Socket Mobile Customer Support Notice CSN-1007
Li-Ion Battery Best Practices
SoMo Product Line

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1 Description

This white paper is intended to give customers guidelines on how to best optimize the life and performance of their Lithium Ion (Li-Ion) batteries. This document focuses on the Li-Ion batteries used in the Socket Mobile SoMo however the concepts apply to all Li-Ion batteries. Applying the recommendations in this document will allow users get the most out of their batteries.

2 General issues

The ultimate goal of a battery user is to maximize the life of the battery and make sure that the battery is always used in a safe manner. Maximizing the life of the battery means maintaining a high charge capacity for as long as possible.

At this time lithium-based batteries are the battery of choice for mobile applications. They offer the highest energy density and are maintenance free. However once they are worn and degraded there is no way to restore the battery – it has reached the end of its life. Li-Ion batteries have a defined lifespan.

Normal expiration of lithium-based batteries is caused by two processes: aging and usage. The Li-ion battery effectively has a timer that starts ticking as soon as the battery leaves the factory. Due to the Lithium Ion chemistry, the device internal structure slowly degrades over time, reducing performance (capacity and energy delivery ability) until at some point the battery is unusable. The battery ages even if not used. In addition, battery usage – how it's used, at what temperature, how it's charged, etc. - also reduces battery capacity over time. The aging and usage impact are influenced by a number of factors which are described below.

3 Document Overview

This document is arranged in a hierarchical manner. If the reader only reads a portion of this document, it should include sections 4 and 5. Those two sections provide a straightforward step-by-step description on how to get the most out of a Lithium Ion battery.

Section 4 is a summary set of simple guidelines that can be used to optimize your battery life and performance. The items listed are the high impact factors that will affect the battery. By paying attention to the items in this section users will be able to get the most out of their batteries.

Section 5 describes considerations for battery maintenance programs. All users, particularly large deployments, should put in place a maintenance program, to create the most stable and cost-effective deployment.

Section 6 goes into much more detail on factors that affect battery life. In addition some of the tradeoffs and reasons for failure are discussed. This section gives direction on further optimizations that would be useful for corporate deployments and larger users.

Section 7 addresses safety questions that have come up over time regarding the SoMo battery system.

The final section is a list of references for readers interested in delving deeper into the issues and technology.

4 Simple Guidelines

Expect battery life to be a maximum of either 300-500 discharge/charge cycles or 2 years. Replace batteries beyond that point. The discharge/charge cycle count is provided in the Power Plus Battery Friendly® Utility located in the Settings folder under the System tab or by tapping the battery icon at the top of the home screen (only available in WM6, SP7 or above with MCU hardware revision of 2.7 or higher. Older units need to be sent to the factory for a firmware update to the MCU). For more information on this utility see Socket's SoMo documentation section at:

http://ww1.socketmobile.com/products/handheld-computers/tech-specs.aspx)

- Recharging a partially charged Li-ion battery causes no harm (as in memory effects seen in other battery technologies). Avoid repeated deep discharges and minimize time spent at full charge.
- Charge only between 0 to 40º C (32 to 104º F).
- Use only between -20 and 60º C (-4 and 140º F) (internal battery temperature).
- High battery temperature and leaving the battery at full charge are the two main preventable contributors to shortened battery life. A battery left at full charge in a warm or hot environment will see significantly shortened life.
- When not in use, store batteries in cool area at about 40% charge to maximize battery life.
- Avoid storing (for long periods of time) spare Li-ion batteries for later use.
- Only charge the batteries in Socket approved chargers.

5 Battery Maintenance

Users should create a battery maintenance program much like one would follow with a car maintenance program. ***This program will improve overall battery performance, enhance system reliability and deployment stability, and will reduce replacement costs.*** We can not state strongly enough how important this is to a complete deployment program.

One side effect of aging and usage in a Li-ion battery is that the battery loses its ability to support large current surges that may occur during startup of programs, hardware, etc. The result could be an intermittent failure that is very hard to track down – an example might be WLAN failures. One of the primary reasons for the maintenance program is to be proactive and prevent these kinds of spurious issues which are very costly to a deployment and hard to track down.

Such a program would perform the following on a regular basis:

1) Check the charge/discharge cycles on battery and replace batteries that have exceeded the 500 cycle count. This information is provided in the Power Plus Battery Friendly® Utility (only only available in WM6, SP7 or above with MCU hardware revision of 2.7 or higher). It is found in the "Usage" tab, as "remaining charges %:".
2) Monitor age of battery – replace after 2 years.
3) Inspect batteries for physical damage or effects like bulging (see section 7.3).
4) Exercise battery – do a full discharge of a battery to re-calibrate the internal battery fuel gauge (see 6.3). It is recommended to do this roughly every 6 months. To do this:
    a. Take the battery out of the charger
    b. In the Power settings section, "On Battery power", uncheck "Turn off Device if not used for:"
    c. In the Backlight settings section, in "On Battery Power:" uncheck "Turn off backlight if device not used for:"
    d. Let the device run down the battery till it shuts off (overnight is usually sufficient)
    e. Recharge the battery in one pass from the 0% to 100% - it must go thru the complete charge cycle.

6 Detailed recommendations to prolong battery life

6.1 Maximum Charge/Discharge Cycles

A Li-Ion battery provides 300-500 discharge/charge cycles. The battery prefers a partial rather than a full (deep) discharge. Frequent full discharges should be avoided when possible. Instead, charge the battery more often. A maximum of 80% depth of charge is recommended. With Li-Ion batteries there are no "memory issues", so there is no concern with partial charges/discharges. Minimize time that the battery is at full charge.

6.2 Battery Priming

With older battery technologies it was always recommended to charge the battery completely. Again with older technologies after the battery aged, it was recommended to completely discharge and charge again, to "regain capacity". These techniques were called "priming". Priming will NOT make a difference with Li-Ion because the maximum capacity is available right from the beginning. A full discharge does not improve the capacity of an older Lithium Ion battery.

6.3 Digital memory

Although Li-Ion batteries are memory-free in terms of performance degradation, the SoMo battery has an internal "fuel gauge" circuit that can exhibit what engineers refer to as "digital memory". The battery recalibrates its capacity measurement (i.e. for example the point where it tells you the battery has 10% battery capacity left – found in the Power Plus Battery Friendly® Utility in the settings section of a SoMo). The reason is:

Short discharges with subsequent recharges do not provide the periodic calibration needed to synchronize the “fuel gauge” or battery capacity monitor of the battery. A deliberate full discharge and recharge every 50-100 charges or 6 months corrects this problem. Letting the battery run down to the cut-off point in the equipment will also do this. If ignored, the fuel gauge (battery capacity readings) will become increasingly less accurate.

6.4 Charging temperature

a. Batteries charge best at room temperature.
b. Cold temperature charging is a serious safety issue. Li-Ion batteries SHOULD NOT be charged below 0°C (32°F). This will cause the battery to become more susceptible to catastrophic failure later if subjected to impact or high rate charging.
c. The charging safety circuit in the SoMo will prevent the charging of the battery if its internal temperature is above 40°C (104° F).

6.5 Operating Temperature

a. Li-Ion batteries operate within the range of -20°C to 60°C (-4°F to 140°F).
b. Batteries may fail to work at low temperatures but the batteries will not be damaged.
c. It is not recommended to discharge Li-Ion batteries at temperatures above 60°C (140°F). The battery can be permanently damaged if used above that temperature.
d. Operating batteries at an elevated temperature (above 40º C / 104° F) dramatically shortens their life. SoMo users might inadvertently operate in this condition if they leave their SoMo in a charger with the display permanently on in a high temperature environment. The high temperature along with the unit being consistently at 100% charge can cause conditions that will shorten the battery life. Battery life could be reduced to as little as 6-12 months (25-50% of typical battery life), independent of the charge-discharge cycles.

6.6 Charging considerations:

a. The charger design in the SoMo and in the SoMo cradle is designed to maximize the life of the battery.
b. After charging is complete, the charger shuts off completely and prevents any over-charging (sometimes called trickle charging) of the battery. In the SoMo the charger protects the battery so the charger can be left on indefinitely.

6.7 Battery Aging

Aging of Li-Ion batteries is an issue that is often ignored. A Li-Ion battery in use typically lasts between 2-3 years, whether it is used or not. Aging starts from the date of manufacture. The speed by which the Lithium Ion chemistry ages is governed by temperature and amount of charge in the cell, and results in a capacity loss manifested by increased internal resistance caused by oxidation. This process is irreversible. Eventually, the cell resistance reaches a point where the battery can no longer deliver the stored energy although the battery may still have ample charge.

For this reason, an aged battery can be kept longer in applications that draw low current as opposed to a function that demands heavy loads. Conversely the battery may perform properly in most cases but when there is a current surge due to some special

high current function turning on, the system may fail. This will look to be an intermittent failure and is very hard to track down. See the “Battery Maintenance” section.

6.8 Battery Storage

The impact of storage on battery life is strongly affected by the temperature and charge level of the battery. A fully charged Li-ion battery that is stored at 40°C (104° F) suffers a capacity loss from 100% to about 65% in as little as one year. Note that an application that keeps a battery at constant full charge will be equivalent to storing the battery at full charge.

To optimize battery life, battery storage should be done at low temperature (10 - 15º C / 50 - 59° F) at about 40% charge level (approx. 3.7-3.8V at battery). If a battery is stored at 25º C (77° F) and 40% charge level, it will lose about 4% of its capacity after 1 year. Stored at 0°C (32° F) and 40% charge, the battery loses only 2% capacity over a year. Most battery manufacturers store batteries at 15º C (59° F) and 40% charge.

6.9 Battery Cycle Life

Manufacturers of commercial Li-ion batteries specify a maximum cycle count of 500 at room temperature. At that stage, the battery capacity would drop from 100 to below 80 percent. If operated at 40°C (104°F) rather than at room temperature, the same battery would only deliver about 300 cycles.

7 Safety Notes

7.1 Battery usage warnings

Warning	Reason
a. Only use a Socket Mobile, Inc. specified charger.	Manages proper charging of the battery to prevent issues associated with trickle charging, overcharging, etc.
b. Do not throw the battery in fire, or add heat.	The battery has an organic electrolyte that will ignite if heated to a high enough temperature. The batteries go into a thermal run-away condition leading to venting of flaming gases.
c. Do not short circuit the battery terminals.	The SoMo battery is protected against short circuit, but not all Li-Ion batteries are protected. If this is done to an unprotected battery it can overheat, ignite and explode.
d. Do not disassemble, alter, or solder the battery.	By altering a battery one can accidentally short out an internal cell potentially causing the battery to overheat, ignite and explode.
e. Do not use the battery for any purpose other than specified.	By altering a battery one can accidentally short out an internal cell potentially causing the battery to overheat, ignite and explode.
f. Li-Ion batteries should not be charged below 0°C (32°F).	Charging at very low temperature can cause metallic lithium to plate out on the anode. This can not be undone, and done repeatedly will make the battery more vulnerable to impact, crush or high rate charging.

g. Do not physically damage the battery.	By altering a battery one can accidentally short out an internal cell potentially causing the battery to overheat, ignite and explode.
h. Never use the battery above 60°C (140°F).	We recommend being conservative in this area because internal cell temperature will be higher than air temperature. Above 130°C (265°F) the cell becomes thermally unstable and thermal runaway takes place leading to venting of flaming gases.

7.2 Battery protection circuits in the SoMo

Batteries used in the SoMo as well as the SoMo charging systems have a number of built-in protection features to prevent dangerous situations from occurring with the battery.

a. Protection against over-voltage charging: Circuitry in the battery will not allow the battery to be charged above 4.3V
b. Protection against under-charging: Circuitry in the battery will not allow charging if the cell voltages drop below 2.5V. Note that other circuitry in the SoMo will not allow battery voltage to drop below 3.2V when in the system, so this would only happen if a battery is left in storage for an extended period.
c. Protection against charging at high temperature: A combination of circuitry in the battery and SoMo will not allow the battery to be charged if the battery core temperature is above 45º C (113° F).
d. Over-current protection: If excessive current is seen at the battery terminals, then the battery protection circuitry will shut off the battery output.
e. Short-circuit protection: If a short at the battery output is detected then battery protection circuitry will shut off the battery output.
f. Fuse protection: The charge input path to the battery (C+) is fused at 1A. The discharge output path (D+) is fused at 5A. This provides an extra level of protection in case the output of the battery is shorted.

7.3 Bulging Battery

Bulging batteries deserve a special discussion since there has been so much press over the last few years on the issue. A battery is bulging or swollen when it expands larger than its normal size. By nature of the Li-Ion technology, the charge/discharge cycle will gradually cause a Lithium Ion battery to bulge slightly. There are a number of factors noted below which can accentuate the problem.

Over the life of a battery (500 charge/discharge cycles), a typical SoMo standard battery could expand in thicknesses as much as 5 to 10%. Based on feedback from various vendors and experience in the field, this is normal. When a battery bulges beyond this point it should be replaced. Users may not notice the bulging until the point where the battery does not fit well in the battery compartment – this is well beyond the 10% expansion point and the battery should definitely be replaced at this point.

A battery expanded to that point is not a serious danger however it should no longer be used. It has gone beyond its useful life. If the user continues to use it significantly longer, at some point it could damage the SoMo product, and in the extreme cause, explode, posing a risk to the user. It is best to dispose of it at this point.

The battery should be disposed of or returned to Socket if it is under the 90 day warranty period for consumables.

Bulging can be caused by a number of factors with the following being the key contributors. Based on Socket's experience almost all bulging battery failures are due to a combination of items (a), (b) or (c).

a. Age or a large number of charge/discharge cycles.
b. Used or stored at high temperatures.
c. Batteries that are held over a long period of time (greater than 6 months) close to full charge. In addition many have a large number of very short re-charges cycles. For example situations where the units sit in a charger most of the time.
d. Charging an over discharged battery (below 2.5v) – SoMo batteries are protected to not allow this to happen.
e. Over charging (charging above 4.3V or trickle charging) – There are two protection mechanisms in place to prevent this. First, the batteries are internally protected to not allow charging above 4.3V. Second, the charger circuit automatically stops charging when the battery reaches full capacity at 4.2V.

The user should manage their battery deployment and monitor for this problem.

8 References

Most of the information in this document was derived from industry sources. One of the best resources we have found on the web (and an associated book) is at:

http://batteryuniversity.com/learn/
http://batteryuniversity.com/
http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

Battery University is a site sponsored by battery tester manufacturer Cadex Electronics, Inc. The text is written by long time battery industry expert Isidor Buchmann and covers all aspects of battery technology in a very readable and balanced fashion.

The following sites have even more technical details if the reader is so inclined:

http://electronics.howstuffworks.com/Li-Ion-battery.htm/printable
http://en.wikipedia.org/wiki/Li-Ion_battery
http://www.mpoweruk.com/lithiumS.htm
http://pubs.acs.org/cen/science/85/8551sci1.html
http://www.batteryeducation.com/2006/08/lithium_ion_rec.html
http://www.batteryeducation.com/battery_teczhnology/