Next-Generation Sensor Networks using Energy Harvesting and Ultra-Low-Power Wireless

Power consumption is a central design consideration for wireless sensor networks whether they are powered using batteries or energy harvesters. Vital to success for either approach, however, is the need for hardware that uses power intelligently.

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Sensors

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Many of today's wireless sensor network solutions solve only the wiring problem in sensor applications—they successfully make these networks easier to install and simpler to configure. Most wireless sensor networks are powered from batteries that require regular changing and/or recharging but, since battery life is inherently limited, this can create a maintenance problem, especially for larger networks. Using an ultra-low-power wireless network enables the development of devices that can run for decades using only a small watch-cell battery.

Another option is to power these wireless sensor networks using energy harvesting—converting so-called waste energy within the environment into electricity—thereby slashing the time and money required to charge, replace, and reset battery systems. Eliminating the need for batteries also reduces the networks' environmental impact.

Ultra-Low-Power Networks
Current consumption (in milliamps) and duty cycling are important in wireless sensor networks. However, minimizing current consumption is only part of the solution. Several essential issues are key to developing low-power wireless sensor applications—efficiently harvesting, converting, and storing the energy as well as using available energy in the most efficient way, without compromising performance (range, data rate, latency, and/or standards compliance)—but it all starts with an ultra-low-power transceiver radio chip.

This chip usually works in combination with a microcontroller (MCU), which manages the transceiver; switching it on, making it listen, transmit, wait for or receive acknowledge signals, or re-transmit, all in accordance to the communications protocol being used. Handling the transceiver's communication protocol activities, such as listening to whether the medium is free or waiting for an acknowledgement that a transmission has been received, requires the MCU to be awake the entire time and therefore consuming power. With a communication controller, the transceiver can transmit and receive the data independently from the MCU so that the MCU is only awake and in use when further data processing is needed. By using a communication controller-centric chip design (**Figure 1**) rather than a microcontroller-centric design, and by using synchronized wake-ups, it is possible to reduce overall power consumption by 65% or more by eliminating the use of the MCU for the transceiver management functions.

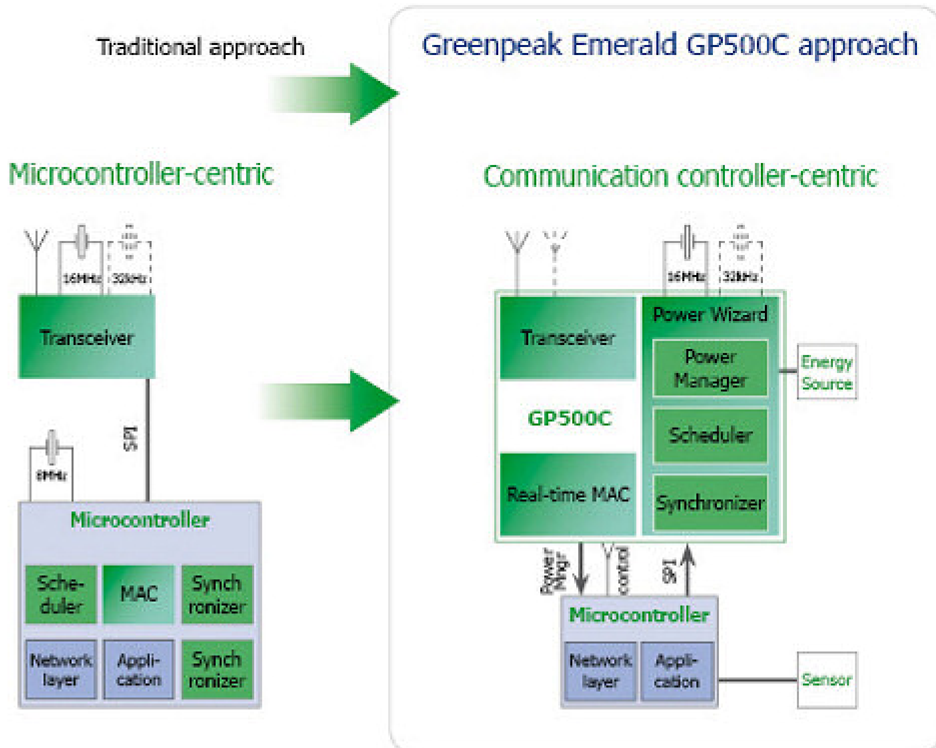

Figure 1. GreenPeak's communication-controller-centric architecture vs. a traditional microcontroller-centric approach. Most transceiver solutions require that the MCU be switched on the whole time during the transmission of a package. By using a communication controller, the MCU is only required to process the data to be transmitted or received (Click image for larger version)

A hardware-based scheduler and synchronizer within the chip itself enables the radio to wake up as needed to check whether there are any data that need to be sent or received. If not, it goes back to sleep. If there are data to be sent or received, the controller wakes up the MCU. The MCU communicates the information at the system level and then goes back to sleep until its next scheduled wake up time. Depending on the application, 9,999 times out of 10,000 there is no message to be sent or received and the controller does not need to energize the MCU. Every time data are sent, the communication controller also transmits a synchronization message to ensure that all the wireless nodes stay together on the next duty cycle.

Figure 2 shows how, by letting the communications controller decide when to wake up and check for messages, it is possible to greatly reduce overall energy consumption. Governed by the scheduler and synchronizer components inside the communication controller, the system wakes up for a brief moment to check to see if there are any messages and then goes back to sleep.

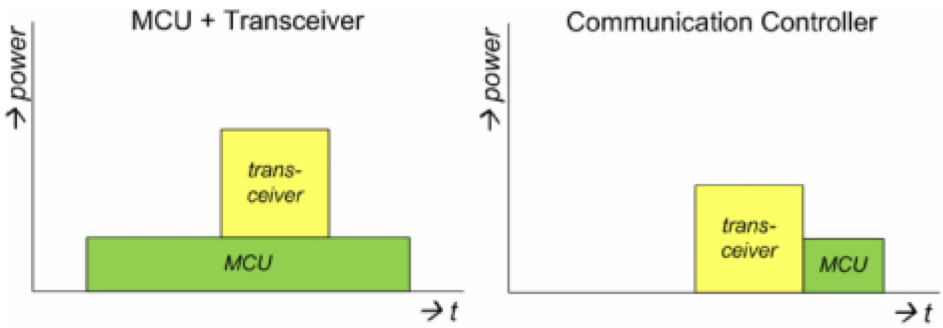

Figure 2. By letting the microprocessor sleep until it is needed, it is possible to save >65% of energy usage as compared to the typical always-on transceiver

If you multiply the power savings for this individual node to a wireless network of hundreds of nodes, then the entire network will be able to operate using far less power than required for a traditional microprocessor-based network.

Energy Harvesting Solutions: Bursters vs. Tricklers

In the last decade, we have seen an explosion in research efforts to use a variety of energy sources to supply autonomous sensors. The industrial market has recognized that energy harvesters can replace batteries in numerous applications and promise to guarantee true, maintenance-free wireless sensor networks.

Energy harvesting devices can usually be divided in to two general categories: the "bursters" and the "tricklers." A burster produces a short but strong spike of energy, while a trickler usually behaves as a power source with a weak but steady output (**Figure 3**). For all current energy harvesting devices, energy storage of some sort—whether it is in the form of a super-capacitor or a thin-film battery—is required. From an electronics perspective, this distinction is important as the adaption circuitry is different for each. In the case of bursters, the adaptive circuitry must be able to react fast, resist over-supply, and be able to burn off excess energy without creating a heat problem. For tricklers, the adaptive circuitry needs to be very efficient in terms of conversion and storage.

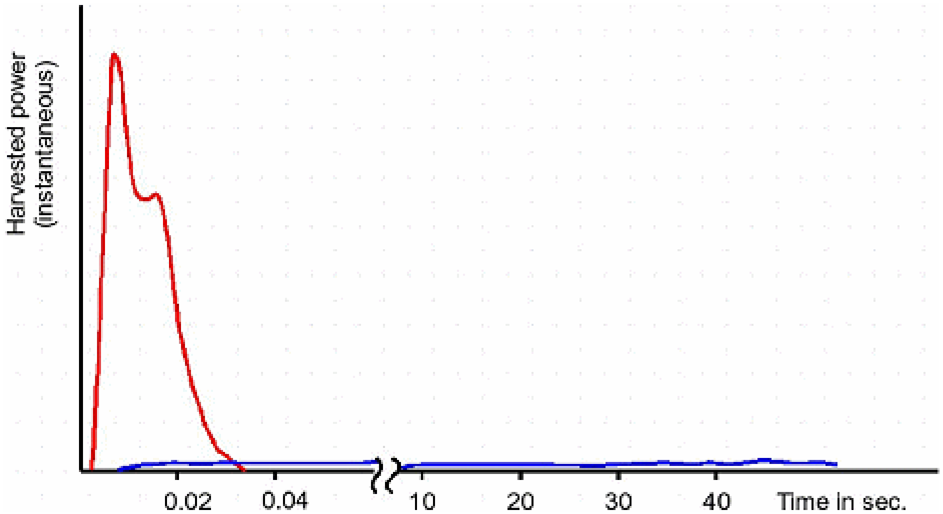

Figure 3. Harvested power characteristics of a burster (red) and trickler (blue) showing the variation of available energy with time

Dynamo or microgenerator. The most common energy burster is the dynamo or microgenerator. It is a miniature AC generator in which motion is used to create energy instead of energy being used to create motion. Operating in an industrial environment, it converts kinetic energy from the vibration of equipment running at mains frequency (50 or 60 Hz) into electrical energy. Used to power a wireless sensor network, it allows operators to continually monitor plant equipment, providing valuable data about the condition of equipment including pumps, motors, and fans. Pilot projects currently underway combine energy harvesting with condition monitoring technology to check the state of health of electrical machinery.

Piezoelectric devices. Another energy burster is the piezo element, where energy is created from mechanical torsion of a piezoelectric material, which produces an electrical charge in response to an applied physical stress. Options here are piezoelectric ceramics, macrofiber composites, and bimorph actuators, all of which can produce an electrical change of a few hundred volts over a very short period of time. A mass is attached to the free end of a beam of the piezoelectric material. Vibration causes the mass to move up and down, flexing the material, and inducing a voltage across the material in response. Piezo elements can be sensitive to wear and tear.

Solar cells. The most well-known energy trickler is the solar cell. Certain varieties of solar cells can extract energy from the limited light that is available indoors. To be usable for sense and control networks, the energy must be stored and the usage of the energy controlled. A task (e.g., transmission of a data packet) is only started when there is enough energy to finish it (e.g., receive the data receipt acknowledgement). Solar cells have a big advantage: they are relatively cheap but they only work when there is light, which presents a problem as most networks need to be reliable, independent from lighting conditions, and function 24/7. Solar cells are the only energy harvesters that are already being produced in sufficiently high volumes and at sufficiently low cost for use in sense and control networks. However, small batteries are still needed to store power for times when the network must operate but no light is available.

Peltier devices. Another trickler energy harvester is a Peltier element that uses temperature differences as its energy source of choice, e.g., a wall of a house, where the outside temperature differs from that of the inside. Usually a temperature difference of 5°C gives enough usable energy to accumulate for consumption. Unfortunately, the dependability of Peltier elements is limited because temperature differences usually cannot be controlled.

Inherent Challenges of Using Energy Harvesting

There is plenty of power in the environment and there are multiple options available to tap into this in order to power autonomous sensors. However, at this moment, there is no one single solution for all applications—each power system needs to be customized to its specific application and also, it may require simultaneous use of two or more energy harvesting technologies. To choose between tricklers or bursters, the designer needs to examine which energy harvesting technology will be the most effective in his or her particular application and provide the optimum ROI.

Using energy harvesting to create a truly autonomous sensor network and system is still quite expensive. But every day, as the technologies improve and the costs of the energy harvesters drop, the reality of "No Batteries Needed" is coming closer. In the meantime, reliable ultra-low-power networks that can operate off of a single cell battery for the life of the device are already rolling out.