

Smartphone Battery Inadequacy

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Mobile phones are always getting better and better: A state-of-the-art smartphone from 2010 is capable of much more than a conventional mobile phone from 2004. But has power use in mobile phones changed over this same period? Why do smartphones seem to run out of battery power so much faster than mobile phones did a few years ago? In this paper, I will attempt to shed some light on the difference between old and new phones in terms of how much power they consume and how long their batteries can last.

The battery life of a mobile phone is essentially just influenced by two characteristics: its battery capacity and its rate of power consumption. These two factors are more or less independent and I will treat them separately in the following two sections.

Mobile Phone Battery Capacity

All mobile phones in recent years have used lithium-ion rechargeable batteries as a portable power source. By 2002, lithium-ion had begun to dominate the older competing battery technologies (nickel-cadmium and nickel-metal-hydride) in the mobile phone market, and in other battery markets as well: in that year, worldwide sales of lithium-ion batteries (in terms of currency) was more than 50% greater than the other two types of batteries combined. This market domination happened because of lithium-ion's lighter weight and lack of memory effect, despite its higher cost and risk of thermal runaway. [1] This was several years before the modern smartphone became commonplace; so in a comparison between a modern smartphone and a conventional mobile phone, it suffices to consider only lithium-ion batteries as a possible battery technology. (In this paper, I define a smartphone to be a mobile phone with features targeted at mobile computing.)

This puts clear limits on the battery capacity the mobile phone can have. Historically, the energy density of lithium-ion batteries has increased at a rate of 10% per year on average. [1] All mobile phone manufacturers have the same incentives to use the best possible batteries, so market forces should constrain contemporary mobile phones to have batteries with equivalent energy density, and over time the average mobile phone battery capacity should follow the same 10%-per-year upward trend set by the lithium battery industry.

Battery capacity is therefore inextricably linked to battery volume. For a mobile phone to have a higher-capacity battery, it must have a physically larger space for a battery as well. Of course, this does not change the fact that mobile phones are manufactured in a wide array of form factors. The physical size of mobile phone batteries does vary from model to model; however, the variation is not significantly large. I estimate that almost all mobile phones (since 2004) are roughly the same volume, within about 25%. I suspect this is due to a combination of market forces and ergonomics: smaller mobile phones sell better because they are lighter and fit better in pockets (and are also seen as higher-quality), so the manufacturers make the mobile phones as small as possible without sacrificing usability. For these reasons, the battery capacities of most mobile phones, whether they are smartphones or conventional mobile phones, are fixed within 25% of the average.

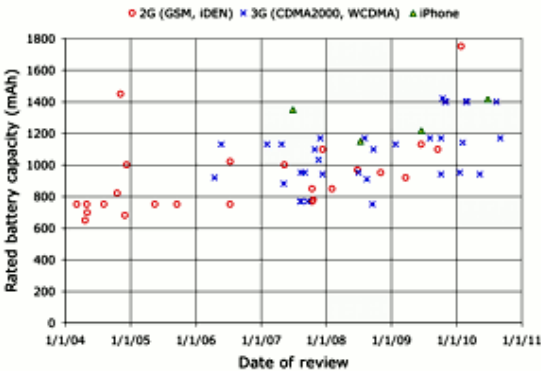


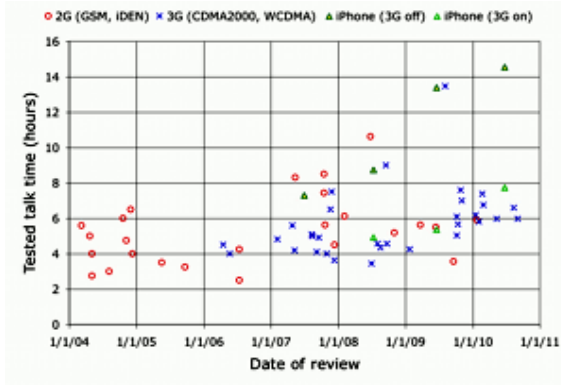
Fig. 1: Mobile phone battery capacity (2004-2010). The data are originally from CNET Reviews. The 2G and 3G data are for various Motorola phones; the first four generations of Apple iPhone are included for comparison.

To check these predictions, I have compared them to a set of mobile phone battery capacity data. I found a third party, [CNET Reviews](#), which collects mobile phone specification data to supplement its editorial reviews. My data set consists of all Motorola mobile phones for which CNET recorded a battery capacity value. I also included the four generations of Apple iPhone because they make a good point of comparison as very popular and well-known smartphones. Unfortunately, the iPhones' battery capacities are not well-documented anywhere, so the values I have used here are only my "best guesses" compiled from hearsay and photographic evidence. I have not been able to confirm all of these battery capacity data points, but I have checked a few of them. Consider the following three mobile phones: Motorola Razr V3 (reviewed by CNET on 1 Dec 2004), Motorola Q (24 May 2006), and Apple iPhone (30 Jun 2007). In a 2009 journal paper, Chang, Chen, and Zhou attest that the battery capacities of these three phones are 710 mAh, 1130 mAh, and 1400 mAh. [2] On the other hand, the values I have used in this paper for these phones are 680 mAh, 1130 mAh, and 1350 mAh. The small discrepancies here are possibly due to rounding and unit conversion errors.

The total sample size is 62 phones. Admittedly, these data come from the Internet and may not have ever been published in a print medium. As such, there is a chance that some of the data are potentially inaccurate or spurious. None of the individual data points here should be considered particularly authoritative. However, I think it is unlikely that the overall trend is wrong, so there is still some value in the data set as a whole.

I have plotted the phones' battery capacity ratings versus the date each phone was reviewed by CNET Reviews in Fig. 1. I have divided up the data into phones capable of connecting to third-generation networks (3G), which are generally smartphones, and phones which use the older second-generation networks (2G), which are generally not.

Fitting this data to a power-law function, I find that the growth rate is between 6.7% and 9.4% per year (one-sigma confidence levels) and the standard error in the battery capacity estimate at any point in time is about 20%. These results are consistent with my expectations of a growth rate of 10% and a standard error of 25%. Interestingly, the two most obvious outliers, the Motorola i315 (6 Nov 2004, 1450 mAh) and the Motorola Brute i680 (25 Jan 2010, 1750 mAh), are both marketed as ruggedized phones with oversized batteries.



Mobile Phone Power Consumption

To my eyes, it looks like the 3G phones in Fig. 1, collectively, are not equipped with significantly larger or smaller batteries than the 2G phones released at the same time. If smartphones run out of battery power faster than conventional mobile phones, it cannot be due to the size of their batteries. Instead, there must be a difference in power consumption.

The rate of power consumption of any mobile phone is, of course, highly variable: it depends strongly on the type of operation the mobile phone is subjected to. In standby mode, for example, it will consume much less power than during a call. A call uses the phone's radio circuitry and antenna, which communicate with the cellular base station antennas, as well as its LCD screen and backlight and the speaker in its

Fig. 2: Tested mobile phone battery life during voice calls (2004-2010).

earpiece. The amount of power consumed will also depend on the distance from the base stations, the backlight timeout setting, the earpiece volume, and the actual content of the voice transmission.

Between a smartphone and a conventional mobile phone, many of these factors will not be much different if the external conditions are the same during a call. The main difference is in the radio circuitry: a 3G connection uses around twice as much power as a 2G connection during a call. [3] A similar relationship holds during text messaging and data transmission. Interestingly, the power consumed by a 3G connection does not depend very strongly on the data bitrate, which suggests that there is a large fixed power cost associated with turning on the

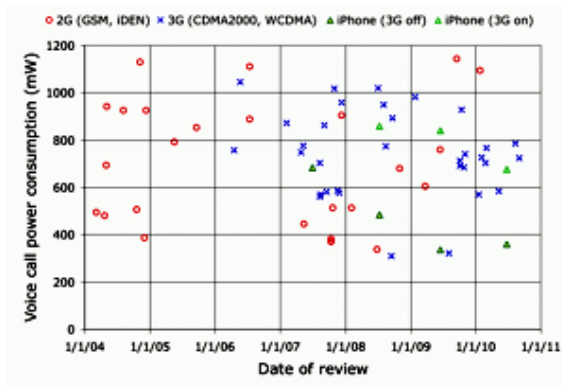
3G radio circuitry whether any data is being transmitted or not. [4] So all other things being equal, I would expect a 3G smartphone to consume more power during a call than a conventional 2G mobile phone.

To check this prediction, I will return to the data set I used above. The mobile phone manufacturers generally do not publish values for the amount of power their phones consume. They do publish values for the battery life while the phone is being used for voice calling ("talk time"), but these values could potentially be sales propaganda. On the other hand, CNET Reviews has done talk-time battery life tests on each of the mobile phones in this data set using a consistent test procedure. I have plotted CNET's battery life values in Fig. 2. CNET claims to have used the following test procedure: [5]

When we conduct our talk-time battery life test, we start with a fully charged phone. The phone's display is set to a brightness level of 50 percent, and the backlight is set to turn off after 10 seconds. The phone's volume level is set to 50 percent. We call a landline and attach an earbud to the landline's receiver. The earbud is attached to an MP3 player, which plays a set of repeating audio files. We immediately begin recording the amount of time that passes until the phone's battery drains and it shuts off. We run this test multiple times until we have at least two sets of scores that are within +/-5 percent of each other, and we report the average.

For three of the four iPhones, CNET Reviews performed battery testing with the phone in 3G mode and with the phone in 2G mode, so I have separated these data using different colors in the figure. (The original iPhone did not have a 3G radio even though it was a smartphone.) Overall, there seems to be an upward trend toward higher battery life from 2004 to 2010. But this could be due to the increases in battery capacity that happened over the same period of time. To find out I need to know the actual power consumption.

For each phone, it is a simple matter of dividing the battery capacity (in milliamp-hours) by the battery life (in hours) to get the average current draw (in milliamperes); then multiplying this by the battery voltage gives the average power usage (in milliwatts). Each of these phones uses a 3.7-volt lithium-ion or lithium-ion polymer battery.



The results of these calculations are plotted in Fig. 3. There is no discernible trend in power usage! It turns out that cell phones in fact have used roughly the same amount of power for making voice calls over the entire period from 2004 to 2010: it takes 400-1000 mW of power to make a mobile phone call. More accurately, the sample mean of all 65 of these data points is 717 mW, and the sample standard deviation is 221 mW.

The iPhones used about twice as much power in 3G mode as in 2G mode, in line with my prediction. However, I expected there to be a significant difference between the other 2G and 3G phones in this test, but I can see little to no difference in those data. The smartphones in this test do not stand out from the conventional mobile phones. One potential explanation is that the 3G-capable phones may not have all been connected to 3G networks: CNET did not state which network they were

Fig. 3: Calculated average power consumption during voice calls.

testing each phone with (except for the iPhones) and may not have been controlling this variable. Or there might simply be too much uncertainty in the data to see the difference.

The data seem to suggest that a smartphone does not use any more power during a call than a conventional mobile phone. But this is not the whole story. Mobile phones can do other things than making calls. In particular, smartphones have many functions that conventional mobile phones do not. While a conventional mobile phone is generally capable of telephony, SMS, and perhaps some digital photography, a smartphone with a full-featured operating system is functionally closer to a laptop computer. Applications that run on smartphones can heavily use the processor, LCD screen, and GPS, and transfer data with Wi-Fi or 3G. Each of these features draws a significant amount of power, especially if they are all used at the same time. So while making a call is one of the

highest-power functions of a conventional mobile phone, a smartphone's state-of-the-art features are capable of consuming much more power.

CNET did not test this for the phones in Figs. 1-3. However, Zhang *et al.* have conducted power consumption tests using a power meter on an HTC Dream smartphone. [6] They found that the phone's CPU, Wi-Fi, audio interface, LCD, and GPS and 3G radios could each draw several hundred milliwatts of power. When they used the phone for web browsing, playing a game, YouTube video streaming, and Google Maps GPS navigation, the power consumption peaked at about 1500 mW, 1800 mW, 1900 mW, and 2200 mW respectively (from Fig. 9 of [6]). This is significantly more than the 717 mW average power consumption during voice calls. In other words, smartphone power consumption can double or triple during heavy use compared to voice calls. At this level of elevated power use, the HTC Dream's battery (which has a capacity of 1150 mAh) will last less than two hours. And this is the real reason for the difference between smartphones and conventional mobile phones: not only do smartphones have distinctive power-hungry features that other phones lack, but these features can be used in combination with the cellular radio and concurrently with each other. This is the basis of smartphones' big advantages in computing and entertainment power. But it comes with a literal power cost as well.

Conclusion

Over the last seven years, mobile phone batteries have improved slowly, but mobile phone complexity has gone up according to Moore's Law, which is several times faster. This has driven up the amount of power a mobile phone can consume much faster than battery technology has been able to keep up.

The data suggest that smartphones and conventional cell phones use about the same amount of power to make voice calls, and that this amount of power has not been growing over time. So smartphone users have the ability to control their power usage: A smartphone's battery will last as long as a conventional mobile phone, if they are both used simply as telephones. But it seems smartphone users would rather use their devices to the fullest, using their power-hungry features to do things that are impossible on conventional phones. This functionality comes at a price.

We are now getting used to doing all sorts of things with our smartphones. But unless something dramatic happens in the battery industry, we will need to get used to more frequent recharging as well.

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