IT'S NOT ABOUT MILLIAMPS ALONE

WHEN BUILDING AN EFFECTIVE SENSE AND CONTROL NETWORK

WHITE PAPER

A fox or a squirrel, which one is stronger? Most people will answer "the fox", because it is a larger, more powerful animal. But if you define the question more precisely, the answer is different: "A fox or a squirrel, who is better placed to live through live through cold, harsh winters ?" The answer is "the squirrel". A squirrel hibernates during the darkest and coldest periods and is able to survive by changing its metabolism. The fox, in contrast requires constant supply of food and water and is the lesser of the two animals relative to living through the winter.

A remarkable analogy exists with low-power wireless sensor applications. Many solutions solve the low-power in a traditional fashion: they reduce power by decreasing the current consumption during operation. However, this "traditional" way of reaching low power in not sufficient to answer the needs of wireless sensor applications. They require a different way to optimize for low power. In a way, many current solutions for wireless sensor applications have a "fox-based" design, whereas a real answer to the application needs requires out-of-box thinking to come up with the hibernation capabilities of the squirrel.

About wireless sensor networks

Wireless sensor networks and applications are having an enormous impact on our daily lives. Quickly and inevitably, wireless technology is making the world more comfortable, safe, and environmentally friendly.

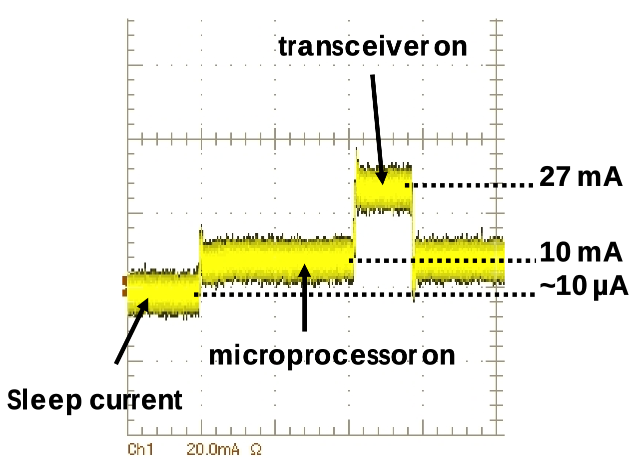
Since its inception, wireless sensor technology has been inexorably linked with low-power electronics. Not surprisingly, when a data cable is replaced by wireless communications, one also wants to eliminate the power cable. Otherwise, the *wiring* problem is only half solved, and in the technology-universe, that equates to *not solved*.

Low-power: The new definition

Wireless sensor communications and low power go hand in hand. In fact, *low power* is just as important as the *reliability* of the communications itself. Before the advent of wireless sensor communications, low power was synonymous with low current consumption. The lower the milliamp figure, the better the device was at low-power operation. It was all about how many or rather how few milliamps the electronics consumed. To further reduce power consumption, when the device did not need to communicate, it was turned off, to be awoken when an alarm situation was raised or a periodic status update was called for (*duty cycling)*.

Current consumption continues to be very important in wireless sensor networks. So not surprisingly, state-of-the-art wireless sensor communication components score well on power consumption and utilization of wake-up/sleep modes for duty cycling. However, power consumption is only part of the solution. Four other factors must also be addressed in order to achieve low power in wireless sensor applications.

1. **Peak current:** The plot below depicts the current consumption in three typical wireless sensor node states for a commonly used wireless sensor platform. In state one, the microprocessor and transceiver are in sleep mode (10µA). In state two, the microprocessor is switched on while the transceiver is asleep (10 mA). In state three, both the transceiver and the microprocessor are awake (27 mA).



These current draws can be sustained with high-power batteries such as alkaline cells, but typically exceed the tight energy budgets available with small batteries or energy harvested sources. These energy sources share an important feature -- they have a hard time generating the peak current needed to awaken the electronics, even if they can cope with the *average* current consumption throughout the wake-up/sleep cycles. A coin cell battery, for example, has a typical maximum output power of 15 milliamps, far below the peak value that most wireless communication systems require.

When closely examining the power consumption behavior of electronic circuits, it becomes apparent that what initially looks like a flat current curve actually bears more resemblance to a mountain range with peaks and valleys. When certain functional blocks become active, they draw peak current. When two functional blocks switch on simultaneously, the peak amplitude doubles. The secret to reducing the peak power lies in carefully managing the turn-on and turn-off time for key functions so that double peaks can be avoided. Doing so enables GreenPeak components to run off a coin cell battery without requiring additional energy buffering components.

2. **Graceful Power Failure:** When an energy source has dried out, such as a depleted battery or a solar cell at midnight, the electronics cannot communicate and are *dead* for all meaningful purposes. This is clearly a situation to be avoided whenever possible. But in many applications, this situation can arise and must be taken into account, either as a normal event (solar cell at midnight) or as an exceptional condition (depleted battery).

   In both cases, the power problem can be dealt with, provided the application is intelligent enough to detect the upcoming problem *before* the energy source has completely dried out. During this *last breath,* the device should perform a number of actions to inform its environment of the situation, transmit some critical data and put itself in a state that allows fast recovery when the power is restored.

   To accommodate failing low-power energy sources such as batteries and solar cells, GreenPeak's devices employ a technique known as "Graceful Power Failure". During normal operation, the devices carefully monitor the state of the power circuits. As they encounter declining power levels, they raise different levels of alarms ranging from early warning to near-death. The alarms are escalated and communicated to other parts of the system, thereby enabling the system to be placed in a state consistent with the alarm condition.

3. **Low-power Mesh Routing:** One of the most dramatic differences between wireless sensor communications technology and other well known wireless technologies is the ability of sensor nodes to forward messages from other nodes located further down the communications chain. This technique, known as *mesh routing* or *multi-hop networking*, provides an effective and reliable means of spanning large infrastructures, beyond the range of what a single wireless link can do.

   For a node to forward a message received from another node, it needs to be in an awake and receiving mode when the original wireless message arrives.

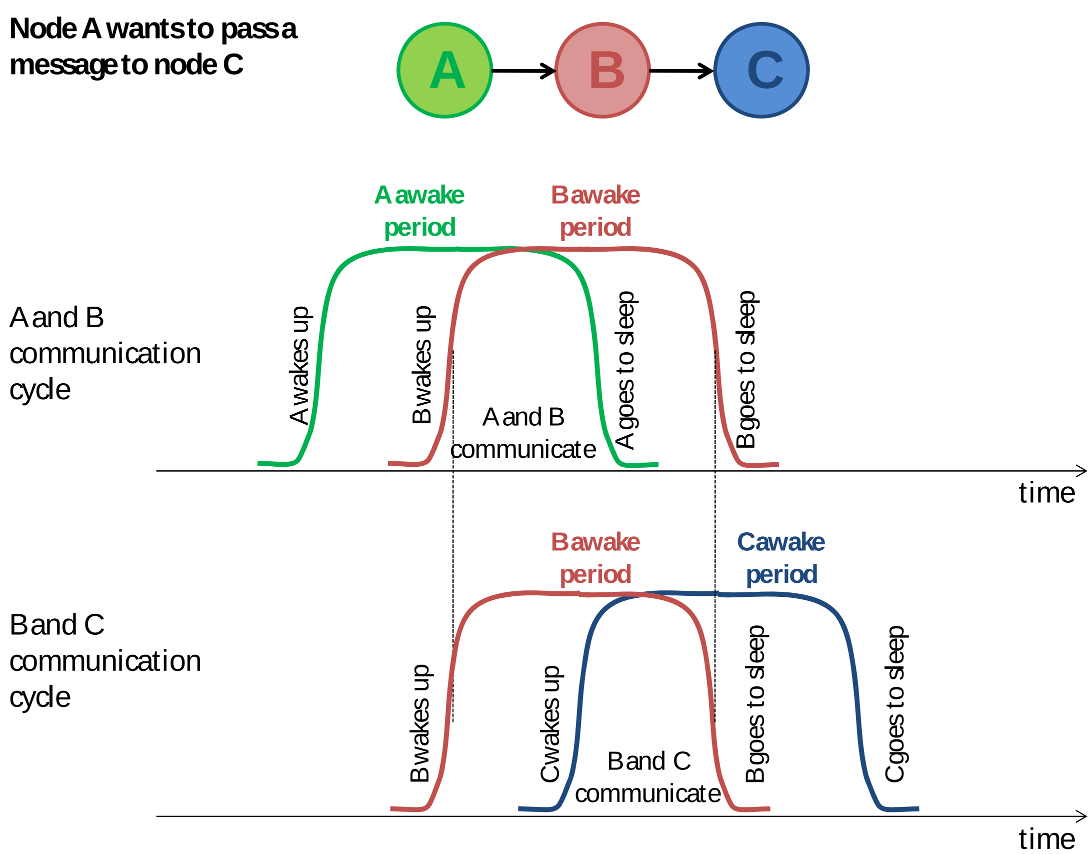
Unfortunately, the reception mode requires so much power that it can drain batteries in a matter of a few days. As this is too short for real-life applications, the most straightforward solution, as specified by most industry standards, is to limit the multi-hop capability to the nodes that are permanently connected to the main power. In such a framework, low-power devices, which are assumed to be in a power-down mode most of the time, are not capable of retransmitting messages from other devices. These low-power devices, known as *end-devices*, are located at the end or beginning of the communications chain.

This framework, which combines *mains-powered mesh routing* devices and *low-power end-devices*, works for some applications. Take, for example, an office lighting application utilizing interconnected wireless luminaires and light switches. The luminaires, which are connected to the main power source, house the *mesh routing* communication nodes. The switches, which are not mains powered, are a natural place for the end-devices.

Many other applications do not fit well in such a framework. Think of gas detection, fire detection, access control, precision farming, battlefield monitoring, perimeter surveillance, and warehouse temperature monitoring. In these applications, mains power is not readily available or even present. Running a power cable in these applications would be cost prohibitive, offsetting the benefit of wireless communication.

To address this class of applications, which have been found to be more prevalent than mains-powered, multi-hop applications, a totally different framework is required. In this framework, known as low-power multi-hop networking, or low-power routing, all of the nodes, including the mesh routing nodes, operate in low-power mode.

The key to this approach, which GreenPeak refers to as "synchronized wake-up", is to coordinate receiving activity in a way that eliminates the need for the mesh routing nodes to continually operate in receive mode, thereby significantly reducing power consumption. The picture below depicts how low-power-routing works when Node A wants to send a message to Node C, through Node B. All nodes in the pictures are low-power nodes, sleeping most of the time.



The breakthrough lies in synchronizing the sleep/wake-up cycles of the nodes to each other. Nodes wake up when they *expect* a message from a neighboring node. This enables the routing nodes to operate in a nearly powerless sleeping state most of the time, thereby achieving ultra-low-power operation. Clearly, more wake-ups will occur than strictly required to carry the data, as neighboring nodes will not always have data to transmit. However, the additional power required for periodic wakeups and synchronization is more than offset by the power saved by eliminating the need for continuous receive mode operation.

4. **Sleep current:** Wireless chips are usually quoted on their power consumption in receive and transmit mode. Remember, however, that in order to achieve low power, the devices must be duty cycled, moving between alternate sleep and awake states. The longer the required battery life, the longer the device sleeps between wake-up periods.

   Unfortunately, electronic circuits never really "sleep". Although the powered-down circuits don't do anything meaningful from a functional standpoint, a small leakage current flows through the transistors. This leakage can amount to several tens of microamps.

> Sleep current is not usually considered an important design factor, but it becomes extremely important when designing a circuit that must live for five years or more on a battery, sleeping most of its life. If the design is not optimized for low leakage current, the majority of the power will be spent on *sleeping*.

Low-power and standards: a natural fit?

Wireless sensor applications prosper best within a sphere of industry standards, which gives OEMs the freedom to purchase from a larger pool of suppliers. Most importantly, standards allow devices from different vendors to interoperate, a feature that is paramount in applications ranging from building automation to industrial automation.

Current standards within the wireless sensor universe include ZigBee, ISA SP 100, Wireless HART and others. As many wireless sensor applications benefit from low-power operation, it is no surprise that wireless sensor communications standards have pre-defined features to enable low-power operation. For other features, it is left to the technology provider to implement the standard in such a way that it achieves low power. Yet other characteristics go beyond the scope of standards.

At GreenPeak, we realize that all three sorts of features (standard defined, implementation specific, and beyond the standard) are equally important and deserve an equal amount of design attention. That is why we optimize our devices for low power at every design stage. Our sleep current and peak current technology, for example, is implementation specific, whereas our low-power mesh routing and graceful power failure technology extends beyond the scope of today's industry standards.

About GreenPeak

GreenPeak is focused on ultra-low-power wireless sensor communication technology. Our products are designed according to leading standards such as IEEE 802.15.4 and ZigBee, and used in devices and applications that need to run for five years or more on either battery power or in a battery-less setting drawing energy from energy harvested sources. The four low-power techniques introduced in this paper are just a few of the factors we have taken into consideration when designing our technology. Ultimately, techniques such as these will prove critical to large scale adoption of wireless communication technology in most sensor applications.

The GreenPeak CM-08 ultra-low-power wireless module.