# Demo: Design and Evaluation of Underground Wireless Sensor Networks for Reforestation Monitoring

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## Abstract

In this demo, we present a platform for a wireless underground sensor network (WUSN). For a large-scale monitoring in places sensitive to disturbances, wireless sensor nodes with a very long battery life time are required. The cost of these nodes can be reduced by using relatively cheap standard components. With optimizations, a low-power communication and operation can be achieved. With our extremely low-power prototype, an underground communication over a distance of 7.5 m (both nodes in a depth of 20 cm) was achieved, while the communication distance underground to above-ground ranged up to 80 m.

## Categories and Subject Descriptors

C.3 [**Special Purpose and Application-Based Systems**]: Microprocessor/microcomputer applications; C.2.1 [**Network Architecture and Design**]: Wireless Communication

*Keywords*

Wireless Underground Sensor Networks, reforestation monitoring, agricultural monitoring, precision agriculture

## 1 Introduction and Motivation

ReviTec [2], a project of the Centre for Environmental Research and Sustainable Technology (UFT) at the University of Bremen, aims to revitalize degraded soil and stop desertification. This is achieved by deploying bags from biodegradable fabric, which contain a bioactivated substrate and other amendments. These bags should enable the soil beneath to loosen up and store rain water over a longer period of time. Furthermore, they function as fertility islands to initiate and accelerate ecological succession.

For research and evaluation purposes in a new project in Cameroon it is necessary to monitor the moisture and temperature of the soil beneath the bags over a long period of time. Manual measurements are very time-consuming and disturb the vegetation due to the need of performing measurements beneath the bags. Including the sensors in the bag deployment and connecting them per wire places the sensors at risk of being stolen or damaged by wildlife. Also, due to the size of the area for future research (many hectare), wiring the sensors would be very impractical. Finally, security risks limit the accessibility of the sites in the many regions of the Sahel. Given a careful deployment, these risks can be circumvented with a wireless underground sensor network (WUSN).

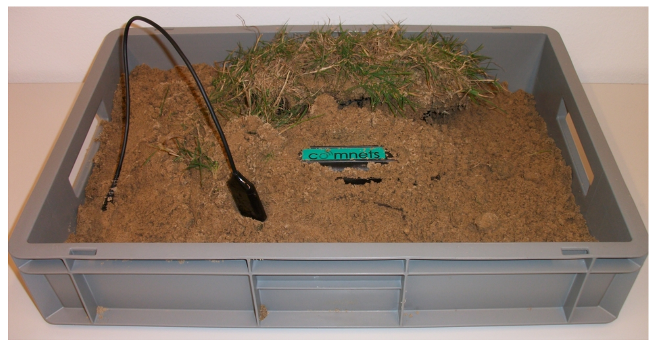


**Figure 1. Application demo: Sensor and node placed in soil**

The goal of this work is to create a wireless sensor node with the ability to measure soil moisture and temperature with a battery lifetime of at least three to four years for the complete system, which can be deployed either underground (e.g., Figure 1) or above ground.

## 2 Description of the Transceiver Nodes

A "Wattuino Pro Mini" microcontroller board [1] from Watterott, which is an Arduino Pro Mini clone powered by an Atmel ATMega328p, is the base for the current prototype. The authors in [4] have already shown that a frequency of 2.4 GHz is not suitable for WUSNs, while 434 MHz shows a much better performance [3]. Regarding this, the sensor node (Figure 2) is equipped with a 434 MHz transceiver (HopeRF RFM69CW). Several improvements are implemented to reduce the overall energy consumption of the system.

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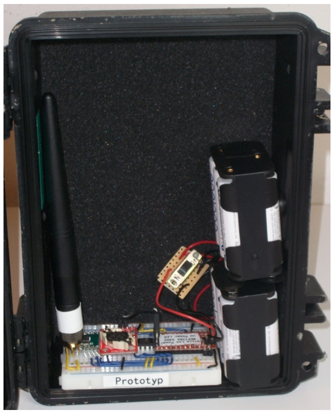



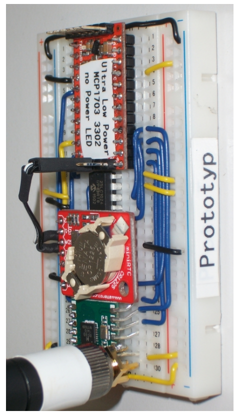



**Figure 2. Box with the node and two battery packs (left), Prototype node based on a Wattuino, without sensor (right)**

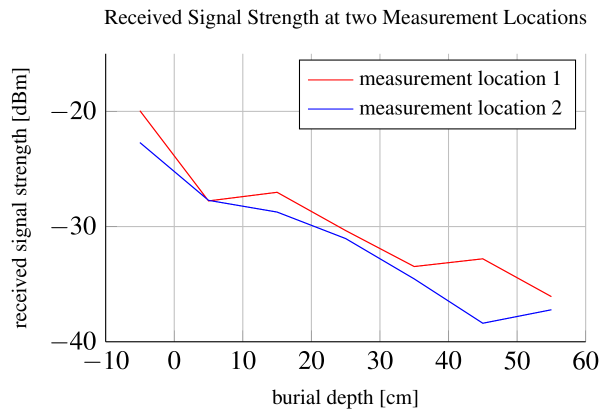



**Figure 3. Measurement results for the received signal strength for burial depths between** $-5$ cm **(above ground) to** 55 cm **in steps of** 10 cm

For the first measurements, the antenna was realized as a quarter wavelength whip, with a small (27 mm x 39 mm) conductor plate functioning as ground-plane. Although this setup does not provide a good matching to the output impedance of the transceiver, it shows quite good performance. The prototype now has a SMA-connector attached directly to the transceiver with a 433 MHz antenna. A better antenna design, which could also allow the module to be much smaller (e.g., a PCB antenna) is a subject for further work.

For the prototypes, the modules are placed and connected with each other on a breadboard for an easier exchangeability. The whole setup is placed in a box of 210 mm x 170 mm x 90 mm (Figure 2), which allows a better relocation after the measurements. To complete the sensor nodes, a volumetric water content and temperature sensor is attached to the system. Additionally, an EEPROM is used to store the measurement results, and a real-time clock further helps to reduce the power consumption of the whole system.

## 3 Measurement Results

In first tests, the communication range (underground to above-ground) was between 45 m and 80 m, depending on the moisture of the soil. In these measurements, the transmitter (underground) was buried in a depth of 20 cm, while the receiver was placed at a height of about 130 cm above ground. An underground to underground communication was possible over a distance of 7.5 m through moist soil (with both nodes buried in a depth of 20 cm).

A measurement of the received signal strength for different burial depths was also performed. A spectrum analyzer was used to measure the strength of the signal transmitted by the node. The receiving antenna was attached to a horizontal wooden pole, which was mounted to a trolley. The box with the node was placed on the ground or buried, with the antenna in parallel to the receiver's antenna. With the receiving antenna at a distance of 65 cm above the ground, the minimum vertical spacing between the box and the antenna was 60 cm when the box was lying on the ground.
Two different locations were chosen for the measurements, where areas of 3 m x 3 m were freed from vegetation. The soil at both locations is a sand with a thin (approximately 3 cm) layer of clay at a depth of about 30 cm.

Figure 3 shows a strong attenuation of the signal by the soil of up to 15 dB. While the signal strength would be expected to decrease continually, especially the red trace shows another behavior. This may be caused by the measurement time and the settings of the spectrum analyzer, but influences of the soil are also possible. An analysis of this behavior is part of continuing investigations.

By removing the power indicator led and replacing the voltage regulator by a more efficient type the current drawn by the system was reduced from 1.8 mA to 22.4 $\mu$A in deep sleep mode. Further improvements, especially regarding the current consumption in active state, are part of continuing optimizations.

## 4 Further Work

Additional measurements will be performed to achieve more accurate results and a simulation model for the underground radio propagation will be created. Equipped with a volumetric water content and temperature sensor, additional flash memory and a RTC, the node will be deployed and evaluated in a reforestation project in Cameroon. Provided with a multi-hop communication protocol, the nodes will later create a network for extremely low-power data collection for reforestation projects.

## 5 References


[1] https://github.com/watterott/wattuino.

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[3] A. Silva and M. C. Vuran. Communication with aboveground devices in wireless underground sensor networks: An empirical study. pages 1–6. IEEE, 2010.

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