Wireless Sensor Network Nodes for RTLS, Biomonitoring, and Authentication Applications

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Abstract— **Real-time and distributed sensing of large amounts of data, environmental, social or other, collected by very small and low-cost sensors is becoming a critical feature in more and more applications. In this paper, we are demonstrating with our developed prototypes that it is possible to deploy Wireless Sensor Network (WSN) nodes in-between prototype sensors and the Internet gateways. As a proof of concept, sensors in location tracking, health monitoring and secure identity verification applications are enhanced with essential WSN features. These sensing devices can be considered as some of the first Internet-of-Things nodes that bring the ubiquitous cognition vision closer and closer.**

Keywords-WSN; real-time and distributed sensing; location; ECG monitoring; identity verification

I. INTRODUCTION

As we move on to the ubiquitous cognition era, the capability of gathering, storing, and processing large amounts of data collected from spatially distributed sensors in a centralized, efficient and low-cost way is becoming more and more essential. Although researchers have demonstrated a plethora of ultra low-cost and physically small sensors, only few of these efforts have taken the extra step to integrate these sensing modules with massive wireless sensor network (WSN) platforms. The necessity of deploying WSNs in sensing systems is highlighted by (i) the increased physical range achieved and the ability to overcome non line-of-sight and path loss effects through multi-hopping, (ii) the enhanced communication reliability even if some WSN node fail through multipath and (iii) the decreased power consumption of the radio transmission with multi-hopping since it is more power efficient to relay packets a number of times over lower-strength shorter links, than transmitting high strength signals over long single-hop wireless links.

Toward that goal, we are demonstrating with our developed prototypes that it is possible to deploy WSN nodes in-between prototype sensors and the Internet gateways. In particular, we are presenting in this paper novel WSN-enabled prototypes that realize real-time and distributed remote sensing in different applications, namely location tracking, health monitoring and secure identity verification. The primary task of the WSN nodes here is not as data generators, as this role is almost entirely taken over by the sensors. Instead, the WSN nodes serve simply as data routers that relay the sensed information through wireless multi-hop links to one or more gateways. As a proof of concept, the networking capabilities of the proposed prototypes are provided by either Zigbee, a low-power communication protocol based on the IEEE 802.15 standard, or Crossbow's proprietary multi-hop protocol.

II. LOCATION TRACKING

The physical location information of a device or a user is a vital aspect of an ever-increasing number of applications, such as meteorological and environmental applications, crowd sourcing and social networking, geographic-aware routing protocols, etc. As an enabler of this vision, we have developed a credit-card-sized, battery-less, solar-powered tag (shown in Fig. 1), the position of which can be tracked in an open-space environment through lateration, a method of estimating the position of the tag by calculating (through the received signal strength) its distance from three or more anchor points [1].

The anchor points, whose exact location coordinates are known before hand, are the Crossbow MICA2 WSN nodes. As a result, the WSN nodes here are not anymore the lowest-level devices in the network infrastructure hierarchy. We have managed to establish a completely stand-alone, asynchronous communication link between the simple, low-power consuming transmitter of our prototype tag and the MICA2 node. This bridging of low-cost sensors with standard and very popular WSN platforms opens up a broad range of communication possibilities, not available before. A set of requirements had to be met for the prototype tag to be able to successfully "speak" to the WSN nodes. From the networking reference layer design perspective, not only does there have to be physical layer compliance in terms of carrier frequency (904.4MHz) and proper modulation (FSK) of the RF transmission by sensor but also that the transmitted packet has to be properly bit encapsulated medium access control wise (the fields being: Preamble, Sync, Addr, Type, Group, Length, Data, and CRC).

Recent advances in low power analog, RF and digital circuitry has made it possible to utilize hybrid renewable energy scavenging solutions such as that generated by ambient RF, vibration & heat differentials with appropriate transducers in addition to solar. Prototypes described in [1, 2, 3] show the feasibility of such an approach for practical applications

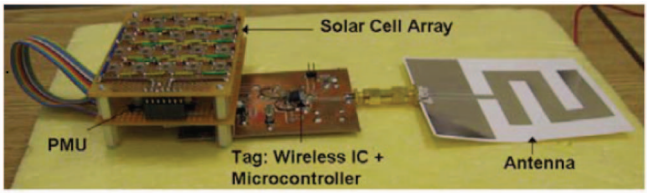

Figure 1 Solar Powered Battery-less tag prototype

through the use of high-efficiency antennas, power and RF electronics to achieve an operable RF-to-DC power conversion.

III. Health Monitoring

For more than a century Electrocardiography (ECG) remains the best and least invasive method for the intended task. Eliminating the usage of wires in medical operation theaters, as well as for senior people that need to wear monitoring devices for a continuous tracking of their heart condition is, undoubtedly, a highly desirable feature and a big step forward for the technological advancement of ECG.

The electrical impulses within the heart act as a source of voltage, which generates a current flow in the torso and corresponding potentials on the skin. The frontal projection of the cardiac vector can be captured by three standard limb leads / electrodes, which are bipolar leads which measure the potential difference between the right arm, left arm, and left leg (as shown in Fig. 2a).

The two wireless modules proposed [4] support multi-hopping over the popular Zigbee protocol and their size is 7cm x 7cm x 1cm. The first design is powered by an Atmega32 microcontroller that is interfaced with the Xbee Pro Zigbee module for the wireless transmission. The relatively high current demand of this Xbee module has necessitated the proposal of a new design that includes a single system on chip that houses both the microcontroller and the RF transmitter. The second design is based on the TI CC2530. Both designs operate at a bit rate of 9600 bits/sec for transmission of a single lead II signal. The sampling rate used is 500 samples/sec and resolution of ADC is 8-bit in the first design and 9-bit in the second. Both designs are analyzed with electrodes placed close to the heart, which provide a better quality of signal, and the ECG data obtained from the tested circuit is shown in Fig. 2b.

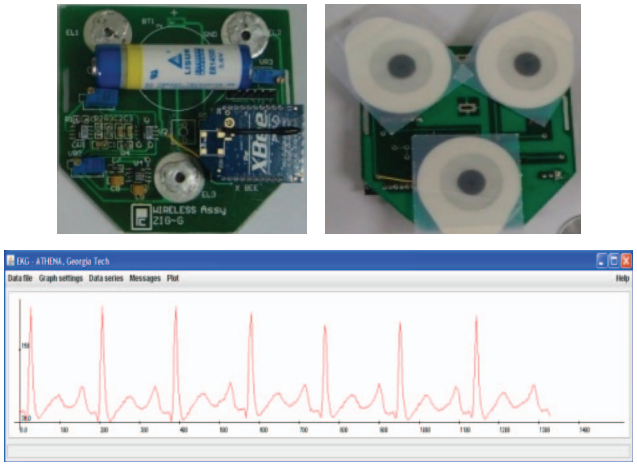

Figure 2 (a) Wireless EKG transmitter, (b) Plot of the obtained EKG signal

IV. Secure Identity Verification

In [5] we have developed a complete system that aims to render any typical RFID tag physically unique and hard to near-exactly replicate by just complementing it with a random conductive and dielectric 3D scattering structure, which serves as a certificates of identity or genuineness. Fine aspects of this system include a completely passive operation, interoperability with any RFID tag technology of any frequency band without requiring any RFID reader software modifications and a cost comparable to that of typical, passive RFID tags.

The unique near-field response, or "signature", of the certificate instances is extracted as a set of S21 curves by our reader prototype, shown in Fig. 3b, over the 5 to 6 GHz frequency range. Each one of the S21 curves of the RF fingerprint corresponds to a single coupling of a pair of antenna elements of the reader's antenna array.

As a means to allow ease of use and portability of our RFID-CoA reader within store premises or industrial facilities, we have leveraged the wireless connectivity capabilities of the incorporated MCU chip. Our reader design, shown in Fig. 3a, provides two different RF interfaces, where very small Zigbee and Bluetooth modules can be attached. Specifically, two very good such compatible wireless networking module options are TI CC25305 and TI CC25406, for Zigbee and Bluetooth, respectively. As a result, our reader can receive various public keys from different issuers and transmit the extracted identity verification data on top of the standardized and highly reliable Zigbee Pro and Bluetooth wireless networking standards to a central location and a mobile device, respectively, over AES (Advanced Encryption Standard)-128 bit encrypted wireless links.

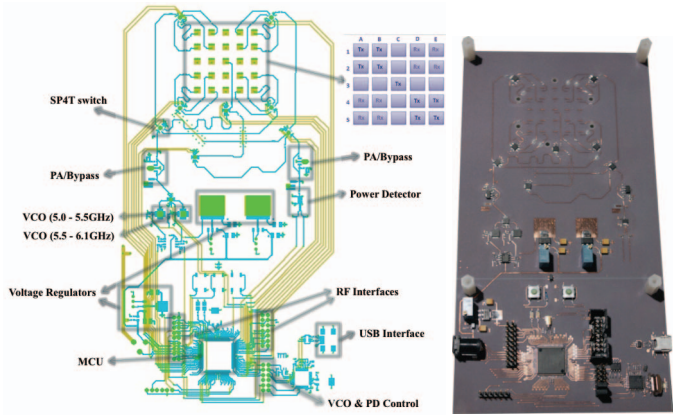

Figure 3 (a) The RFID-CoA reader board circuit schematic, (b) The RFID-CoA reader's bottom digital plane, including the MCU.

V. Conclusions

With the three different WSN-enabled prototypes developed and presented we are demonstrating that the vision of real-time and distributed remote sensing is more and more becoming a reality. Applications, such as location tracking, health monitoring and secure identity verification, can enormously benefit from bridging their deployed low-cost sensors with WSN nodes that provide direct access to Internet gateways.

References

[1] V. Lakafosis; R. Vyas, M.M. Tentzeris, "A localization and position tracking solution utilizing solar-powered RFID tags," Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference, pp.1-4, 12-16 April 2010

[2] R. Vyas, V. Lakafosis, M. Tentzeris, "Wireless Remote Localization System Utilizing Ambient RF/Solar Power Scavenging RFID Tags", IEEE International Microwave Symposium, pp 1764-1767, Anaheim CA, USA, May 2010.

[3] G. Orecchini et. Al, "Wearable Battery-free RFID tag with Human Energy Scavenger", IEEE International Microwave Symposium, pp 1-4, Baltimore MD, USA, May 2011.

[4] V. Mukala, V. Lakafosis, A. Traille, M.M. Tentzeris, "A novel Zigbee-based low-cost, low-power wireless EKG system," Microwave Symposium Digest (MTT), 2010 IEEE MTT-S International , pp.624-627, 23-28 May 2010

[5] V. Lakafosis, A. Traille, H. Lee, E. Gebara, M.M. Tentzeris, G. DeJean, D. Kirovski, "RFID-CoA: The RFID tags as certificates of authenticity," RFID (RFID), 2011 IEEE International Conference, pp.207-214, 12-14 April 2011.