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Smartphone batteries: better but no breakthrough

Deloitte predicts that the rechargeable, lithium ion (Li-Ion) battery technology used in all smartphones will improve only modestly in 2015. We expect a 2015 Li-ion battery to have no more than five percent greater unit charge or milliampere hours (mAh) compared to a 2014 model of the same dimensions and voltage. Longer battery life is likely to remain a key factor for those choosing their next smartphone.[118]

However, most new smartphone owners may still get a 15 percent increase in battery life, but this will mostly be due to other factors. New devices will benefit from efficiency improvements in the components that draw power from batteries (principally processors, radio transmitters and screens) as well as from better software. Further, we expect that the mAh of the average battery shipped in smartphones will increase by up to 25 percent in 2015,[119] due to the increase in average size of smartphones sold, with battery capacity rising at a greater pace than screen area.[120] (Battery life will not increase by the full 25 percent: larger screens use more power and newer phones typically offer increased functionality, leading to more intensive usage).

The smartphone has benefited from Moore's Law – the consistent, significant increase in performance at the same price point – with processor and connectivity speeds seeing the biggest increments.[121] Consumers have often yearned for a similar breakthrough for battery. However since the introduction of Li-Ion technology, which predates the arrival of the smartphone, they have continually been disappointed.

Indeed, there is unlikely to be anything more than a modest improvement from Li-Ion in 2015 or at any time in the future. At most it may yield just a further 30 percent performance before hitting a ceiling, with perhaps a 20 percent improvement by 2017.[122]

So any major inflection in battery performance would require the use of different technology. Li-Ion batteries are currently based on a common chemistry, and use a variety of lithium salts, organic solvents and electrodes. New batteries could use different physical structure of an anode or cathode (or both) such as a nanostructure. Alternatively they could vary the material used in the electrode(s), vary the anion that makes up the salt with lithium, or vary the electrolyte chemistry or material. Or they could move away from lithium chemistry completely, perhaps by using graphene.

Across all of these possible innovations, we do not foresee any breakthrough battery technologies being in the market in 2015 – or, regrettably, before the end of this decade.

The challenge of formulating a better battery

The lack of progress in smartphone battery capacity is not for lack of trying, but simply because it is extremely difficult to identify a battery chemistry that is better and suitable for use in the highly diverse operating environments in which the billions of consumer electronic devices we own are used. Many private companies and public organizations are and will likely remain focused on inventing a better battery chemistry – the reward for the inventor is enormous – but the need to optimize the many different characteristics that define what a 'good' battery is makes the task a challenging one (see: Formulating a better battery).

Internal combustion engine vehicles, of which there are currently over a billion in use,[123] still use a 12 volt lead acid battery whose fundamental design is over a century old.

We are not aware of any breakthrough battery chemistry in commercial development in 2015 that offers significant improvements across a sufficient range of these characteristics. But even if there was such a breakthrough, there would be further, time-consuming hurdles to pass: it is highly unlikely that a replacement for current Li-Ion batteries that could be 'dropped in' to existing devices and form factors will be available within the next three years.

118. In a Deloitte survey fielded in 14 developed countries in May to July 2014, 'battery life' ranked, on average, as the second most important factor when choosing a next smartphone, following the option 'To be a smartphone'. In Germany, Singapore and Spain, 'battery life' ranked number one.

119. Deloitte estimate, based on over 40 percent of smartphones sold in 2015 having a five inch or larger screen, and of significant numbers of iPhone mobile digital device users moving from a four inch screen to a 4.7 inch or larger screen. iPhone, Apple Pay, Touch ID are trademarks of Apple Inc., registered in the U.S. and other countries. Deloitte TMT Predictions is an independent publication and has not been authorised, sponsored or otherwise approved Apple Inc..

120. Screen area is a single diagonal dimension; batteries occupy volume in three dimensions. Assuming bezel size and device thickness remain constant, a phone with a five inch screen has 20 percent greater screen area than a four-inch device, but its volume is about 50 percent greater, a proportion of which is likely to be allocated to accommodating a larger battery.

121. Not all the improvements are driven by Moore's Law: some are driven by non-Moore's Law effects such as new standards, software, radio technology, antennas.

122. The rechargeable revolution: A better battery, Nature, 5 March 2014: http://www.nature.com/news/the-rechargeable-revolution-a-better-battery-1.14815#/batt2

123. World Vehicle Population Tops 1 Billion Units, Wards Auto, 15 August 2011: http://wardsauto.com/ar/world_vehicle_population_110815

Formulating a better battery

A battery suitable for use in everyday consumer-electronics devices needs to balance the following properties:

- Specific energy. It needs to concentrate as much total energy into as little weight as possible (measured in watt hours per kilogram).[124] Low device weight is a key source of competitive advantage among device vendors.[125]

- Energy density. As much total energy should go into as little volume as possible (measured in watt hours per liter).[126] There is a relentless race among vendors to make ever-slimmer devices;[127] bulky devices are typically regarded as being of lower value.

- Specific power: how much peak power (measured in watts per kilogram) can be delivered per unit weight.[128]

- Cost per energy unit. There are some emerging technologies, which have fantastic performance in terms of specific energy, or energy density, but whose cost is currently prohibitive. For example, one very promising field of battery research is graphene, but this nanomaterial currently costs over $100 per gram to manufacture. The price will fall, but as of 2015 a graphene battery in a smartphone would add about $1,500 for the raw material alone. In contrast, a $20 smartphone battery contains less than $0.02 worth of lithium carbonate.[129]

- Self-discharge: the rate at which a battery loses its power with no usage. This can affect the stand-by life of a device.

- Operating temperature. Devices need to function between zero and forty degrees Celsius. There are some battery technologies that only function at very high temperatures, making them unsuitable for use by the public, but which may still have industrial applications, such as large-scale energy storage. Other technologies are badly affected if left in a hot car for only a few minutes.

- Output current. The stated capacity of a battery (in watt hours) is usually dependent on the current (in amps) it is expected to deliver. A battery must be able to satisfy the current requirement of the device in which it is installed and still offer sufficient capacity.

- Safety. There are some battery-like technologies that have existed for many years, such as hydrogen fuel cells which are used to power public transport and are being trialed in passenger vehicles. However they are unsuitable in devices for safety and practical reasons: the fuel for fuel cells is often flammable or even explosive, and therefore may not be allowed on aircraft.

- Durability: the number of charge/discharge cycles that a battery can undergo; both full charge/discharge cycles as well as partial discharges.

- Efficiency. The amount of power needed to charge the battery compared to the amount of power the battery can store is important, because all ‘wasted’ power is manifested as heat, and heat usually damages batteries. A compact battery must be efficient or it will overheat, especially during fast charging.

- Complexity of the charge system. Current smartphones house the charging circuitry. (What most people refer to as the charger is just a power supply). A battery with a complex charging system requires more electronics, resulting in increased cost and bulk.

124. Specific energy, Wikipedia, As accessed on 4 December: http://en.wikipedia.org/wiki/Specific_energy

125. All energy storage is normally expressed in watt hours, but since all smartphone batteries work at the same voltage (3.8 volts) most smartphone battery capacity is described in mAh.

126. Energy density, Wikipedia, As accessed on 4 December: http://en.wikipedia.org/wiki/Energy_density

127. The market demand for ever thinner phones is one of the reasons why the user-swappable battery has disappeared on a growing range of phones. User-replaceable batteries require a battery compartment and a door to be incorporated into the housing to accommodate fool-proof replacement without exposing sensitive electronic components to static discharge, dirt, and so on. Batteries have to be encased in a tough plastic housing to mitigate the risk of puncture by careless users which would result in the destruction of phone as a consequence of leaking electrolyte.

128. Power-to-weight ratio, Wikipedia, as accessed on 4 December 2014: http://en.wikipedia.org/wiki/Power-to-weight_ratio

129. Spot lithium carbonate prices are around $7,000 per tonne, or $7 per kilogram, or $0.007 per gram. A 2000 mAh battery weighs 32 grams, and 2-3 grams of lithium, so roughly 2 cents of lithium.

A manufacturer would need to run extensive tests on any new battery technology that is being positioned to replace Li-Ion. Will the batteries last as long as expected, when used by consumers, in ways in which the designers may not have anticipated? Is there any risk of the new batteries catching fire if improperly charged, for example through the use of unapproved third-party chargers? Would mistreatment of the device – whether intentional or not – present a potential hazard to the user? Battery engineers can test a product extensively, but may not be able to replicate consumer usage fully. Further, batteries are expected to last a minimum of 2-3 years for almost all consumer devices, and therefore require reliability testing for at least that long, if not longer.

The new battery type would likely require a different charging technology, or may need different packaging, or other system design considerations. An advantage of Li-Ion is that the shape and format of the battery can be varied considerably to meet the needs of the system designer. This would not be the case if, for example, a battery required a metallic container. Similarly, a new chemistry may produce a voltage significantly different from the 3.65 – 3.7 volts of a Li-Ion battery which would require the smartphone to include voltage conversion circuitry, or, perhaps, reengineering the underlying semiconductor technology, which would be non-trivial.

Device component advances will reduce power consumption

While the batteries themselves are unlikely to experience a greater than five percent improvement in 2015, improvements in overall device design can enable – assuming steady state usage – more hours of usage between charges.

The three main drains on battery life for the typical smartphone are: the screen, the processor and the radio. Improvements in processor and radio design are likely to yield the biggest improvements in getting the most minutes out of each milliwatt.

The screen is a key differentiating feature and power drain of devices. Unfortunately we anticipate only modest improvement in display power consumption in 2015, although we do foresee significant change possible by 2020. A smartphone with a four-inch screen might consume about 0.75 watts and its battery would have about 5-6 watt hours' capacity. In real-life conditions, assuming concurrent usage of the screen, processors and radio, this would allow for only about four to five hours of constant usage.

We expect that power consumption by the display is unlikely to improve markedly in 2015: most smartphone displays are transmissive LCDs, which incorporate a backlight.[130] Lower-power display technologies are on the market, the most advanced of which is OLED (Organic Light Emitting Diode).[131] The key constraint on wider adoption of OLED screens in 2015 is cost. We expect OLED displays to displace backlit LCDs over time, but it may be five years before they predominate even in high-end phones.[132]

In the past year, the average size of smartphone screens has increased – and this has indirectly improved battery life. A larger screen drains the battery more and also permits a larger battery to be included, with battery capacity increasing at a greater pace than the screen size. A version of the same phone that has a screen 20 percent larger (with identical components aside from display dimension and battery volume) may last up to 40 percent longer.[133]

The processor used in many 2015 smartphones should be significantly more efficient than 2014 models, delivering a 30-40 percent increase in processing power per watt, in line with Moore's Law. Most processors used in devices – from smartphones to PCs – have experienced annual improvements in power efficiency over the past 40 years.

To illustrate this point, consider that in the mid-1980s, PCs operated at about one MIPS (millions of instructions per second) and consumed about 100 watts.[134] A 2015 PC with a high-end processor such as an Intel Core i7 typically delivers over 100,000 MIPS, but still consumes the same 100 watts. For more information on how processor design can reduce power consumption, see the side bar: Chip design and power efficiency.

Although processors are becoming more energy efficient compared to an equivalent device from last year, smartphones are incorporating ever more powerful processors, which require more energy. It is likely that the first smartphones with 3 GHz processors will launch this year. Software and hardware designers, anticipating consumer demand, will inevitably find applications for increased performance. For example, current leading games designed for smartphones feature far more complex, 3D graphics and video than the 2D games popular with the first smartphones.

130. This technology places a heavy draw on the battery as the entire screen has to be lit, even if a significant number of pixels may be dark or "OFF"

131. This is an emissive screen, which combines the display and backlight function.

132. Our current view is that OLED may become the default on high-end phones as of 2020.

133. The iPhone 6 and iPhone 6 Plus mobile digital devices share most components, including the same processor and motion co-processor. The larger model has a larger screen and a larger battery, but can support significantly longer Internet use and video playback. See: Apple Inc., as accessed on 4 December 2014: https://www.apple.com/uk/iphone/compare/

134. A 2015 PC would require about 10 megawatts if performance per watt had remained as it was in the 1980s.

The radio, which enables data to be transmitted and received, is the third most significant drain on power.[136] Over the past two decades, the energy required to transmit or receive each bit of data has fallen steadily and significantly, by about 30-40 percent per year.[137] Sending a 100 KB photo using a 4G phone should use less power than using a 3G phone, and significantly less than with a 2.5G phone. This is because 4G phones transmit at a faster rate, meaning that the radio is used for less time. Sending the same photo over 4G may take a quarter of the time it would take over 3G.[138] Further, the technology behind 4G is significantly more efficient in terms of coding, which allows for additional power savings.

However faster transmit rates are likely to change user behavior; the ability to send a photo faster is likely to prompt the sending of more and/or higher resolution photos, or the posting of video in place of photos.

As for voice calls, early analogue mobile phones required a continuous signal at one watt power when making a call: today's 4G phones can deliver up to several hours of continuous talk time for that same single watt.

Side bar: Chip design and power efficiency

Chip design is a major contributor to greater efficiency. Smartphones are built around a "system on a chip" (SOC), which combine much of the electronics of the mobile device onto a single integrated circuit.[135] One of the benefits of this approach is the ability to shut down parts of the SOC which are not needed at the time. If a user shuts off smartphone display, the graphics and display controller of the SOC may also be shut down and the processor itself put to sleep, only to awaken occasionally to check for user input (via the touchscreen or buttons), receive or transmit via the radio, or use Wi-Fi or Bluetooth. Power consumption of a 'sleeping' processor in a smartphone is a fraction of when it is awake: about 1 mW (0.001 Watts) versus 100 mW. Integrating faster processors reduces power consumption. A slower processor may take 0.5 seconds to complete a task, and consume 50 mW; a faster processor doing the same task in half the time would consume a little over 25 mW.

A further reason for the reduction in the drain by the radio on the battery for every voice minute or megabyte sent is decreasing transmit distance. As the number of cellular network base stations has increased, cells have become smaller, meaning a reduced distance between the phone and the base station, and shorter distances mean that transmitting from the phone to the tower requires much less power. The recent proliferation of private and public Wi-Fi routers has enabled a further decrease in transmit power. Smartphone users who predominantly connect to Wi-Fi, should experience longer battery life than those relying mainly on the mobile network

135. An SOC might special purpose processors to handle things like graphics and radio communications or these might remain separate devices for design reasons. Some even include rudimentary processors which exclusively handle a single I/O port, ensuring extremely rapid response time to events, well beyond what would be possible from the "main" CPU running the operating system.

136. For a detailed analysis of power efficiency in LTE smartphones, see: An empirical LTE smartphone power model with a view to energy efficiency evolution, Intel Technology Journal, 2014: http://vbn.aau.dk/files/176790997/An_Empirical_LTE_Smartphone_Power_Model_with_a_View_to_Energy_Efficiency_Evolution.pdf

137. This is in line with Moore's Law

138. Second generation (2G) mobile technology, launched in 1991 is capable of up to 64 Kbit/s transmission; fourth generation (4G), launched in 2009, can deliver speeds of up to 75 Mbit/s. This represents about a 50 percent increase in speeds per year

Smartphone users who predominantly connect to Wi-Fi (presently mostly for data, but increasingly for voice), should experience longer battery life than those relying mainly on the mobile network.

Bottom line

Battery life is becoming an increasingly primal anxiety among digital natives. This anxiety is to an extent self-inflicted: more frequent use of more power-hungry applications on larger devices consumes more power. Our devices would last longer if we used them less, or used them differently. But the rapid progress in smartphone capability looks likely to continue in 2015, which means that the smartphone users will use their phones more frequently, and for a wider range of applications. The gains from new or larger batteries are likely to be balanced out by greater usage.

Phone users who started using mobile telecommunications back in the mid-90s or earlier will be familiar with predecessors to Li-Ion, such as nickel metal hydride, which had markedly inferior performance. These individuals may yearn for a similar step-change increment in performance from batteries. The good news is that one day there is likely to be a new formulation that offers a significant improvement, but that day is unlikely in 2015. In the interim, see our suggestions on how to improve battery life in the side bar.

Frustrations with battery life present many opportunities for vendors.

Smartphone vendors may differentiate their devices in terms of processor design, battery capacity and fast-charging capability.

Network operators with high-density networks and/or a large network of public Wi-Fi hotspots may advertise the fact their network can reduce battery consumption, due to lower transmission drain on their customers' batteries. When a network is overloaded, the phone can spend a lot of time on unproductive tasks, such as waiting for the file to download, or pinging the network to ask whether it can download packets. A congested network can cancel out all the improvements in battery chemistry or semi-conductor efficiency.

Component vendors can offer a range of different external power supplies.

Public venues and public transport facilities can differentiate their facilities through the offer of charging units. There are likely to be ever more locations offering opportunities to recharge, from airport lounges, to planes, trains and automobiles.[139]

Side bar: How to improve smartphone battery life

- Replace the battery with a fresh one, as it will typically have a greater ability to retain power. Over time, with successive recharges, batteries lose their ability to charge.
- Charge frequently and never let the battery drain completely. A Li-Ion battery that is typically discharged by 25 percent before being recharged should last about twice as long as a battery which is half depleted before being recharged.[140]
- Use a phone with a larger screen, as it will likely have a larger battery.
- Keep the display backlight as dim as practicable.
- Use the phone on a relatively uncongested network.

139. A growing range of taxi cabs in major cities are expected to incorporate USB chargers. See: Next-Gen NYC Taxis to Have USB Ports for Phone Charging, Tested, 5 April 2012: http://www.tested.com/tech/43768-next_gen-nyc-taxis-to-have-usb-ports-for-phone-charging/; London's new Metrocab electric taxi could save cabbies £40 a day, Auto Express, 16 January 2014: http://www.autoexpress.co.uk/car-news/85276/londons-new-metrocab-electric-taxi-could-save-cabbies-ps40-a-day. New fleets of trains incorporate USB chargers, see: On board the new Eurostar, the sleekest under-sea train, CNet, 13 November 2014: http://www.cnet.com/uk/pictures/on-board-the-new-eurostar-the-sleekest-under-sea-train-around-pictures/

140. Note also that the charging circuit, which is in the smartphone and not in the charging unit, will typically power the phone off the charger while the battery is being charged and stop charging the battery once it is fully charged. Therefore there is some advantage in terms of battery life to leave the charger plugged in provided the battery is not overheated, which is unlikely to happen with a smartphone. For more information on how to prolong the life of a Li-Ion battery, see: BU-808: How to Prolong Lithium-based Batteries, battery University, as accessed on 4 December 2014: http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

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