SoMoS - a Multidimensional Radio Field Based Soil Moisture Sensing System

Florian Liedmann and Christian Wietfeld
Communication Networks Institute (CNI)
TU Dortmund University
Dortmund, Germany
{florian.liedmann|christian.wietfeld}@tu-dortmund.de

***Abstract*—Soil Moisture Sensing is important for many safety-critical, agricultural or even Smart Home applications to identify risks and take countermeasures at an early stage. By only punctually measuring the soil moisture, unfavorable events between the measurement points will possibly be undetected or recognized too late, because the detection radius is very limited. Therefore, this paper describes, how an innovative multidimensional radio field based Soil Moisture Sensing System can be developed with minimum invasion. It is shown that the measured variation of the underground communication link quality enables the detection of events impacting the soil moisture by the proposed sensor system.**

***Keywords*—Soil Moisture Sensing System, SoMoS, Wireless Underground Sensor Networks, Software Defined Radio, LoRa**

I. INTRODUCTION

Wireless Underground Sensor Networks (WUSN) are used for many different monitoring applications like soil moisture and movement detection or to supervise the structural health of dams, mines or buildings [1][2]. Even for intelligent and precision agriculture, WUSN play an important role to enhance the quality and quantity of the crops [3][4]. Usually, spot-based moisture detection systems are used to measure and monitor the soil moisture content locally (comp. Fig. 1, left). However,

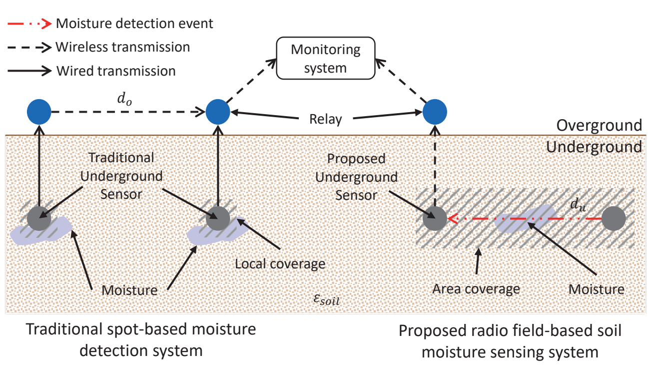

Fig. 1. Different soil moisture detection techniques: Spot-based (left) and radio field-based (right).

the coverage is very small and the moisture may remain undetected. Therefore, this paper presents, how an innovative Soil Moisture Sensing (SoMoS) system can be developed, which is able to detect soil moisture changes and the Volumetric Water Content (VWC) via the radio field itself by measuring the variation of the Receive Signal Strength Indicator (RSSI) of an underground communication link between two sensor nodes in a significantly increased coverage area (comp. Fig. 1, right). The experimental setup in the laboratory is based on a Software Defined Radio (SDR) approach, because the SDR enables the variation of essential parameters of a communication system like operating frequency, modulation or coding and decoding scheme during the development and evaluation process without any hardware changes. In contrast, the field test setup is based on Long Range (LoRa) radio modules with a very small design and low power consumption. The use of LoRa as a Wireless Underground Sensor is quite new and an innovative field of research. Current research, which considers soil moisture detection via the radio field, focuses on different commercially available communication systems like ZigBee at 2.4 GHz [5] or Ultra-Wideband (UWB) at 4 GHz [6]. But due to the very high path loss in the frequency range above 1 GHz, the communication range is very limited. However, the experimental results correspond with the analytical considerations and make clear that soil moisture detection via the radio field between two sensors is possible. In contrast to WUSNs using electromagnetic (EM) waves for signal propagation and communication, an alternative solution called Magnetic Induction (MI) was developed to increase the link quality and communication distance [7]. Because of the complex development, no commercial solutions are available as yet and due to the very special technical challenge to detect soil moisture, the sensing system presented in this contribution is based on EM wave propagation.

This paper is organized as follows: Section II describes the design and experimental validation of the developed Soil Moisture Sensing System based on SDR in the laboratory. Section III presents the evaluation of a multidimensional sensor field based on LoRa radio modules in a field test. Finally, the conclusion is provided in Section IV.

II. DESIGN AND VALIDATION OF THE SOIL MOISTURE SENSING SYSTEM IN THE LABORATORY

Each developed Soil Moisture Sensing (SoMoS) transceiver is based on an Universal Software Radio Peripheral (USRP) N210 from Ettus Research as Software Defined Radio (SDR) and a log periodic Printed Circuit Board (PCB) antenna with about 6 dBi antenna gain. Due to the wide variety of the SDR platform, the authors already used the system in various applications like precise vehicle positioning in urban canyons [8]. To analyze and evaluate a multidimensional sensor field in the laboratory, a homogeneous distribution of sensors, soil material and moisture content is required. Therefore, glass cubes with a dimension of 0.4x0.4x0.4 m are used for the experimental setup. Each of the outer cubes holds a SoMoS transceiver and due to the highly directional antennas, they can be left in air for the laboratory measurements. The four center cubes are filled with sand. In general, each cube filled with soil will be defined as a voxel v_{xy} in the following. This multidimensional sensor field with eight SoMoS transceivers around a 2x2 soil matrix is shown in Fig. 2. In a consecutively

Fig. 2. Eight SoMoS transceivers around a 2x2 soil matrix. The bottom right voxel is filled with wet sand.

manner (Round Robin, Half Duplex Mode), each transceiver continuously sends a narrow-banded cosine signal with a transmit power of 10 dBm with an operating frequency of 433 MHz within a given period of time. On receiver's side (opposite), the signal will be pre-processed, Fourier transformed, filtered and plausibility checked. Then, the measured RSSI values will be stored for further post-processing routines and an evaluation of the system. The bottom right voxel is filled with wet sand ($\approx$ 22% VWC), the other voxels with dry sand ($\approx$ 5% VWC). The modular setup allows the evaluation of the soil moisture content with a Radio Tomographic Imaging (RTI) approach, which was already used by the authors in a different context [9]. The measured RSSI values will be rated relatively to the given scenario and visualized in a (monochrome) heatmap (Fig. 3, left). With (1), the average RSSI of each row and column will be calculated, where x and y are the row and column indexes, n_x and n_y the amount of measurement values m per row and column, respectively.

$$\overline{RSSI}_{x/y} = \frac{1}{n_{x/y}} \sum_{k=1}^{n_{x/y}} m_{k,x/y} \tag{1}$$

Now, the average RSSI per voxel v_{xy} can be calculated with (2), done in Fig. 3 (right).

$$v_{xy} = \frac{1}{2} \left(\overline{RSSI}_x + \overline{RSSI}_y \right) \tag{2}$$

As visible in Fig. 2, voxel v_{11} contains all measurement results of the communication links directed through the dry amount of sand in the 2x2 soil matrix. On the contrary, voxel v_{22} contains all measurement results of the communication links directed through the wet amount of sand. Therefore, the additional attenuation induced by the soil moisture in voxel v_{22} for the given scenario will be calculated with $\Delta_M = |v_{22} - v_{11}| = 8.25dB$.

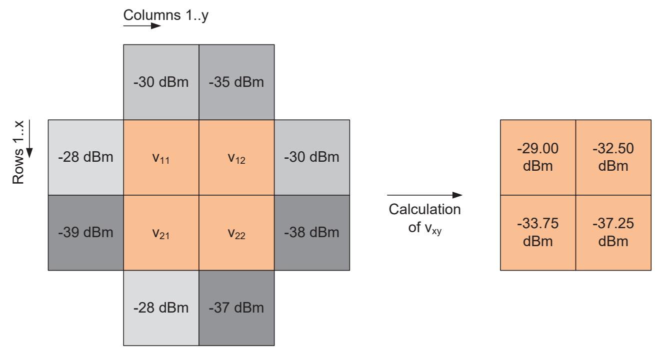

Fig. 3. Raw RSSI (left) and average voxel RSSI (right) measurement values of the multidimensional sensor field.

As introduced in [10], the receive power of the underground signal is affected by an additional path loss, which is depending on the soil medium and its composition parameters like bulk and specific density, moisture content, dielectric constant and magnetic permeability, which result in an attenuation and phase shifting constant of the soil. Therefore, Δ_M can be validated analytically by calculating the additional soil attenuation of sand for the given VWC values of 5% and 22%. This is visualized in Fig. 4, where the additional path loss vs. VWC for a voxel width of 0.4 m is plotted. The difference

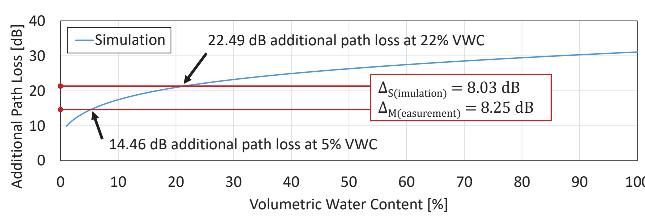

Fig. 4. Comparison of simulated and measured path loss.

between 22% and 5% VWC should now approximately be the same as the determined attenuation during the measurements. For 22% VWC, the additional attenuation is 22.49 dB, for 5% VWC it is 14.46 dB. Therefore, the analytical attenuation Δ_S is 8.03 dB, which approximately equals the measured value Δ_M of 8.25 dB. The SDR-based SoMoS system shows valid behavior and is able to detect soil moisture via the radio field.

III. Evaluation of the Soil Moisture Sensing System in a Field Test

To evaluate the system in a field test, the SDR approach will be adapted to a LoRa-based system with some major benefits. The transceivers (Adafruit Feather 32u4 with 433 MHz LoRa radio module) offer a high receiver sensitivity, are much smaller and can be placed in a waterproof acrylic glass cylinder (Ø 0.1 m). With a small battery, they work for several months in passive sleep mode with random wake up. The transmit power is still 10 dBm. The experimental setup before burying is shown in Fig. 5. Each transceiver, which will be

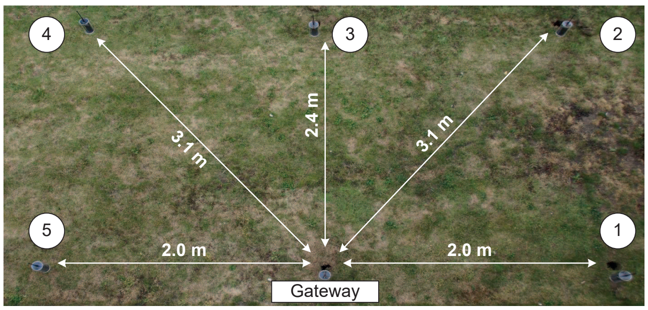

Fig. 5. Top view of the LoRa-based SoMoS system with one gateway and five nodes before burying.

called SoMoS node in the following, is equipped with an external λ/4 rod antenna. One of the nodes is configured as a gateway and listens to the channel all the time. The other nodes wake up randomly within several minutes and request channel access. If granted (channel not busy), they send five LoRa packets in a predefined period of time to transmit the measured RSSI from gateway and several system states. Fig. 6 visualizes the side view of the field test after burying the nodes in a depth of 0.6 m. The distance between surface and

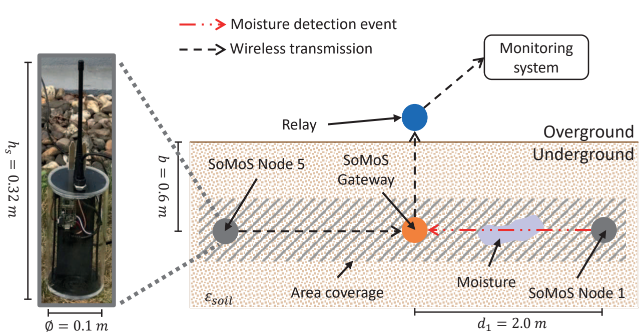

Fig. 6. Side view of SoMoS Node 1 & 5 with centered gateway after burying.

the top of the node antenna is 0.28 m and the soil consists of clean and dry topsoil. The surface between gateway and SoMoS Node 1 (0.5x2.0 m) will now be watered with 30 l of rainwater, which simulates a precipitation of 30 mm/m². Fig. 7 shows the measurement results before and after burying as well as during the precipitation event. The burial results in an additional signal attenuation of 5 dB, the precipitation slowly and continuously affects it with 13 dB in total within a period of 5 hours.

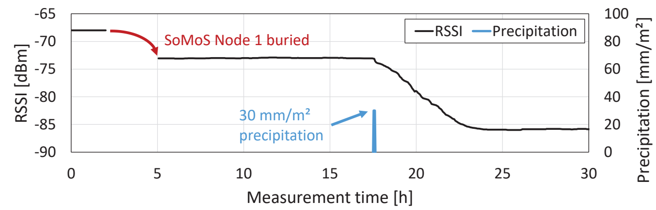

Fig. 7. Measured RSSI values of SoMoS Node 1 at gateway during the burying and precipitation event.

IV. Conclusion

This paper shows the feasibility of a multidimensional radio field based Soil Moisture Sensing System to detect soil moisture changes due to varying signal attenuation with different hardware platforms at an operating frequency of 433 MHz. To validate the functionality, the measured path loss of the SDR-based setup was compared with the analytical determined underground path loss induced by the given VWC. Future work may include long-term monitoring of the signal attenuation after a precipitation event and an evaluation of the maximum communication distance. Further, the SoMoS system will be used to detect seepage water at a dam.

Acknowledgment

This work has been partially conducted within the German TaMIS project, which is part of the nationwide geotechnology research program funded by the German Federal Ministry of Education and Research (BMBF) (03G0854A).

References

[1] I. F. Akyildiz and E. P. Stuntebeck, "Wireless underground sensor networks: Research challenges," *Ad Hoc Networks 4.6 (2006): 669-686*.

[2] S.-U. Yoon, E. Ghazanfari, L. Cheng, S. Pamukcu, and M. T. Suleiman, "Subsurface event detection and classification using wireless signal networks," *Sensors 12.11 (2012): 14862-14886*.

[3] D. Chaudhary, S. Nayse, and L. Waghmare, "Application of wireless sensor networks for greenhouse parameter control in precision agriculture," *International Journal of Wireless & Mobile Networks (IJWMN) Vol 3.1 (2011): 140-149*.

[4] X. Yu, W. Han, and Z. Zhang, "Path loss estimation for wireless underground sensor network in agricultural application," *Agricultural Research 6.1 (2017): 97-102*.

[5] H. R. Bogena *et al.*, "Hybrid wireless underground sensor networks: Quantification of signal attenuation in soil," *Vadose Zone Journal 8.3 (2009): 755-761*.

[6] M. Malajner *et al.*, "Soil moisture estimation using uwb," in *2016 IEEE/ACES International Conference on Wireless Information Technology and Systems (ICWITS) and Applied Computational Electromagnetics (ACES)*. IEEE, 2016, pp. 1–2.

[7] X. Tan, Z. Sun, and I. F. Akyildiz, "A testbed of magnetic induction-based communication system for underground applications," *arXiv preprint arXiv:1503.02519 (2015)*.

[8] B. Niehoefer, F. Schweikowski, and C. Wietfeld, "Smart constellation selection for precise vehicle positioning in urban canyons using a software-defined receiver solution," in *Communications and Vehicular Technology in the Benelux (SCVT), 2013 IEEE 20th Symposium on. IEEE, 2013*.

[9] V. Köster, A. Lewandowski, and C. Wietfeld, "A segmentation-based radio tomographic imaging approach for interference reduction in hostile industrial environments," in *Position Location and Navigation Symposium (PLANS), 2012 IEEE/ION. IEEE, 2012*.

[10] L. Li, M. C. Vuran, and I. F. Akyildiz, "Characteristics of underground channel for wireless underground sensor networks," *Proc. Med-Hoc-NetŠ07 (2007)*.