Demo Abstract: Exploiting Ultra-Low-Power Ultrasonic Wake-up Triggering for Sensor Nodes Distance Measurements

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ABSTRACT

Out-of-band signaling provides a valuable support to the management of wireless sensor networks. Among other signals, sound has a propagation speed in air which is fast enough to be neglected in typical sensor network applications, and slow enough to be measured by means of low-cost embedded systems. An ultrasonic triggering mechanism has been recently developed for VirtualSense, an ultra-low-power sensor node featuring a Java runtime environment. Ultrasonic triggers provide on-demand wakeup capabilities that can be exploited by routing nodes to be switched on whenever there is a packet to be routed towards the sink, while spending all the idle time in an ultra low power inactive state where even the radio module is turned off. In addition, the same hardware components can be used to perform pairwise distance measurements that can be exploited for localization. In this demonstration we show the possible use of VirtualSense ultrasonic wake-up modules as distance estimators.

1. INTRODUCTION

Wireless sensor networks (hereafter also denoted WSNs) are usually characterized by severe computational, power and cost constraints, which pose to designers challenging issues at different system levels. In particular, many research works have been proposed, during the last decade, in order to cope with the requirements imposed by low power budgets in WSNs. Given that the radio module of the motes has to be powered on to enable the reception of incoming packets, a central problem is to devise power management techniques that could bound energy waste due to channel listening. In order to mitigate this problem, tailored solutions have been proposed, either by means of specific communication protocols (a.k.a. *rendez-vous* schemes) that typically trade off latency for power consumption [3], or through the design of ad-hoc low-power *wake-up* receivers which are in charge of monitoring the radio channel while the main radio of the node is powered off [1].

According to the scientific literature, there is evidence of better performance of wake-up receivers w.r.t. to rendez-vous schemes in terms of both power savings and latency in a wide range of application scenarios [3, 1]. A common feature characterizing wake-up receiver solutions is the use of the radio channel (within the 433MHz-2.4GHz interval) for triggering the wake-up of the receiving node. Departing from this standard scheme, we recently developed an *out-of-band* approach which exploits ultrasound propagation to selectively wake-up target nodes. The system has been designed to meet sub-μA standby consumption by means of off-the shelf, low-cost hardware components. The prototype module has been designed as a layer of VirtualSense nodes [2]. VirtualSense is an open-hardware/software project targeting the development of ultra-low-power Java-programmable motes. An interesting byproduct of ultrasonic triggering is that the same module can be used to estimate distances between two given nodes through the adoption of proper measurement protocols.

The aim of this demonstration is to show the suitability of the ultra-low-power ultrasonic wake-up module of VirtualSense as ranging estimator. The system is connected to a mobile hand-held device by means of a Bluetooth interface placed on board of motes.

In Section 2 the overall system architecture is introduced, in Section 3 the setup of the demonstration is described, while in Section 4 conclusions are given.

2. SYSTEM DESCRIPTION

Figure 1 reports the prototype layer of the ultrasonic wake-up transceiver. Thanks to the modular structure of VirtualSense hardware, the layer can be stacked onto the structure of any VirtualSense node. The power consumption of the wake-up receiver has been characterized. Experimental results show that the module consumes less than 1 μA when powered at 2V, fully maintaining its reaction capability with respect to ultrasonic triggering events. The developed ultrasonic module also supports selective triggering, by encoding the target node's address within the transmitted ultrasonic wave.

2.1 Distance measurement protocol

The protocol for the indirect measure of the distance between two nodes A and B can be summarized as an echo-

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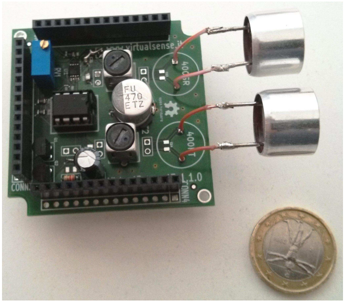

Figure 1: Prototype of the ultrasonic wake-up module.

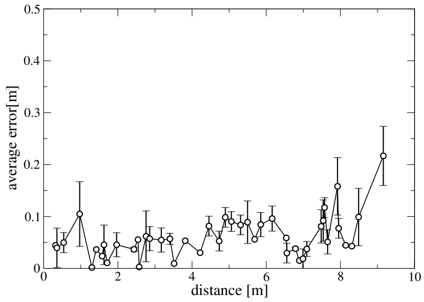

Figure 2: Empirical average error as function of distance.

reply scheme. In particular, both nodes switch on their microcontroller units (MCUs) and ultrasonic modules. Then, node A starts a timer and sends an ultrasonic pulse which acts as an echo-request. Upon the detection of the ultrasonic pulse, Node B replies by means of an echo radio packet acknowledging the reception. When node A receives the radio packet sent by B, it stops the timer and estimates the distance with an accuracy that depends on the resolution of the time measurement (t) and on the variance of overhead introduced by the measurement system (t_{ov}). Given the speed of sound s_{sound}, node A computes distance estimate $\hat{d}$ according to the following equation:

$$\hat{d} = (t - t_{ov}) \cdot s_{sound} \quad (1)$$

The overhead time t_{ov} is the sum of three components: i) the execution time needed by the software running at both nodes A and B; ii) the time needed for detecting the ultrasound pulse; iii) the time-of-flight of the radio packet. We experimentally quantified the contribution of the first two terms and found that they are invariant with respect to the distance to be measured. Regarding the third and last component, since the propagation speed of electromagnetic waves is six order of magnitude faster than that of sound, the contribution of the time-of-flight of the echo radio packet can be neglected. Indeed, within the range of connectivity of VirtualSense modules (around 8m), the clock period of the MCU is greater than the propagation time of electromagnetic waves, making it not significant to take into account the contribution of the radio time-of-flight to the overhead. When the MCU clock is set at 24MHz, the radio packet size to 1 byte and the timer maximum resolution to 250μs the system allows us to measure distances in the range [0.3m-10m] with an empirical average absolute error of 0.06m, which falls below the theoretical resolution of the proposed method (0.09m for a time resolution of 250μs). Figure 2 reports the results of experiments performed to characterize the accuracy of the measurement setup. Results refer to estimates of 50 distances (uniformly chosen in the [0.3m-10m] range) between positioned motes, whereas error bars represent standard deviation computed over 5 measures for each point.

3. DEMONSTRATION SETUP

The demonstration aims at showing the capability of the proposed system by using two VirtualSense nodes equipped with ultrasonic wake-up modules and performing distance measurements by means of the above described experimental protocol. The mote which acts as initiator of the echo-reply protocol is equipped with a Bluetooth interface in order to establish communication with a smartphone running the Android O.S., on which we implemented a client application for the management of the measurement protocol. Figure 3 reports a picture of the experimental setup including two motes placed on a level ground and a handheld device running the application.

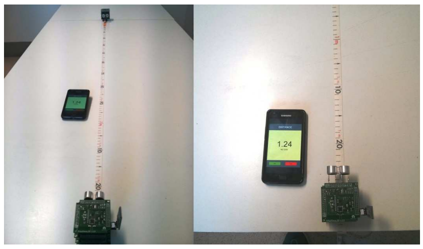

Figure 3: Experimental setup

4. CONCLUSIONS

We presented a hardware/software platform to estimate distances among wireless sensor network nodes. The added value of the proposed architecture relies in the possibility of exploiting an ultra-low-power ultrasonic module developed as wake-up system for sensornets. The same layer can be used either for implementing sophisticated power management policies or for measuring euclidean distances between nodes located in line of sight.

5. REFERENCES

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