Environmental sizing of smartphone batteries

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Abstract

Smartphone use has increased at a phenomenal pace worldwide. In 2011 more smartphones have been sold than desktop pc's, notebooks, netbooks and tablets together. The total worldwide smartphone sales reached 472 million units in 2011, and 149 million of them were sold in the fourth quarter of 2011. The smartphone is, like almost every other mobile device, powered by batteries, limited in size and therefore capacity, which makes energy management paramount. While global demand and use of mobile devices continuously expands, the energy density of smartphone batteries has grown at an insignificant rate, but the use period still decreases because of high loads and big screens. In this paper we have studied the power breakdown of five smartphones on sale in 2011. We have defined three different user profiles for "heavy", "moderate" and "light" users and we can state that theoretically it is sensible to re-size the battery based on the user profile. While keeping the user period acceptable we can decrease the battery capacity for moderate and light users with 25%, reducing the worldwide energy needed to product smartphone batteries with 2.1 to 3.4PJ per year. In practice the aging of the battery will result in a decreasing battery capacity over its life. When taking this into account most batteries comply with the moderate users and only a resizing strategy for the light users is sensible. This will account for only 20% of all users and can result in a worldwide decrease of energy needed for producing the smartphone batteries with 0.5 to 0.9PJ.

1 Introduction

Smartphone use has increased at a phenomenal pace worldwide. In 2011 more smartphones have been sold than desktop pc's, notebooks, netbooks and tablets together. According to Gartner [1] the total worldwide smartphone sales in 2011 reached 472 million units which is an increase of 58% compared to a year before. In the last quarter of 2011 149 million smartphones were sold showing that there is a tremendous increase in sales. Like almost every other mobile device the smart phone is powered by batteries, limited in size and therefor capacity. The capacity of a smartphone battery is generally larger than the usual cell-phone batteries, mainly due to the higher number of functionalities, like internet browsing, multi-media applications, its larger display and faster CPU, continuous flow of background processes due to data transfer, GPS and roaming, and a more intensive use of the smartphone compared to a regular cell phone, mainly used for making phone calls and sending text messages.

The increasing growth of smartphones, direct related to the number of batteries used, plus the increased user activity have a large influence on the impact of the battery on our environment. First of all more batteries have to be produced leading to increased material demands and higher energy consumption due to production (embodied energy). Second the intensive use of the smartphone means a shorter life-span of the battery and early replacement of the battery or worse wasting of the product. Thirdly during the short user period more electricity is used to recharge the batteries and fourthly the disposal after breakdown of the battery or the cell phone or at the end of the economic lifespan of the smartphone the batteries can emit toxic waste to water, soil and air.

The hypothesis is that when battery size is coupled with the intended use of the smartphone, the overall environmental impact of smartphone batteries can be reduced significantly. To find out if it is possible to decrease the battery size of smartphones, we have measured the energy consumption of different functionalities on a smartphone (section 2) and researched the user profile of smartphone users by means of a literature study (section 3). The results of the measurements are presented in section 4. A theoretical experiment is performed, where the potential of battery resizing is investigated, by making use of the generalized user profiles and the power consumption of the measured smartphones (section 5). The potential reduced burden of this strategy on the environment is examined globally based on cradle-to-gate energy consumption. Because this is a theoretical exercise the practical implementation is also discussed in section 5. This paper finishes with conclusions in section 6.

Specification	*Blackberry Torch 9800*	*HTC-7 Trophy*	*Nokia N8*	*Samsung Galaxy S2*	*Sony-Ericsson Xperia Mini*
Weight (g)	161	136	133	116	100
Battery Weight (g)	26.4	28.2	26.0	32.6	25.0
Capacity (mAh)	1270	1300	1200	1650	1200
Capacity (mWh)	4700	4810	4440	6105	4440
Screen size	3.2” (360x480)	3.8” (480x800)	3.5” (360x640)	4.3” (480x800)	2.5” (240x320)
Software	BB 6.0	Windows 7	Symbian3	Android 2.3.4	Android 2.3.3

Table 1: Some specifications of the tested devices.

2 Experimental setup and data collection

2.1 Smartphones under test

The power consumption of five different smartphones, sold in 2011 have been measured, the Blackberry Torch, the HTC 7 Trophy, the Nokia N8, Samsung Galaxy S2, and the Sony Ericsson Xperia Mini. All phones are equipped with lithium ion/polymer batteries working at a minimum Voltage of 3.7V. Table 1 lists some specifications of the tested devices. The weight of the different components were measured with the KERN 572 scale.

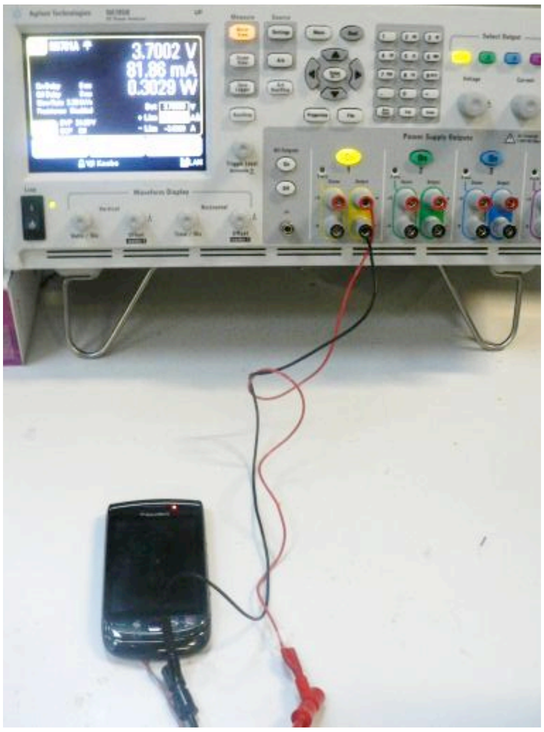


Figure 1: Measurement setup.

2.2 Power consumption measurements

The power consumption measurements were conducted at the Design Engineering labs of the faculty of Industrial Design Engineering (Delft University of Technology in the Netherlands). An Agilent N6705A DC Power Analyser has been used to power the smartphones and monitor the current draw at a frequency of 1000Hz. The battery was emulated by the Agilent Power Analyser at a constant voltage of 3.7V. Probes are attached to the battery input pins present on the smartphone (Figure 1).

To maintain consistency in the tests for the different smartphones, a test protocol for measuring the power consumption of different functionalities is developed. The smartphones are benchmarked on their functionalities and not their components.

The power consumption of the following functionalities are measured over an indicated period:

1. Idle state: without connection to Bluetooth, Wifi and the network averaged over a period of 120 seconds;
2. Making a 2G phone call: the average is taken of a 15 seconds ringing, picking up the phone, and talk for 60 seconds;
3. Making a 3G phone call: same as previous;
4. Bluetooth: while transferring a 1MB image file or 4MB music file, considering a start-up and approximate 20 second file transfer;
5. Wifi: the power consumption was averaged over a period of 180 seconds wherein the application is started, searched for networks, connect to the local network, a period with no traffic, opening a Gmail account or the TU Delft website.
6. 3G internet: same as previous;

7. Media: playing a 4 minute MP3 file, where the average power consumption is taken over a period of 240 seconds;
8. Camera: averaged over a period of 120 seconds where the application is started, one photo is taken and a 10 seconds recording is taking;
9. GPS: the average is taken over a period of 120 seconds where the application is started, the GPS module fixes the satellites and fixes to the location;
10. Streaming Video over Wifi: the average power consumption is taking while showing a youtube film of 60 seconds;
11. Streaming Video over 3G: same as previous;
12. Radio: the power consumption is averaged over a period of 120 seconds where the application is started, and played at one FM station.

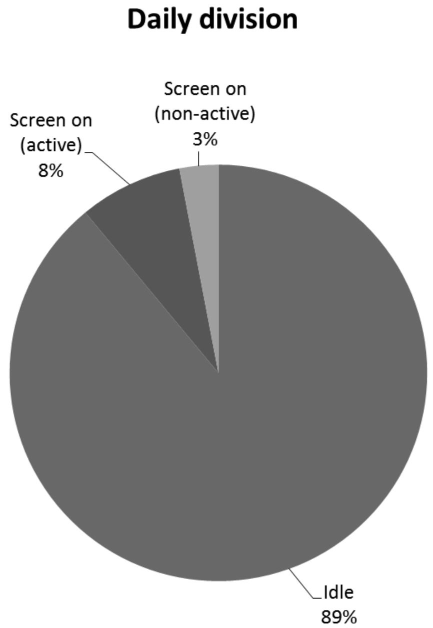
The power consumption logged over the indicated period is averaged and taken as the power consumption of this functionality.

3 Definition of the user profile

To calculate the power consumption of the smartphone for different users different user profiles have to be defined based on the intended use of the device. Classification is important in order to differentiate users based on usage time, type activities and periods with certain activities or combinations thereof.

The simplest classification focusses on the distribution of the total usage time. Shye *et al.* [2] characterized the smartphone' user activity based on 25 users. An average user actively uses its smartphone only 11% of the total days' time (2.6 hours), of which 8% is active with screen on and for 3% of the total time the screen is on, but there is no activity. Even though the active time accounts for a small fraction of the total time, it consumes the majority of the energy, namely 54%, where 46% of the power is consumed during its idle period of 21.4 hours.

The same studies by Shy *et al*. [2] also divides the "active period with activity" in functions (states) which are being used during this period (plotted in Figure 2). Main activities are making a phone call, wifi with traffic and without traffic and media applications like music or video. Miscellaneous is defined as the use of applications like productivity apps (office, PDF reading, etc), the use of Bluetooth, sending text messages, using the GPS function for tracking a ride or navigation and playing games. Based on [3] we can say that games account for 5%, the use of Google Maps accounts for 3%, and the use of productivity tools like office or reading a PDF, accounts for 5% of the total active time. The rest activity (34%) is used by bluetooth, texting or other applications.



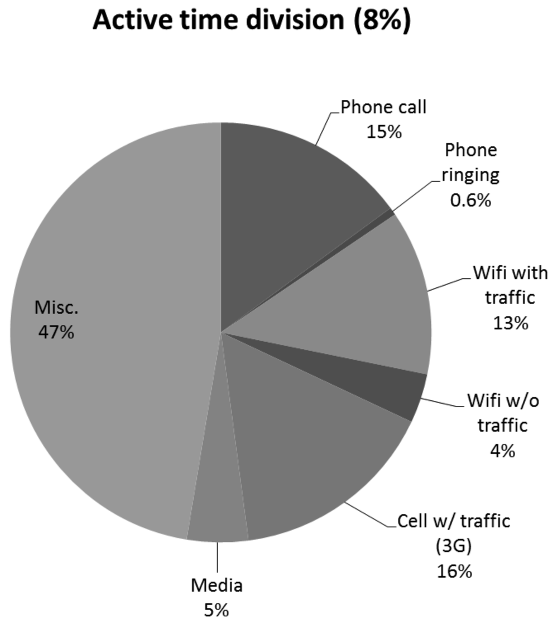


Figure 2: Average use time as a percentage over a full day, data from [2].

Another classification can be based on the "user type", which is researched by Falaki *et al*. [3]. They used detailed traces from 33 users while using their HTC Dream (Android OS) smartphone over a period in between 7 to 21 weeks. They characterized the intentional user activities, the interactions with the device, the applications used, and the impact of those activities on network and energy the usage. A great diversity is found among users. For instance the average number of interactions per day varies from 10 to 200, and the average amount of data received per day varies from 1 to 1000MB. The usage time of the 33 users range from 30 minutes per day to a maximum of 500 minutes (8 hours), or roughly 1/3th of the day. Figure 3 shows the average active time of the users described in the study. The average usage time of all users is roughly the same as described in the study of Shy *et al.*, approximately 150 minutes (~2.5 hours).

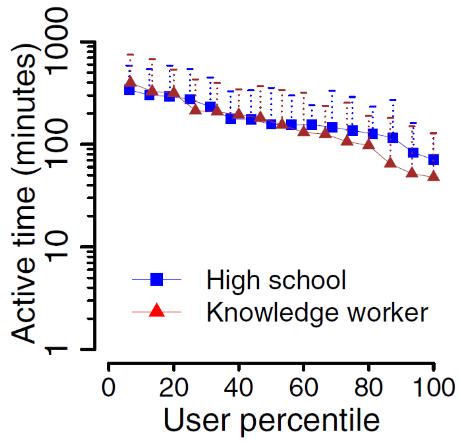


Figure 3: The average and the upper end of the standard deviation of the active time of 33 users when using the HTC Dream smartphone, courtesy of [3].

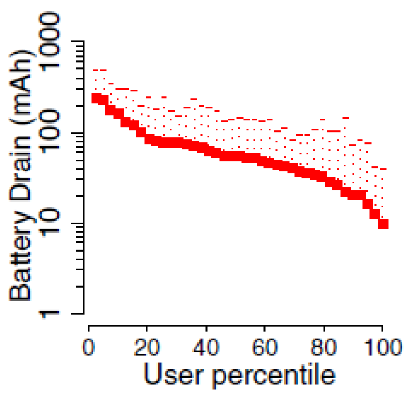


Figure 4: The mean and upper end of the standard deviation of one hour energy drain for the specified dataset, courtesy of [3].

When we look at the battery drain over a one hour period a distinction can be made between "heavy", "moderate" and "light" user. At 20% and 80% of the user percentile you see a distinct change in inclination, which we use to define heavy users, the first 20% which use the smartphone for more than 300 minutes actively per day, moderate users, all users in between 20 and 80%, and the remaining 20% is defined as light users, which use the smartphone up till 110 minutes per day:

Heavy	$t_{active} > 5$ hours per day	$< 20\%$
Moderate	$1.8 < t_{active} < 5$ hours per day	$20 - 80\%$
Light	$t_{active} < 1.8$ hours per day	$> 80\%$

3.1 Environmental impact calculations

To calculate what the impact is of resizing a battery a life cycle inventory (LCI) is conducted. The focus of this assessment is on cradle-to-gate energy [4]. This analysis will include battery material production and the manufacturing of the lithium-ion batteries. Sullivan and Gaines (2012) divide the chain of unit processes into two separate life-cycle stages. The first is the Battery Material Production (*mp*), which refers to winning the raw materials from the earth or a recycling stream, and refining them into usable basic materials purchased by a manufacturer to produce battery components. The second stage is Battery Manufacturing (*mnf*), which represents all process needed to convert these basic materials into battery components, such as the anode, cathode and electrolytes. Cradle-to-gate (*ctg*) battery production denotes the sum of these two life-cycle stages:

$$E_{ctg} = E_{mp} + E_{mnf}$$

Where E_{ctg} stands for the total energy needed for production (E_{mp}) plus the amount needed for manufacturing (E_{mnf}) the battery in question. The Cradle-to-gate energy production of lithium ion batteries is in between 104 and 225.3 MJ/kg, with an average of 180.1MJ/kg. Assuming the user will charge/discharge his smartphone 1000 times during the three-year life-time of the phone the energy during the user phase can be calculated.

4 Results

4.1 Power breakdown

The mean power consumption of the different functionalities for the five smartphones can be found in Table 3.

4.2 Energy-use per day breakdown

When we combine the average usage time as described in Figure 2 and the average power consumption per activity we can calculate the overall

	Blackberry Torch[1]	*HTC-7 Trophy*	*Nokia N8*	*Samsung Galaxy S2*	*Xperia mini*
1: Idle	42	35	55[2]	42	38
2: 2G call	556	788	827	707	672
3: 3G call	577	938	866	985	581
4: Bluetooth	216	- [3]	440	684	693
5: Internet (Wifi)	587	860	840	944	1042
6: Mobile Internet (3G)	1666	841	1001	721	841
7: Media	276	474	510	480	503
8: Camera	1417	1385	995	1379	1230
9: GPS	615	1241	769	1255	883
10: Wifi (video)	1144	960	1161	935	992
11: Video (3G)	2016[2]	1344	1277	1359	1010
12: Radio	- [4]	629	626	296	569

Table 3: Average power consumption (mW) per defined functionality for the 5 measured smartphones.

energy use per day. Based on the literature described in Shy *et al.* [2] and Falaki *et al.* [3] we have setup a generalized usage breakdown described in Figure 5, which is used to calculate the overall energy consumption of a generalized moderate user.

Table 4 shows the overall energy use for a moderate user (p50). Besides the daily energy consumption the rated capacity of the devices' battery is given, the percentage of the use over the battery capacity and the maximum battery recharge cycle (in days).

We can do the same thing with the heavy and light users wherefore the active use time is more than 5 hours for the heavy user, and less than 1.8 hours for the light user. The idle time is respectively 79% and 93%. Table 5 and Table 6 show the average energy use per day for the mean heavy and the mean light user.

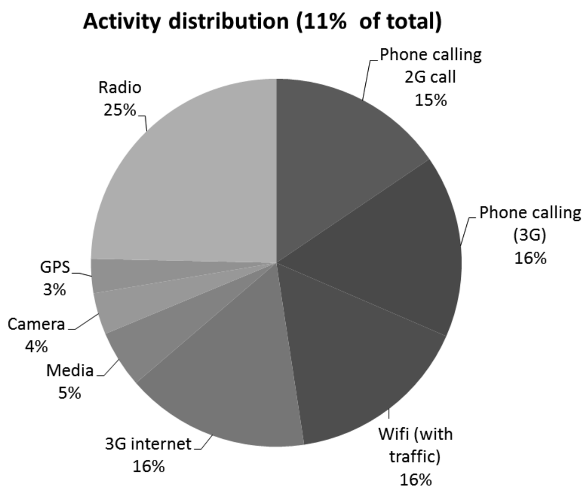


Figure 5: generalized usage breakdown of the active time on a smartphone (11%) based on Shy *et al.* [2] and Falaki *et al.* [3].

1 A different cellular service provider was used for 3G.

2 Idle power measurements were done over a window of 10 seconds instead of the standardized 2 minutes.

3 No Bluetooth files transfer option available.

4 No build-in radio is available.

	Blackberry Torch 9800	***HTC-7 Trophy***	***Nokia N8***	***Samsung Galaxy S2***	***Sony-Ericsson Xperia mini***
Daily energy consumption (mWh)	2551	2904	3311	2804	2828
Rated battery capacity (mWh)	4700	4810	4440	6105	4440
Percentage of use	54%	60%	75%	46%	64%
Maximum charge cycle (days)	1.8	1.6	1.3	2.1	1.6
Average battery capacity consumption (% p.hour)	2.3%	2.5%	3.1%	1.9%	2.7%

Table 4: Average energy use per day for a moderate user (89% idle, 11% active).

	Blackberry Torch 9800	***HTC-7 Trophy***	***Nokia N8***	***Samsung Galaxy S2***	***Sony-Ericsson Xperia mini***
Daily energy consumption (mWh)	3934	4751	5086	4416	4544
Rated battery capacity (mWh)	4700	4810	4440	6105	4440
Percentage of use	84%	99%	115%	72%	102%
Maximum charge cycle (days)	1.2	1.0	0.9	1.4	1.0
Average battery capacity consumption (% p.hour)	3.5%	4.1%	4.8%	3.0%	4.3%

Table 5: Average energy use per day for a heavy user (79% idle, 21% active).

	Blackberry Torch 9800	***HTC-7 Trophy***	***Nokia N8***	***Samsung Galaxy S2***	***Sony-Ericsson Xperia mini***
Daily energy consumption (mWh)	2052	2238	2672	2223	2210
Rated battery capacity (mWh)	4700	4810	4440	6105	4440
Percentage of use	44%	47%	60%	36%	50%
Maximum charge cycle (days)	2.3	2.1	1.6	2.7	2.0
Average battery capacity consumption (% p.hour)	1.8%	1.9%	2.5%	1.5%	2.1%

Table 6: Average energy use per day for a light user (93% idle, 7% active).

Specification	*Blackberry Torch 9800*	*HTC-7 Trophy*	*Nokia N8*	*Samsung Galaxy S2*	*Sony-Ericsson Xperia Mini*
E_{ctg} (MJ)	29.0	24.5	24.0	20.9	18.0
E_{use} (kWh)	4.70	4.81	4.44	6.105	4.44
E_{use} (MJ)	33.8	34.6	32.0	44.0	32.0

Table 7: Overview of energy needed from cradle to gate (ctg) and for the 'primary energy' use for the user phase for the different smartphones.

5 Discussion

5.1 Energy use over the technical life of the tested smartphones

Table 7 shows the energy needed for producing the materials, manufacturing the batteries, and the use of the tested smartphone over its technical life. The efficiency of a current power plant is 40% to 50% [5], and thus the primary energy needed to produce 1MJ of electricity is 2 to 2.5MJ. The table shows that the cradle-to-gate energy is a large part of the total energy consumption from cradle to use phase.

To get more insight in the energy usage the *number of days in between recharge* is plotted in Figure 6 against the active time of a user. The data is interpolated for all five tested smartphones and is based on the usage distribution as described in Figure 5. You can see that heavy users have to recharge their smartphone, in most cases, more than once a day. Light users on the other hand can use their smartphone for more than 2 days in a row, or even longer, and when the user does not use its smartphone at all, he/she only has to recharge every 3 to 6 days depending on the smartphone.

5.2 Resizing and the environmental burden

Table 4 shows that at moderate use the smartphone should easily withhold a single day of use. The numbers in this table also show that the Samsung Galaxy S2 has more than twice the capacity needed to operate daily on a moderate level. When the user is recharging the battery of the Samsung every night the battery in this smartphone could be 54% smaller in capacity. For the other devices the battery could be 25 to 40% smaller in capacity, and relatively more lightweight.

For heavy users Table 5 shows that most smartphones hardly comply with a full days' use. The Nokia N8 for instance has to be recharged during the day/evening for it to still run for a full day. All other devices, but for the Samsung Galaxy S2, will be deep discharged before the end of the day. It has to be noted that the Samsung Galaxy S2 has a large battery, compared to the other smartphones.

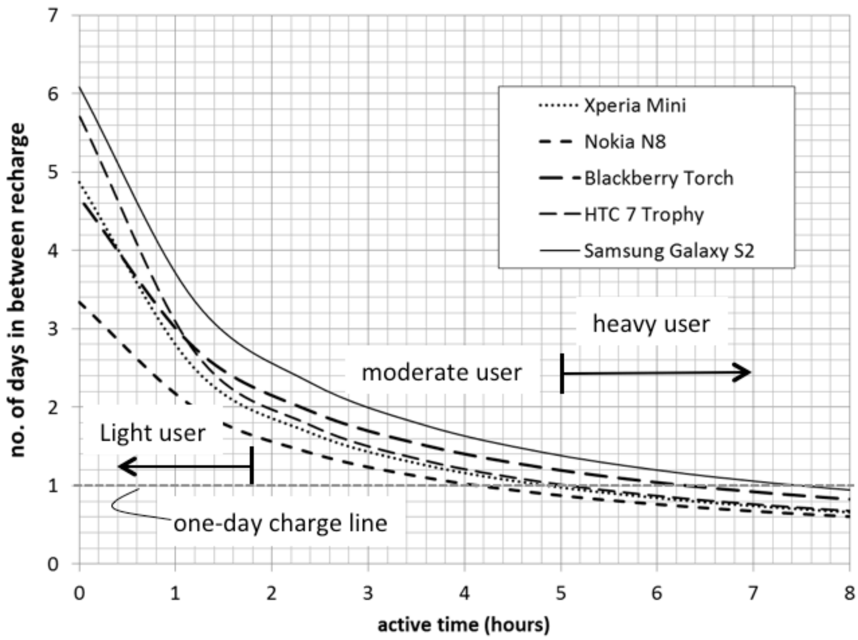


Figure 6: The maximum number of days in between recharges for the measured devices against the active time of the user (0 to 1.8 hours for light users, 1.8 to 5 hours for moderate users and more than 5 hours per day for the heavy users). The energy use of each device is calculated by using the activity distribution as described in Figure 5.

Samsung probably focused on heavy users for the Galaxy S2.

Ligth users consume per day only a small amount of the available battery capacity (36% to 60%), where, again, the Samsung Galaxy S2 is more than two times too big than actually needed. Light and moderate users are unnecessarily burdened with heavy batteries that are surely needed for heavy users when daily recharging is the standard.

As described above, for most moderate and all light users the battery is oversized. What if the consumer is offered multiple types of batteries with different cycle life-weight tradeoffs when buying a new smartphone? What will be the environmental impact? For moderate users the battery can be shrunk with 25 to 54% and for light users this is even 40 to 64%. This means that shrinking the battery with 25% on average, probably won't have much effect on the users' use experience of moderate and light users. This user group covers 80% of the total number of smartphone users as described in section 4. A reduction of 25% in battery materials will reduce the average energy consumption for the cradle-to-gate production of a single battery with 4.5 to 7.2MJ. At first this reduction seems insignificant but taking into account the 149 million lithium-ion batteries sold in the last quarter of 2011 [1], the cumulative yearly saving in energy for 2012, could be 2.145 and 3.457 PJ.

5.3 Practical implementation

All measurements done in this study were taking with new smartphones with a clean install of the operating system as delivered by the manufacturer. By installing applications (apps) which use up background synchronization over 3G or Wifi, stay open in the background even after closing the app, or contain software bugs, clutter the power usage of the smartphone. This cluttering strongly influences the power consumption of the smartphone and can discharge your battery in a shorter period than mentioned above. A large battery is thus not a luxury but a need. Bug-less software writing, power savers, the use of App Killers, and user behavior can increase the battery cycle life.

Besides standby energy consumption, the scenario's described above are all ideal cases, where the capacity fade is not taken into account. Due to pulsed discharges and irregular charging cycle by the user, the cycle life of lithium ion batteries is generally much lower than the cycle-life rated by the manufacturer. Its capacity will fade to 70% in 250 to 500 cycles when fully discharged at 100% Depth of Discharge (DoD), and 1200 to 1500 at 50%DoD [6]. In Figure 7 the same graph is plotted as in Figure 6 but now when the battery is faded to 70% of its initial capacity, which equals the state of the capacity at the end of the batteries' life. Thus taking aging into account the battery needs to start with a 20 to 30% higher capacity to fulfill the needs of the moderate and light users when it is nearing its end-of-life (after 2 to 3 years). Result is that the current

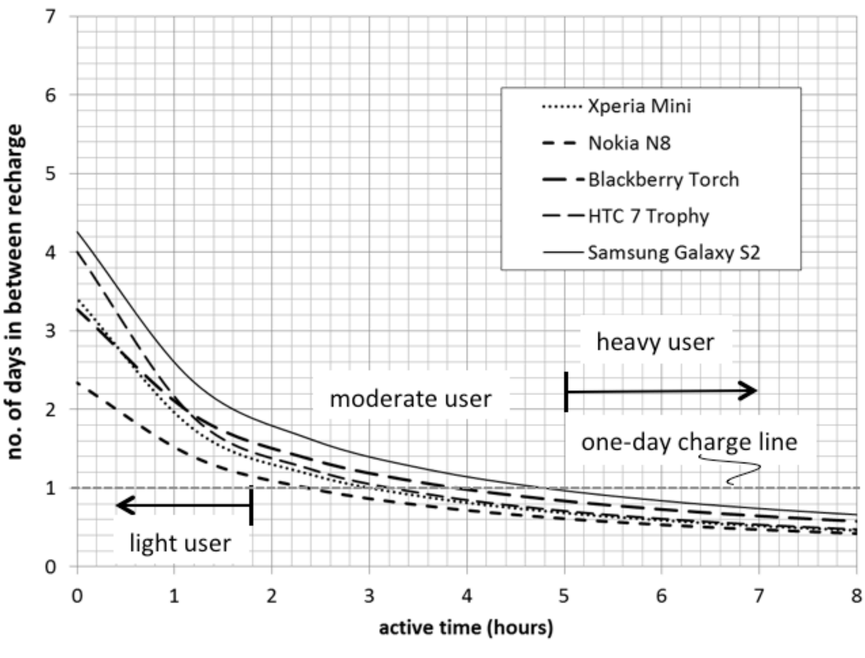


Figure 7: The maximum number of days in between recharges for the measured devices when the battery is faded to 70% of its initial capacity.

batteries comply more-or-less with the user profile of moderate users, but could still be smaller for the light users. Even when the battery is faded to 70%, the light user still can recharge its battery less than once a day for all measured smartphones. A resizing strategy for the moderate users seems not sensible but for light users it does. This still accounts for 20% of all smartphone users, and could result in a decrease of the worldwide energy needed for production of the smartphone batteries with 0.536 to 0.864PJ.

6 Conclusions

In this research we have defined three types of users: the light, moderate and heavy users based on their battery drainage characteristics. To calculate the overall energy usage of these different users we have measured different functionalities for five different smartphones of 2011. We have defined a generic user profile and generic power demand profile of smartphones. By calculating the power usage of the different user profiles we tested if it is feasible to resize the battery for a specific group of users, and herewith lower the environmental impact of the battery.

The capacity of current smartphone batteries do not comply with most of the heavy users profiles, where the user has to recharge the battery more than once a day. The battery is in most cases to small. For moderate and light users though, the capacity of current smartphone batteries do comply and are in some cases even to big where "once-a-day" recharging is standard.

Theoretically resizing of the battery is interesting for moderate (60% of current users) and light users (20%), where a 25% reduction of the battery size does not influence the charging habits of the users. However due to aging of batteries, the proposed resizing strategy is in practice only sensible for the light users (20% of current users). Implementation of a sizing strategy will contribute to lowering the energy use during production of the batteries with 0.5 to 0.9 PJ worldwide.

7 Literature

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