

# Transmission Power Measurements for Wireless Sensor Nodes and their Relationship to the Battery Level

Sebastian Blom\*, Carlo Bellettini, Anna Sinigalliesi, Luca Stabellini, Michele Rossi, Gianluca Mazzini†

**Abstract**— In this work we focus on the new generation EYESIFXv2 [1] wireless sensor nodes by carrying out experimental measurements on power related quantities. In particular, our aim is to characterize the relationship between the level of the battery and the transmission power radiated by the node. The present results point out the non linear and non trivial effects due to the output potentiometer which can be used to tune the transmission power. It shall be observed that a thorough study of how battery and/or potentiometer settings translate to actual transmitted power levels is crucial to e.g. design correct power control algorithms, which can effectively operate under any operational condition of the wireless sensor device.

## I. INTRODUCTION

Recently, the research on wireless sensor networks has been very intense under all aspects ranging from routing to MAC (Medium Access Control) [2] [3] and power off mechanisms [2, 4, 5]. Also, a large amount of work has been focused on the design and actual production of energy efficient sensor devices; in fact, quite a few nodes have been designed and produced so far [1, 6], see [7] for related projects as well as widely used sensor boards. Just to cite a few examples: Mica, Imote, Telos, and the European EyesNedap and EyesIFX. One of the aims that motivated such an intense activity was to reduce the size of existing sensor devices as well as to enhance their energy saving features at every level of the system, ranging from the physical radio unit to the operating system and, at the same time, by not limiting the on board processing capabilities.

In the present work, we focus on the new generation sensor node EYESIFXv2 produced by Infineon [6] within the European EYES project [1], and we present some measurements which try to capture the relationship between battery level and the actual transmission power. We observe that, in previous research dealing with routing and MAC solutions [2] [3] [8] [9] for wireless sensor networks, researchers have often considered the transmission power and hence the covered area, as a constant quantity. However, as it will be pointed out by the experimental results that we will present next, this is not true even when sensors are set to transmit at the maximum (constant) power level. Indeed, we experimentally verified that the actual transmission power is strongly affected by the battery level and that such a behavior is highly non-linear. These facts, could partially invalidate approaches based on the constant transmission power assumption. This high dependence of transmission (received) power on residual energy reserves is the main contribution of the present

\*Corresponding author, email: sebastian.blom@gmail.com. †All authors are with the Department of Engineering, University of Ferrara, Italy. Sebastian Blom is also with the EEMCS department, University of Twente, The Netherlands.

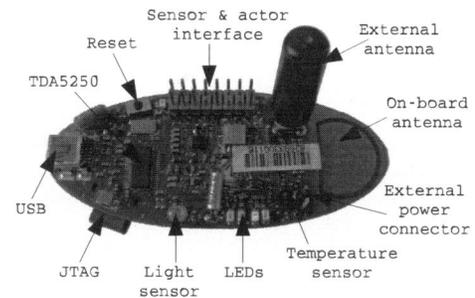


Fig. 1. Top view of the EYESIFXv2 sensor node.

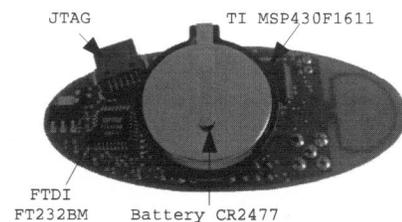


Fig. 2. Bottom view of the EYESIFXv2 sensor node.

paper. We believe that these considerations should be accounted in future research to properly model the wireless sensor network scenario and derive algorithms designed to work in realistic settings.

The paper is structured as follows. In Section II, we first review the main features of the device that we used to carry out our experiments. In Section III, we present the experimental setup and in the subsequent Section IV we report the field measurements where we focus on the RSSI (Received Signal Strength Indicator) as a function of several system parameters. Finally, in Section V we draw the conclusions of our work.

## II. EYESIFXv2 SENSOR NODE

The EYESIFXv2 sensor device is featured with a Texas Instruments MSP430F1611 micro-controller [10] equipped with an internal temperature sensor, integrated 12-bit ADC and DAC converter and can fast wake up from sleep modes ( $\leq 6 \mu s$ ). It has a 16-bit RISC CPU, 10 KB RAM and 48 KB of flash memory. The sensor is designed in order to have an ultra low energy consumption. For instance, the MSP430F1611 works within a low power supply range (1.8  $\rightarrow$  3.6 V) and consumes about 330  $\mu A$  when in active mode at 1 MHz and 2.2 V, whereas in standby and off mode the energy consumption decreases to 1.1 and 0.2  $\mu A$ , respectively. The micro-controller is also equipped with a supply voltage monitor whose accuracy will be looked at in the sequel. More details on the micro controller can be found in [10]. The

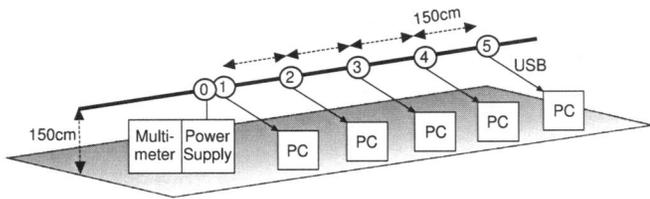


Fig. 3. Diagram showing the setup of the experiment.

radio chip is a TDA5250 produced by Infineon [6] whose main features are: operational frequency 868 MHz, ASK/FSK modulation, data-rates up to 64 Kbps, low supply current for power saving mode and RSSI measurements. In particular, supply currents of about 9 mA and 12 mA are needed to receive and transmit, respectively. Moreover, an on board *potentiometer* can be set to a value between 0 and 255 to control the radiated power. This could be exploited to implement power control algorithms in order to reduce the system interference. Figs. 1 and 2 depict a top and bottom view of the EYESIFXv2 sensor node along with some text to identify the on board components.

### III. EXPERIMENTAL SETUP

Fig. 3 shows a sketch of the test environment. The experiment was performed indoor and in total six nodes were placed at 150 cm above the floor by securing them to a cord which was spanned across the room. The distance between each pair of nodes was also 150 cm, reaching in total six meters from the sender (node 0 in the figure) up to the last receiver (node 5). At any time, only node 0 was used to transmit. All the others nodes were programmed to listen and record the received data. To be able to monitor the implications of the battery level, the sender was connected to a controlled power supply. This power supply was set to a value in the range [2.1, 3.5] V and modified in steps of 100 mV. Note that 2.1 V is the minimum operational voltage for the radio to work properly. All the receivers were powered thanks to the USB of a PC.

As far as node software is concerned, all nodes were programmed using the latest version of the TinyOS open source operating system [7] which was compiled with *nesc*, specifically *nesc1.alpha11* [11]. On every PC, we ran two Java applications, a SerialForwarder, which we used to acquire the packets received by the sensor nodes and an own written application, which was exploited to visualize, store and process the data. We set the transmitter (node 0) in such a way to send 10 packets, spaced by 200 ms, for each potentiometer setting in the range {150, ..., 255}. Previous experiments showed that values of the potentiometer lower than 150 do not affect the transmission power, which reaches a floor. The scan over the potentiometer settings was then repeated for several values of the supplied power voltage (from 2.1 → 3.5 V). Receiving nodes (1 to 5) were powered by the USB port and hence their power supply was roughly constant and close to 3.5 V. Receiving sensors were finally used to gather the packets transmitted by node 0 and report the related RSSI.

### IV. EXPERIMENTAL MEASUREMENTS

In this section, we report some measurements regarding the RSSI as a function of the battery level, that we carried out on

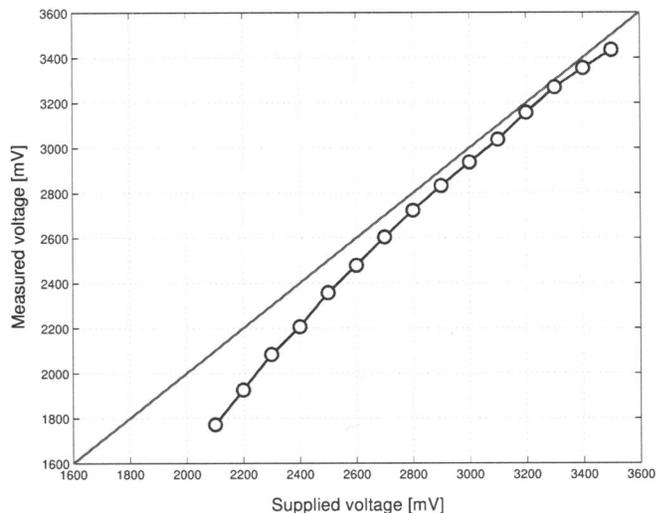


Fig. 4. Relationship between sensed and supplied battery levels.

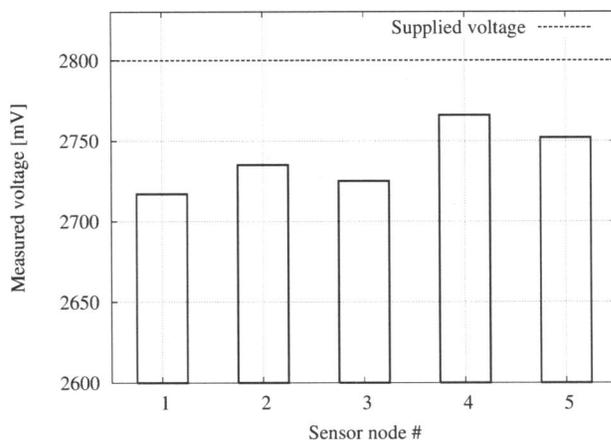


Fig. 5. Measured voltage by 5 different sensor nodes for the same supplied voltage of 2.8 V.

the EYESIFXv2 sensor device. As a first result, in Figure 4, we report the relationship between the battery level (labelled as *measured voltage* in the figure) measured by the on board microcontroller as a function of the actual *supplied voltage* (mV). As can be observed from this graph, the on board measured battery level is quite accurate and follows a quasi-linear behavior, especially for high values of the supplied voltage. This curve is very important as it might allow us to predict, at every node, the current residual level of the battery and use such an information to infer the correct potentiometer setting for the current transmission. In Fig. 5, we report another test where we checked the behavior at 5 different sensor nodes. Each of them was supplied with the same controlled voltage of 2.8 V and all of them were asked to report an estimate for the supplied voltage. As can be seen from the figure, there is some variability in the voltage detected by different devices. In this particular example, the maximum difference in the estimates is about 84 mV which corresponds to about 3 % of the supplied voltage (2.8 V), whereas the average error is about 2 %. This again confirms the accuracy of the micro controller voltage acquisition feature. A more

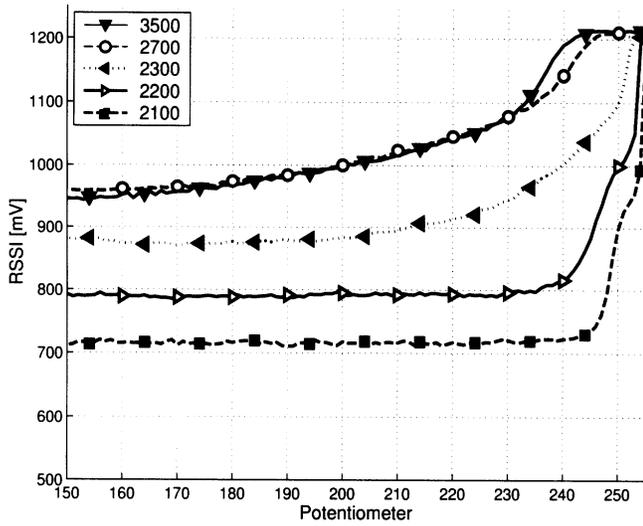


Fig. 6. Mean RSSI measured at node 1 (0 m) as a function of the potentiometer setting at node 0. Several curves are plotted by varying the battery level at the sending node. All voltages are reported in mV.

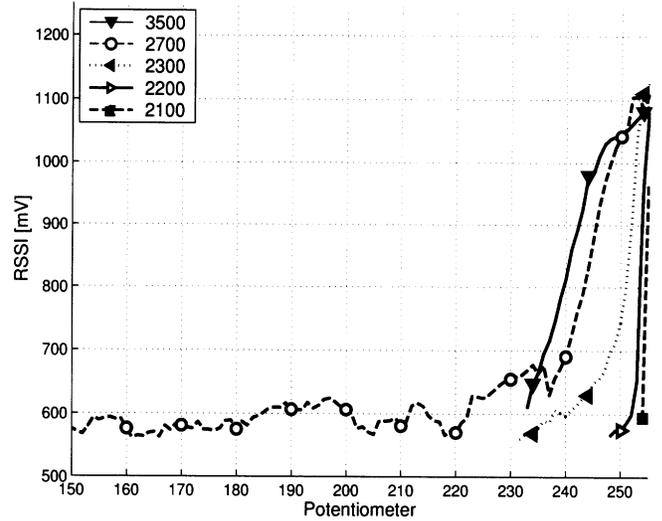


Fig. 8. Mean RSSI measured at node 5 (6 m) as a function of the potentiometer setting at node 0. Several curves are plotted by varying the battery level at the sending node. All voltages are reported in mV.

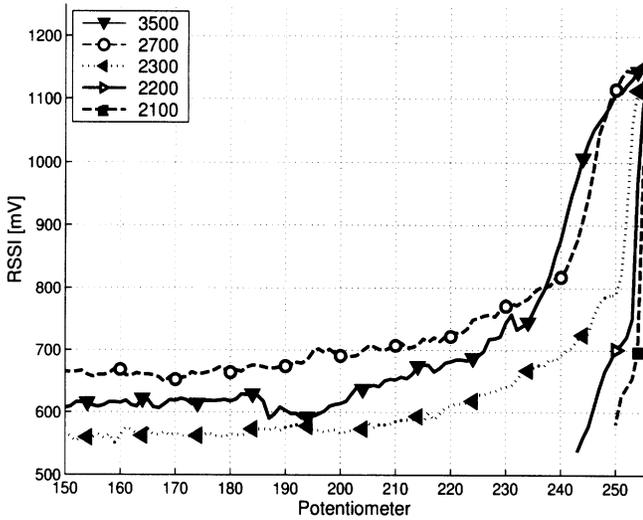


Fig. 7. Mean RSSI measured at node 2 (1.5 m) as a function of the potentiometer setting at node 0. Several curves are plotted by varying the battery level at the sending node. All voltages are reported in mV.

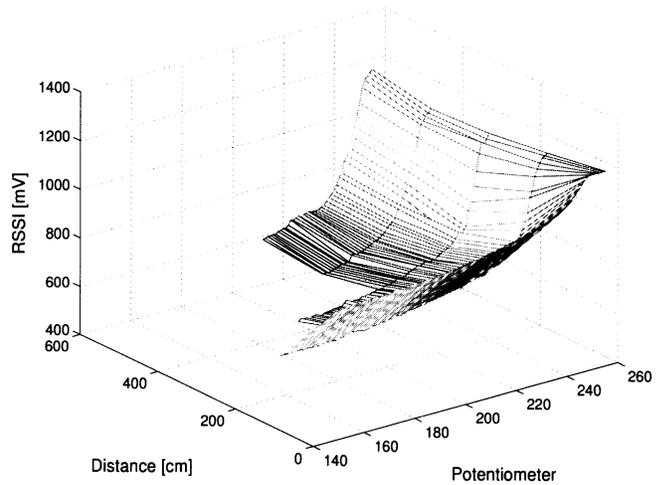


Fig. 9. Mean RSSI as a function of the distance and of the potentiometer setting at node 0. Node 0 is supplied with a voltage of 2.5 V.

refined study of the dispersion of such an accuracy among different sensing units could also be used to improve these estimates. This investigation is left for future research.

In Figs. 6, 7 and 8, we focused on the measurement of other aspects such as the impact of both the battery level and the setting for the potentiometer. To this end, we considered a stabilized voltage generator with a precision of 0.1 mV that we used here to emulate the battery and to have a sufficiently accurate control on the supplied voltage. In these pictures we represent the measured RSSI by nodes at a distance of 0, 1.5 and 6 meters from the transmitting unit as a function of the potentiometer setting. In addition, we also accounted for a varying level of the battery supply at node 0, which in these graphs spans from 2.1 up to 3.5 V. Even if we performed measurements with steps of 0.1 V, for the sake of clarity we only report here 5 curves per plot.

Consider Fig. 6 first. These RSSI values are measured at a distance of 0 meters and for this reason are roughly free from channel attenuation factors such as path loss, shadowing and fading, but are inclusive of hardware attenuation such as losses due to the transmitter and receiver circuitry. When devices move further away, on average we would expect to observe a deterministic shift of the curves obtained with such an approach. If we carefully look at Figs. 7 and 8, we can indeed argue that this is roughly true. Almost all curves appear to be shifted down by a scaling factor, while their shape remain pre-determined by the results gathered at a distance of zero meters. Hence, this first set of results seems to allow for a sufficiently precise prediction of the RSSI measurements that will be gathered at a given distance starting from the values gathered in Fig. 6 (0 m).<sup>1</sup> This fact is very important as, once we know the propagation charac-

<sup>1</sup>We precise that all RSSI measurements are obtained by averaging over 10 samples. We implemented this to filter out the effects of the multi-path fading.

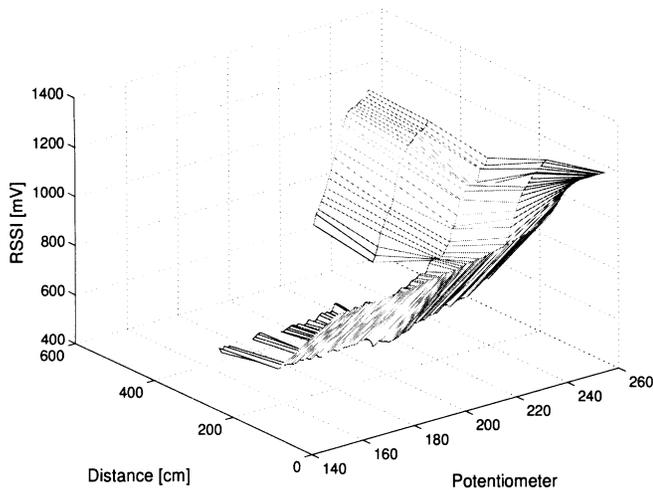


Fig. 10. Mean RSSI as a function of the distance and of the potentiometer setting at node 0. Node 0 is supplied with a voltage of 3.5 V.

teristics of a given environment, we would be able to predict the potentiometer setting to be used at the sending node to respect a minimum RSSI threshold at the receiver. Moreover, we could implement such a distributed power control scheme as a function of the specific value of the battery level at the transmitter. In our current research we are going to further verify our claims by also giving heuristics for a quick calculation of these quantities.

A further interesting observation consists of the high non linearity of RSSI curves. In fact, for a given value of the power supply, it is actually impossible to control the radiated power below a certain critical value of the potentiometer, as the RSSI value will remain mostly constant or even increases for a decreasing potentiometer value.

Furthermore, if we focus on the maximum RSSI, which is achieved by setting the potentiometer to its maximum value (255), we note that its behavior is also highly nonlinear as a function of the battery level. Also, these curves are very interesting as they might be used to implement a practical power control scheme as discussed in the following. First of all, sensors should not set their potentiometer below the critical value. Further, from the relationship depicted in Figure 4, we might estimate the actual value for the battery level and then use it to properly select a curve in Figure 6. From this second graph, we can therefore get an indication of the minimum admitted level for the potentiometer which could be used as the initial power level for the communication with a given receiving device. This minimum power level can be subsequently increased by means of appropriate feedback from the receiver through standard algorithms. A more refined solution can be obtained if we know both the distance separating the two communicating entities and the propagation characteristics, as we could then exploit the above reasoning and try to set the right potentiometer setting in advance.

In Figs. 9 and 10, we report RSSI measurements as a function of both distance and potentiometer settings, by considering the battery level at 2.5 and 3.5 V, respectively.

Finally, we observe that even at relatively short distances the effect of the potentiometer settings seems to be very important.

In practice, we might think of reducing its value for power control and interference savings when the battery is fully charged. However, as the supplied voltage decreases we are soon forced to set the potentiometer close to its maximum value. For instance, a distance of 6 meters requires a potentiometer setting above 230 in order to be able to receive. These facts have again strong implications on power control algorithms with these devices. Also, we stress that such a high variability can have a considerable impact on localization algorithms based on RSSI measurements. In such a case, according to the above results, the battery level is crucial to get good estimates of the distance, which cannot be achieved by exploiting the RSSI alone.

## V. CONCLUSIONS

In this paper, we presented a few results on the relationship between battery and emitted power levels for the EYESIFXv2 Infineon wireless sensor node. From these experimental measurements, we found a strong dependence on the potentiometer settings as well as on the residual energy reserve at the sending node. The presented results can be approximated through appropriate heuristics and subsequently used to evaluate the impact of the measured non linear behaviors on the design of topology control, MAC and routing algorithms. These measurements are crucial to precisely understand and model the relationships between transmission power and battery level. The development of accurate, empirically derived heuristic for the characterization of the RSSI as a function of the battery level is left for future research.

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