OmniSense Wireless Sensor Networks for Facility Monitoring

Prevent Structural Damage Before it Starts

OmniSense Sensor Battery Life

Sensor battery life is critical to the OmniSense monitoring system. The sensors are designed to be permanently embedded into structures in locations that preclude battery replacement. The key factors in determining battery life will be discussed and analyzed in this application note and both a theoretical and empirical analysis of the expected battery life is presented.

1. Introduction

Predicting the life of a battery in any application is non-trivial. Many of us have modern gadgets such as digital cameras and portable computers which provide an indication of remaining battery life, usually in terms of minutes of operation. It is not at all unusual to have your camera tell you it has 30 minutes of operation left and then 2 minutes later it shuts itself off because it ran out of power. This only serves to illustrate that predicting battery life is a difficult problem.

The primary factors in predicting battery life are:

- Battery Capacity – Usually expressed in terms of mAh or milliampere hours. This is the number of milliamperes the battery can deliver for 1 hour while staying above a specified voltage. A battery's capacity is dictated by its chemistry and its physical size.
- Battery Chemistry – Different battery chemistries behave very differently. One critical factor which is dictated by the battery chemistry is the battery's self discharge rate.
- Load – what is the average current drain on the battery? The higher the load the shorter the battery life.
- Operating temperature – Batteries are a chemical reaction and are governed by the Arrhenius equation which states that the rate of a chemical reaction doubles for every increase of 10°C in temperature. Higher temperatures can have either a positive or negative effect on battery life; this will be discussed later.

OmniSense sensors monitor their battery voltage by measuring the voltage when the battery is under maximum load which occurs when the wireless radio is transmitting. This measured voltage is included with every sensor reading and stored in our SQL database. We therefore have a complete record of battery voltage for every reading of every sensor we have sold. This data is extremely useful for documenting real world behavior of batteries and sensors and their operating environment and gives us the unique ability to document just when, where and why a battery has worn out.

2. Battery Type

OmniSense sensors use a $Li\text{-}SOCl_2$ (Lithium Thionyl Chloride) battery. Sensors typically use an ER14505 sized battery with a capacity of ~2.4Ah. While the battery may look like a common "AA" Alkaline battery it is NOT the same. Alkaline batteries only deliver 1.5 volts and have a typical 5 year shelf life. Li-SOCl2 batteries on the other hand deliver 3.6 Volts and have a typical 10-20 year shelf life. Shelf life of a $Li\text{-}SOCl_2$ battery is up to 20 years when properly stored at a temperature of less than 25C.

3. Battery Self Discharge

All batteries have what is called a self discharge rate which is the rate at which the battery will discharge itself when sitting on a shelf connected to no load at all. This is due to the battery's own internal resistance. The rate of self discharge is directly affected by the storage temperature where higher storage temperatures can increase the rate of self discharge. $Li\text{-}SOCl_2$ batteries typically have a self discharge rate of <2.0% per year when stored at room temperature.

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4. Battery Passivation

Li-$SOCl_2$ batteries by design are subject to something called passivation. To put it simply, teh battery is designed to "go to sleep" when not in use. Passivation means that the battery's anode will grow a protective or insulating passivation layer over it which will reduce both the battery's self discharge rate (a good thing) as well as the battery's ability to deliver power (a bad thing in our application). Passivation occurs by design when the battery is stored with no load. In our application the sensors current draw is so low that if we are not careful the battery can become passivated under certain circumstances. In practice we have seen that sensors operating in an environment with large daily temperature swings (roofs are a classic example with up to a 60°F or more daily temperature swing) can trigger low battery alarms when in fact the battery may still be "full". What happens is that as the battery heats up during the day the chemical process that grows the passivation layer is accelerated. As we mentioned earlier the rate of a chemical reaction doubles for every increase of 10°C in temperature . At the same time, when the battery is hot its ability to deliver power is also increased. Therefore during the day the sensor would report normal (i.e. >3.0 volts) battery voltage. But at night, when the battery cools off, the passivation layer built up over the hot day time temperatures is still in place and will impede the battery's ability to deliver power when the battery is colder. Because of this it is not at all unusual to get daily low battery alarms from sensors operating on a roof top even though the battery in fact is near new and near full. We typically advise customers to ignore the alarms. Another option is to increase the current the sensor draws from the battery as that reverses the passivation process and "punches through" the passivation layer. The down side of that of course is the battery life will be shortened.

5. Operation at High Temperatures

As noted earlier operating at high temperatures, ie higher than 25C, can potentially increase the batteries self discharge rate. Counterbalancing that is the passivation process mentioned earlier which protects the battery from self discharge. In practice it's a fine balance and its difficult to predict exactly what the overall impact of operating at high temperatures will have on battery life.

6. Operation at Low Temperatures

All battery's ability to deliver power decreases as temperature decreases. If you have ever lived in a cold climate and owned a car then you know that cars are very hard to start in the winter and "CCA" or cold cranking amps of a battery are very important.

7. Impact of Sensor Reading Rate

As you can see from the chart below, the sensor reading interval, ie the frequency with which a sensor wakes up and transmits a reading to the gateway, has a direct impact on battery life. Note that beyond 15 years the battery life is a function of the shelf life of the battery.

battery capacity (Ah)	reading interval (minutes)	life (Years)
2.4	1	2.4
2.4	5	9.9
2.4	10	16.48
2.4	60	36.2

8. Real World Test Results

We have run sensors with a one minute reading interval and collected over 1,000,000 readings from a single battery. These sensors were in a computer data center with tight climate controls. That translates into a theoretical 90+ years of operation when sampling at a 1 hour reading interval. In practice the battery's shelf life will dominate the battery life equation once you get much beyond a 10 minute sampling rate.

9. Measuring Battery Health

Li-$SOCl_2$ batteries will measure 3.6 volts "open circuit voltage" even when the batter is nearly dead. The more useful measurement is the battery's voltage under a real load. As noted earlier that is how our sensors measure their own battery voltage – i.e. while under the load of the radio while it's transmitting. Users are therefore cautioned to NOT simply measure battery voltage with a volt meter and assume that 3.6 Volts means the battery is good. Most multi-meters have a DC current setting. Our advice is to set your meter to a 1000 or 2000 mA DC setting and measure the battery's maximum current delivery as the best indicator of battery health. A good battery will measure from 100-1500 mA whereas a weak battery will read from 50-100 mA and a near dead battery will read around 30 mA. Note that as mentioned earlier if the battery has been stored for a long time, or for that matter has been in use in a sensor reading once per hour (as that's akin to storage) that the initial current measurement will be low due to passivation. In this situation if you keep the meter on the battery for a minute or more you will see the battery "warm up" as the passivation layer is dissolved by the act of drawing current from the battery. As the battery warms up it will deliver increasingly more current and again, if you see it deliver >100 mA the battery is "good". There is no good way to determine if the battery has 90% or 50% capacity left.

10. Causes of Premature Battery Failure

There are several known causes of premature battery failure. In order of likelihood:

1. The sensor has gotten wet. Sensors typically are not water proof or even water resistant. When sensors get wet they may either fail completely or they may develop weak resistive shorts which will cause the sensors power drain on the battery to increase and therefore shorten battery life. OmniSense does sell both water resistant (ie conformally coated circuit boards) and water proof (ie potted sensors) versions of their sensors on special request. Note that prolonged operation in a condensing environment is the same as getting the sensor wet. Note that we can often tell if a sensor has gotten wet by looking at the RH and WME readings for the sensor.
2. The sensor's battery was inserted backwards. Inserting the battery backwards effectively applies a direct short to the battery. The battery will get very hot and will discharge in a matter of minutes. We have seen where users have inserted the battery backwards, noticed they got hot, and then inserted the battery correctly. They then think all is well as the sensor will operate normally in even report a very high battery voltage but in fact even a short period of time inserted backwards will dramatically decrease battery life. If you have inserted the sensor's battery backwards you should always replace the battery. Note that the battery insertion polarity is clearly marked in the battery compartment. Note also that we can tell from the sensor's battery voltage readings if the battery has been inserted backwards as the voltage graph will show a distinct pattern unique to a battery recovering from being shorted.
3. The battery is defective. Most sensors are stored with the battery in and operating for months or longer before we test and ship them so it's very unusual for a defective battery to pass our testing procedures but it can happen.
4. The sensor is defective and has high sleep mode current drain. Most sensors are stored with the battery in and operating for months or longer before we test and ship them so it's very unusual for a defective sensor to pass our testing procedures but it can happen.

11. Conditioning New Batteries Prior to Installation

As described above, Lithium Thionyl Chloride batteries are designed to "go to sleep" when stored on a shelf. It follows then that before using a battery that has been stored for an extended period of time you should first "wake up" the battery. To wake up a battery you have to put a heavy electrical load on the battery to draw current from the battery. Our sensors place only a very small load on the battery and will, at best, wake a battery up very slowly. If you put a new battery that was stored for a year or more into our sensor without first conditioning it you will likely see its initial readings show a battery voltage in the 2.2-2.8 VDC range. It is therefore best to first condition the battery before using it. To condition the battery, simply measure its current on a ammeter until it can deliver at least 150 mA. Depending on how long the battery has been stored it could take from a few seconds to several minutes before the battery will "wake up" enough to deliver at least 150 mA.