoIP telephone, and video phone. This equipment is typically able to resume functions within short time, often milliseconds, in order to work as intended.

- "Networked equipment with high network availability functionality" or "equipment with HiNA functionality" means equipment with the *functionality* of a router, network switch, wireless network access point or combination thereof included, but not being HiNA equipment.
- Devices without HiNA functionality: all other networked equipment (also known as "Low Network Availability" or "LoNA equipment").

In the Ecodesign Regulation EC 801/2013 there are two sets of power levels (for HiNA equipment or equipment with HiNA functionality and for other networked equipment), under various enforcement tiers (2015, 2017 and 2019), as shown in Table 1. In addition, there are other requirements regarding power management and deactivating wireless network connections (EC, 2014). These though are not addressed in this paper.

Table 1: Power consumption thresholds for networked standby (Adapted from EC, 2014).

Equipment type	Tier 1 (from 1 Jan. 2015). Max. power level [W]	Tier 2 (from 1 Jan. 2017). Max. power level [W]	Tier 3 (From 1 Jan. 2019). Max. power level [W]
HiNA equipment and equipment with HiNA functionalities	12	8	8
Other equipment	6	3	2

The thresholds for not connected standby are currently 0,5W (without status display), and 1W (with status display). When the devices are powered with an external low voltage power supply (EPS), the EU regulation EC 1275/2008, which applies to operating voltage of 6V, is valid. In this case, the power threshold for the EPS is 0,3W.

3. ASSESSMENT OF THE NETWORK STANDBY CONSUMPTION

This chapter discussed the approach used in the assessment of network standby of selected household products, based on work from Dangl (Dangl, 2019). Two selection criteria were essential for choosing the products investigated, namely their presence in Austrian households, and the ability to establish a network connection, for example wired (Ethernet) or wireless by Wi-Fi, or Bluetooth interfaces. For each of the seven product categories considered, at least two product models, and in total 33 different household products were measured: modem with router/switch function (3), network printer (3), game consoles (3), home gateways (6), smart lights (8), smart plugs (8), and home (audio) assistants (2). The measurements of power consumption were conducted with a power meter (Watt meter) model "Wattman HPM 100A" (see Figure 2), following, as close as possible the standby measurement methodology from the Electronic Devices & Networks Annex (EDNA, 2015). The devices were plugged to the power meter, which measured the power consumption every five seconds, for the total duration of the measurement (2 hours). The power meter was plugged to the mains and provided current to the device plugged to it. The power meter was also connected via USB to a computer, where the data from the measurements were recorded. The measured products were in active mode at the start of the measurements, but the points when the device switches to lower power modes (e.g., network standby mode, further to not connected standby mode or any other low power mode) are recorded. The measured data for each standby mode were arithmetically averaged and compared to the existing regulation thresholds for the respective devices.

Figure 2: Power meter Wattman HPM 100A used for the measurements (Source: G. Dangl (left), S. Beletich (right)).

4. POWER MEASUREMENT RESULTS

As 33 measurements of products were completed, only a selection of these is presented. The first case discusses the results from the power measurements of 3 modems under various operation scenarios (no model nor brand names are included), and provides a comparison with the power thresholds according to the Ecodesign regulation.

Modems are "HiNA" devices, with the main function of establishing one or various networks, and as such, they are seldom in standby mode. Table 2 shows that the oldest device measured (Modem 1) is the most energy efficient one in all scenarios, and that modems 2 and 3 do not comply with the (more stringent) 2017 thresholds of 8 W, but comply with the 2015 thresholds of 12 W, for network and not connected standby modes.

Table 2: Results of the power measurements for 3 modems (Adapted from Dangl, 2019).

	Modems with router and switch function					
Device (year)	Modem 1 (2013)		Modem 2 (2017)		Modem 3 (2018)	
Scenario	Standby	[W]	Standby	[W]	Standby	[W]
Wi-Fi + Ethernet + Modem active	No	6,59	No	11,42	No	10,17
Wi-Fi + Modem active	No	6,55	No	10,95	No	9,80
Ethernet + Modem active	No	6,09	No	10,92	No	9,16
Modem active	No	6,10	No	10,72	No	8,85
Not connected	Yes	5,40	No	10,70	Yes	8,51
	Complies?[1]	Diff.[2]	Complies?[1]	Diff.[2]	Complies?[1]	Diff.[2]
2015 Limit 12,0 W	*Yes*	*-6,60*	*Yes*	*-1,30*	*Yes*	*-3,49*
2017 Limit 8,0 W	*Yes*	*-2,60*	**No**	**+2,70**	**No**	**+0,51**

Notes to Table 2:
1: Considering EC 1275/2008 and EC 801/2013 and the device´s year. Bold: non-compliance, Italic: compliance.
2: Diff.: difference to threshold value.

Modems 2 and 3 do not enter in any energy saving mode as long as they are connected and the main function is active. When not connected, modems 1 and 3 go into a lower power mode, with lower power demand than when connected with Wi-Fi and Ethernet. Modem 2 though shows almost the same power demand even when not connected to the network.

These products include three functions, modem, router and switch at the same time. As such these devices do not go into standby unless the three functions are not active. An optimized approach could be that, as soon as a local network is not established, the device could enter into standby mode, because the main function of establishing the network in not running. The secondary function of connecting the local network to internet is not possible even if the modem is connected to internet, because the network does not yet exist. A timer could also be integrated to bring the device into a not connected standby mode, especially when the device is regularly inactive, for example between 23:00 to 06:00. In case it is needed, the modem can be reactivated with a physical button, since the ports are not active. This would allow for a fast start - the modem would not need to connect new to the internet, but would only need to establish the local network.

The second case to discuss is the power measurement for smart lights. A smart light bulb is screwed to a lamp, and through the lamp is mains connected. These smart light bulbs (Light emitting Diode or LED) are wirelessly connected to a network and can be controlled, e.g., turn on or off, dim and change colour. There are different types of network connection such as Wi-Fi to a modem with router function, and controlled by a smart phone App; Bluetooth and controlled with a smart phone App; or with a bridge or modem connected to internet via Ethernet, and a smart phone App to control the smart light.

The results from the power measurements of 8 models of smart lights, for two scenarios are shown in Table 3, including the comparison with the Ecodesign Directive thresholds for two tiers.

Table 3: Results of the power measurements for 8 smart lights (Adapted from Dangl, 2019).

Smart lights							
		Scenarios		Compliance with EC No 1194/2012[2]			
				1 W Limit (2014)		0,5 W Limit (2016)	
Type of connection	Device (year)	Standard operation [W]	No network signal [W]	Networked	Not connected	Networked	Not connected
Wi-Fi	Smart light 1 (n.a.)	0,39	0,59[1]	*-0,61*	*-0,41*	*-0,11*	**+0,09**
	Smart light 2 (n.a.)	0,66	0,83[1]	*-0,34*	*-0,17*	**+0,16**	**+0,23**
Bluetooth	Smart light 3 (n.a.)	0,71	0,71	*-0,29*	*-0,29*	**+0,21**	**+0,21**
	Smart light 4 (n.a.)	0,47	0,47	*-0,53*	*-0,53*	*-0,03*	*-0,03*
ZigBee	Smart light 5 (2017)	0,37	0,37	-0,63	-0,63	*-0,13*	*-0,13*
	Smart light 6 (2016)	0,35	0,35	-0,65	-0,65	*-0,15*	*-0,15*
Z-Wave	Smart light 7 (2015)	0,63	0,63	*-0,37*	*-0,37*	+0,13	+0,13
	Smart light 8 (n.a.)	1,06	1,06	**+0,06**	**+0,06**	**+0,56**	**+0,56**

Notes to Table 3:
1: The device enters in a disruption (error) mode when the network signal is disconnected, and keeps trying to connect.
2: Considering EC 1194/2012 and the device´s year. Bold: non-compliance, Italic: compliance.

The scenario in which the light bulb is not illuminating is already the network standby mode, because there is no other way to reactivate the smart light other than through the network connection (standard operation). If there is no network signal (Signal source is disconnected), the smart light remains listening to (other) mesh network devices, waiting for a reactivation signal, or enters into a disruption mode and keeps trying to connect to the network. The smart light bulbs investigated in this study do not show an energy saving mode.

Almost all smart lights models measured comply with the 2014 Ecodesign thresholds, except for model 8. Compliance is lower (only 3 models comply) when considering the more stringent thresholds of 2016. There are variations concerning the type of connection and their associated standby power, being the two lowest standby measurements those of a ZigBee connection (0,35 W); and a Wi-Fi connection (0,39 W networked standby). A better approach for smart lights could be for example that, as soon as no other device is connected to the smart light, these would change after a short period of time (e.g., 10 minutes) into an energy saving mode where the network module is not active. A timer could be integrated to reactivate and connect the smart light, and if there is no connection possible, the light goes again to standby mode.

5. DISCUSSION

The two cases described for modem and smart light bulbs show that some products investigated do not meet the power thresholds of the Ecodesign regulations for networked and/or for not connected standby modes. It also shows that some older devices, in the case of modems, have lower standby power consumption than newer ones, because new products often come with new features, functions and software packages resulting in higher power requirements, which in turn influence their standby power consumption.

Another aspect observed is that certain products did not switch to an energy saving mode or into a low power not connected standby mode when they were not network active for a given time, but instead remain in a higher power mode than really needed. Based on the analysis from the measurements in this study, recommendations were presented for both cases. The technical as well as policy and user aspects were taken into account to systematically draft recommendations in the form of a design guideline, to support product developers (Dangl, 2019). The technical aspects include the evaluation of the product type and functions, the existing regulations, the type of standby mode (connected, partially connected, not connected, off mode), and the type of network connection (Wi-Fi, Ethernet, etc.). An extract of the guideline is shown in

Table **4**, with a comparison of network connections.

6. SUMMARY

The energy implications of network connected products, as discussed in this paper, are relevant due to the growing number of networked devices in households, and to their own standby consumption. Addressing this networked standby power consumption requires action of a range of stakeholders, especially product developers who need to play an active role in developing really smart and energy efficient products. In this sense, the findings and analysis from the power measurements of a variety of network connected devices in this study were used for drafting a design guideline for the development of household networked devices with reduced standby energy consumption (Dangl, 2019).

Table 4: Comparison of the different types of connection (Adapted from Dangl, 2019).

	Ethernet	Bluetooth	Wi-Fi	ZigBee	Z-Wave
Ranking - home network[a]	1	X	2	X	X
Ranking - smart system[a]	X	2	4	1	3
Transmission type	Cable	Wireless 2,4 GHz	Wireless 2,4/ 5 GHz	Wireless 2,4 GHz	Wireless 868 MHz
Max. transmission rate [Mbit/s]	1000	2	600	0,25	0,04
Ave. reach [m]	100	10	20	20	30
Number of users	Unlimited	8	256	65.000	232
Security measures	Physical connection	Authentication of the connection or within the connection	WPA2	128 bit key	128 bit key
Mesh network	No	Possible[1]	No	Yes	Yes
Transmission stability	Yes, cable	Yes, frequency hopping[2]	No	No	Likely[3]
License costs	No	No	No	No	Yes
Cost of equipment/gear	High[4]	Low	Low	Low	Low
Behaviour when connection is lost	Disconnects	No change	Permanently tries to connect	No change	No change

Notes to Table **4***:*
a: Energy efficiency ranking for standby of household devices, based on the measurement of different devices in this study. The score of 1 is most efficient, the score 4 is less efficient.
X: These kind of connections are not commonly used for creating a home network to connect with the internet and for general usage, or to communicate within smart systems.
1: in principle possible but the standard is a direct connection.
2: change of the frequency 1600 times per second.
3: The possibility of overlapping is low because it uses a different frequency than the other wireless connections.
4: Each new connection needs a new cable. A new switch needs to be installed when the max. number of connected ports is reached.

By understanding the technical aspects of products it is possible to propose various strategies to reduce the power consumption, such as better power management, to automatically reduce the time the devices spend in higher power modes, and increase the time they spend in low power modes, or power scaling*,* which allows turning off unnecessary functions and adjusting processing power to the actual tasks to be performed (Rozite & Siderius, 2014). Product design shall also consider the user behaviour, because consumers tend to purchase smart, connected products for their convenience, rather than for expected energy savings. It is likely that the product´s default settings could also be better adjusted for energy saving

(Rozite, 2018). Placing switches on easily accessible spots of the products or integrating timers would facilitate switching them to lower power modes when they are not in use, or not active in a network, e.g., during night time (Dangl, 2019). Apart from these product design strategies, existing product policy measures should be evaluated, e.g., threshold values of the Ecodesign Directive for Network standby should be regularly revised and compared to the current consumption levels of devices in the market. For example, the power threshold for smart lights when connected (but not illuminating) could be lowered from 0,5 W to 0,35 W because there are already products in the market fulfilling this level.

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AKNWOLEDGEMENT

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