PROBIOTICS—an Energy Autonomous Miniature Wireless Sensor Mote Interacting with your Phone

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This multidisciplinary project aims at demonstrating a miniaturized energy-autonomous wireless sensor node that is powered with a 3-segment PV-cell and a solid-state battery. Despite its 5 x 3.4 x 3 mm^3 size, it is able to interact with tablets, mobile phones and the cloud while harvesting its own energy.

IoT, digitalization and industry 4.0, three fashionable keywords that share a common requirement: achieve seamless data transfer between sensors, a network of distributed intelligence and the cloud with its unlimited computing resources. While power-plugged, bus interconnected sensors might be deployed relatively easily, wiring is costly, voluminous, lengthy and heavy (meaningful for planes, cars) and quite hard to deploy a posteriori preventing flexibility, re-configurability. Although wireless data transfer has gradually eliminated the data routing wire requirements over the last thirty years (mobile phones, WiFi, Bluetooth/BLE), one issue remains: how to cut the last wire, the power plug without getting trapped into the battery replacement/recharge maintenance hurdle?

Energy harvesting is obviously part of the answer but of utmost importance is energy usage optimization through proper architecting and management. Among the different energy sources available widely, harvesting sunlight or even indoor lighting with compact photovoltaic diodes already fulfills the powering requirements for many use-cases. Remembering the hand-held, solar-powered calculators of the late seventies, but considering the humongous performance improvement brought meanwhile by CMOS scaling, may one design a miniaturized wireless sensor node capable of 365 d / 24 h monitoring and seamless interactions with the cloud via mobile phones, tablets?

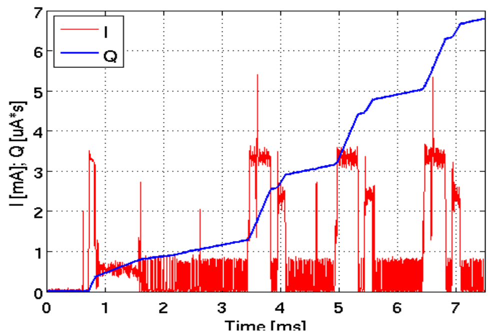

Figure 1: Current profile of a BLE advertisement beacon with RSL10.

The key requirements to build an energy autonomous wireless sensor may be summarized as follow: 1) maintain network synchronization over idle periods with an ULP timing source that is precise enough to organize timely periodic wake-ups so as to perform correlated sampling or exchange data wirelessly among spatially distributed sensor nodes; 2) use smart ULP sensors permitting context-level hierarchical or threshold-triggered sensing autonomously; 3) perform edge processing, *i.e.*, compute at node level to extract higher-level information and minimize the energy cost of transmitting excess data; 4) secure cloud access while dissipating as little energy as possible locally, either via a dedicated local hub gateway, or even better taking advantage of an already widely deployed, standardized, communication infrastructure; 5) manage and optimize the energy harvesting, storage and distribution so as to guarantee the best possible sensing performance and quality of service at any time.

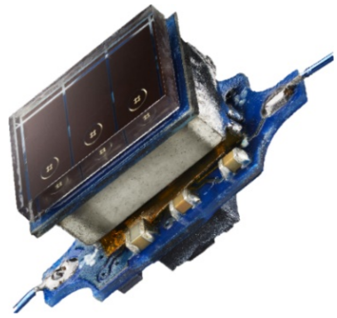

Figure 2: Photograph of the miniature wireless sensor node.

Requirements 1, 3, 4, 5 may all be satisfied with a modern IoT system-on-chip (SoC) such as On Semiconductor's RSL10, one of the lowest power circuit available on the market that relies on CSEM BLE IP. Figure 1 shows the current consumption of the SoC while transmitting BLE beacons consecutively in the three advertisement channels after the system resumes following a timer interrupt. A quiescent current consumption of 250 nA including leakage is reached in timekeeping mode. The charges drawn from a 3 V supply reaches 7 µA·s per beacon, 55% of which is used for the 3 x 35 bytes transmission, 17% to potential acknowledge reception should a master attempt to bond with the device, 28% for the MCU to execute the IRQ code. Within the first 3 ms, the MCU starts the radio XTAL, restores the system clock, performs a battery voltage measurement using the on-chip ADC, turns on the different power management blocks and updates the data to be transmitted, before triggering the modem and returning idle. One gets sub-µA current with 1 beacon / 10 s.

As a smart sensor illustrative of 2, the BMA400, a novel 3-axis accelerometer developed by Bosch, was selected. With a current consumption of 150 nA, 850 nA, 4 µA, 15 µA respectively in off, motion activation, step analysis and full accelerometer modes, this sensor incorporates low-power digital accelerators able to perform, in an autonomous way, (in)activity detection and recognition, orientation detection (tilt), step counting as well as tap/double tap detection. As such high-level context signals are all mapped to dedicated IRQs, both data transfer between the sensor / system MCU and the computational load, are greatly reduced, yielding substantial power savings.

The resulting miniature sensor node is shown in Figure 2. Excluding the antenna, the mote measures 5 x 3.4 x 3 mm^3, while including a 200 µA·h battery and a 3-segments PV-cell forming the power pack. Even when the latter was placed on a west facing window in winter time, 50 µA·h could be harvested daily on average, despite foggy days. This is enough to power the complete sensor node and monitor window tilt, opening/closing and perform glass break detection. One could imagine other applications such as piece of art, asset surveillance or even lapel pin or earrings remote controls using (double)tap functions.

Field tests are under way paving the way towards a cloud of ubiquitous motes that one may merely drop to the cloud!