Battery Life Testing

Lightbug

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INTRODUCTION

This document explains how Lightbug calculates estimated battery life based on update interval frequency. The estimates are generated based on a combination of lab testing results and empirical data collected from devices in the field: we will detail here how these measurements were taken in both settings and how the results are combined to create the battery life calculator shown on the Lightbug website.

LAB TESTING

CURRENT USAGE

The first step in validating energy usage per transmission was to measure current usage over time and integrate into energy for different device modes. Tests were conducted on both 4G and 2G networks from a “cold-start” (device powered off) using default device settings.

Energy usage was measured by wiring a USB current monitor in series between the battery and the device. The measurement accuracy of the monitor was ±0.6mA and power usage (current) was recorded every second before being integrated into total energy usage values.

Power usage in sleep was measured using a DVM accurate to ± 0.001 mA and averaged over multiple readings.

State	2G	4G
[Power usage] **Device Sleep**	0.04mA ± 0.01 mA	0.04mA ± 0.01 mA
[Energy usage] **Single Transmission** (sleep → transmit → sleep)	1.2mAh ± 0.2mAh	0.7mAh ± 0.2mAh
[Energy usage] **Transmission in continuous upload mode** (< 5 min interval)	0.7mAh ± 0.2mAh	0.3mAh ± 0.2mAh

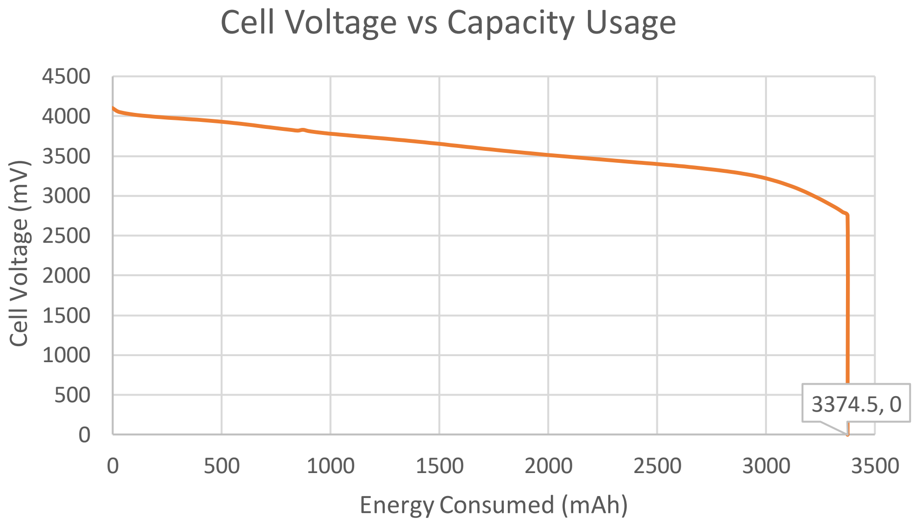
BATTERY CAPACITY

Batteries used in Lightbug devices are carefully selected to ensure battery capacity delivered is as advertised. We only work with trusted suppliers that consistently deliver high quality batteries – as determined through in house testing.

Capacity testing is conducted by fully charging a battery and then applying a constant load until it discharges, monitoring voltage at regular intervals. This is done for each batch at the cell level by the manufacturer, before the batteries are spot welded together to form a 2P (2 parallel) battery pack.

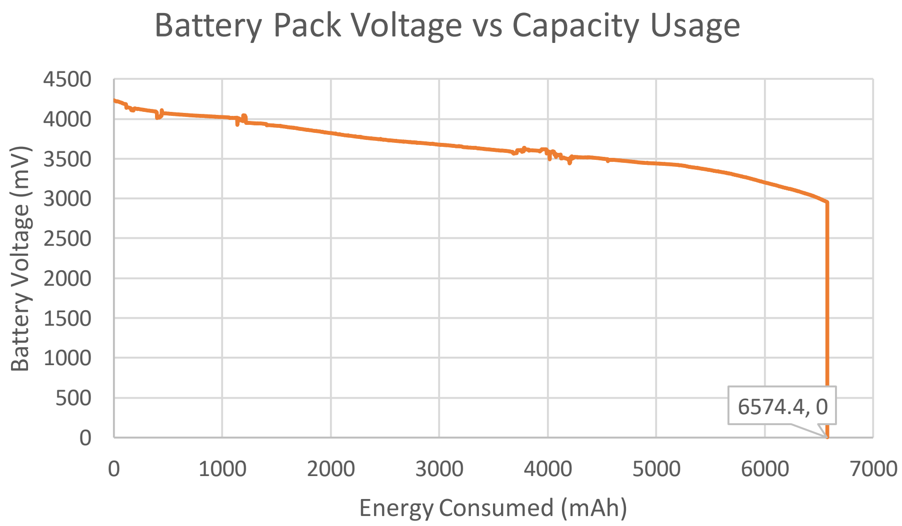
RECHARGEABLE PACKS

Below is the graph from testing of 27 September 2019 batch of rechargeable 3300mAh cells



Here we can see the capacity of each cell was measured at 3374.5 mAh (vs 3300mAh rating) – two of these batteries connected in parallel should therefore produce a pack with 6749mAh capacity.

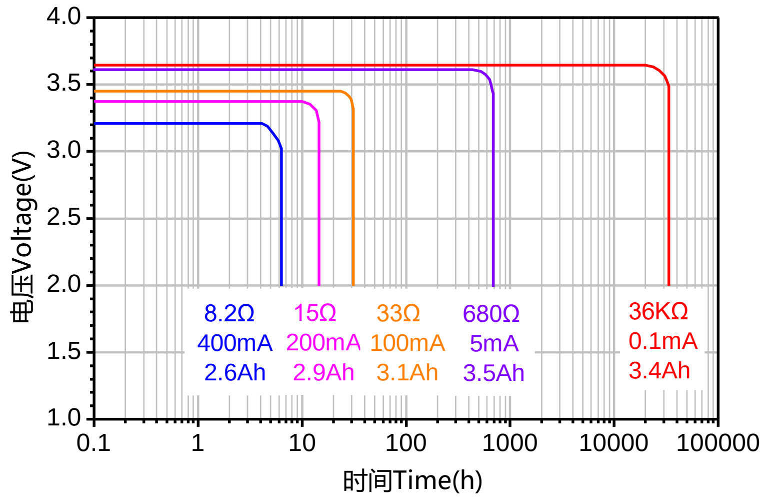
To validate this, we conduct internal testing of the assembled packs to ensure the final product meets the advertised capacity (6600mAH). Below is a plot of voltage over time for a Pro battery rated at 6600mAh discharged continuously at an average current of 145mA over 45.5 hours.



We can see here the measured capacity was 6574mAh – the minor difference (0.3%) when compared to the theoretical value likely being due to accumulated measurement errors.

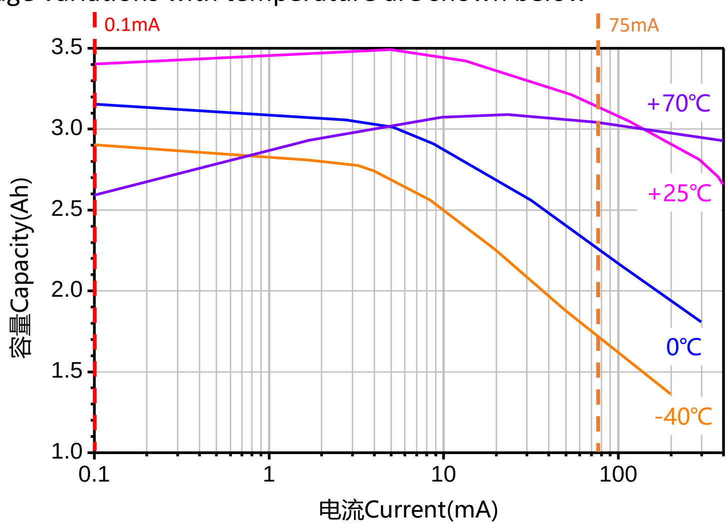
Single use LiSoCl2 packs

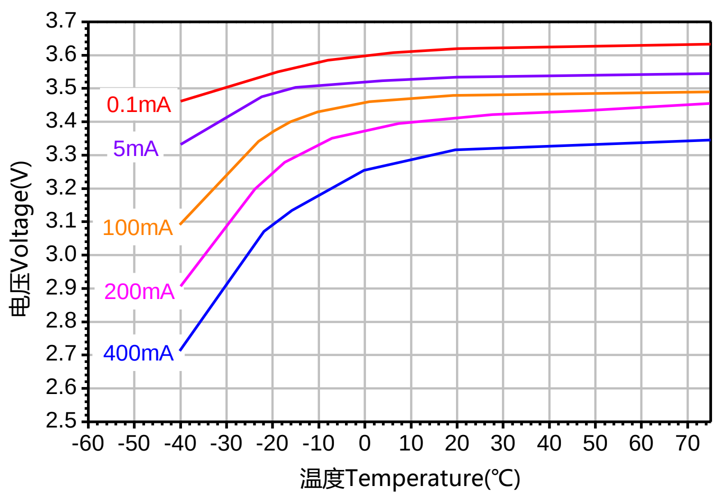
The same testing was conducted with non-rechargeable battery packs. Below are the discharge curves for a single use cell used in the packs rated at 7000mAh (3.5Ah each). As the properties of LiSoCl2 batteries vary more significantly with temperature than rechargeable batteries, additional curves have been included.



LiSoCl2 packs are unable to provide the high discharge currents required for cellular connectivity on their own: capacitors are used to smooth out the short power bursts. The net effect is that the devices take an average of 60-90mA during transmission cycles, and 0.04mA during sleep cycles. As such the orange curve (33Ω) is most representative during transmission cycles (~0.3% of device lifetime) and the red curve (36KΩ) most representative of sleep (~99.7% of device life).

Capacity and voltage variations with temperature are shown below





FIELD RESULTS

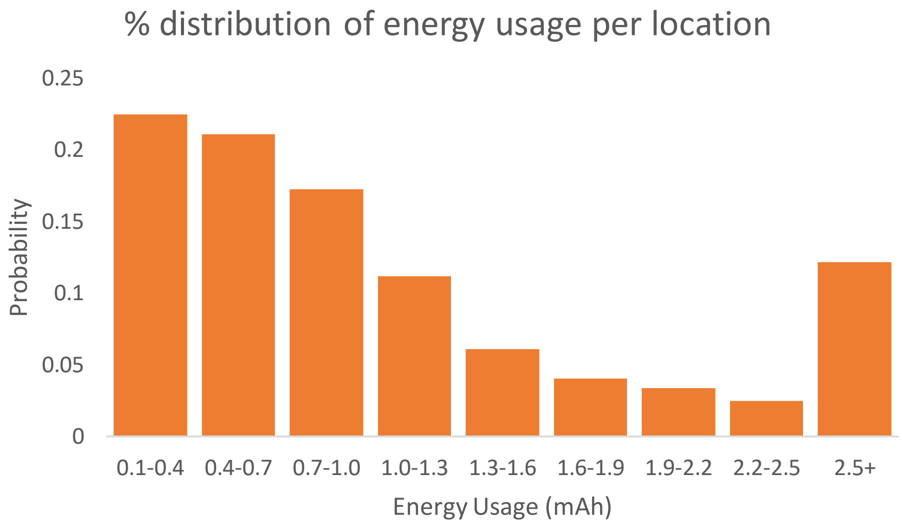
In April 2019, Lightbug products started to include an on board current monitoring solution as standard. This current (power usage) monitoring performs the same function as the lab equipment described above and readings are aggregated by the on board processor.

As the new hardware was gradually rolled out, we were able to collect "real world" power usage metrics. In aggregate, the average power usage across all devices with the current monitoring was

1.281mAh

Average value **over 1 890 845 location updates**

By binning the data in 0.3mAh chunks, we can obtain a probability distribution as follows



The non-normal distribution of points can be explained by network variations. Specifically data points with lower power usage are typically associated with transmissions over the low energy 4G network, whilst transmissions taking 1.0mAh to 2.5mAh are typically associated with 2G transmissions. Transmissions taking more than 2.5mAh will generally occur after one or more failed transmissions (due to poor network coverage): since energy usage is only reset to 0 upon successful transmission, failed transmission attempts will continue incrementing the energy usage counter.

CALCULATIONS

The above data can be combined analytically to calculate estimated battery life of devices.

The first step in this calculation is to calculate the energy usage per day:

$$E_{day} = (I_{sleep} \times 24h) + (N \times E_{transmit})$$

Where I_{sleep} = 0.04 mA (sleep current), N is the number of transmissions per day and

$E_{transmit}$ = 1.281 mAh (average energy consumption in real-world)

If we take the example of one location update every 12h, ie N = 2:

$$E_{day} = 0.04\ mA \times 24\ h + 2 \times 1.281\ mAh$$

$$E_{day} = 3.52mAh$$

For a quick estimate, we can now divide battery capacity by this daily energy figure:

$$Life\ (days) = \frac{Battery\ Capacity}{E_{day}}$$

For our 12h update example, this yields

Life = $6600 \div 3.52$

Life = 1874 days = 5.13 years

For a more accurate estimate, we must also account for battery self-discharge. Empirically, the self-discharge for batteries properly stored at 20°C is measured at 0.5%. However we will use the nominal 1% value specified by battery manufacturers to account for variations in operating temperature. Note that this discharge value is measured in relation to remaining capacity (not original capacity).

1% per year equates to 0.0027% per day ($1 - \sqrt[365]{0.99}$): we must now calculate the battery life iteratively by subtracting self-discharge and power usage per day until our simulated battery is completely discharged. Using this method, we now get

Life for 2 updates per day = 1829 days = 5.01 years

For non-rechargeable LiSoCl2 batteries, due to variations in temperature and current draw, a 10% error margin should be applied. (Note self-discharge on LiSoCl2 is assumed to be negligible compared to temperature variability):

Life = $(7000 \times 0.9) \div 3.52$

Life = 1790 days = 4.9 years