Empirical Evaluation of Wireless Underground-to-Aboveground Communication

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Abstract. Hybrid Wireless Underground Sensor Networks (WUSNs) is an emerging area of research that promises to provide communication capabilities to buried sensors and aboveground devices. In this work, experimental measurements are presented at the frequency of 433MHz for short-range distances (<15m). The effects of the soil moisture and the maximum physical distances are some of the investigated aspects.

1 Introduction and Related Work

Wireless Underground Sensor Networks (WUSNs) are an extension of Wireless Sensor Networks (WSNs) aiming the underground scenario. A Hybrid WUSN is characterized by the intense use of aboveground devices in conjunction with the buried sensors [1]. Some examples of Hybrid WUSN applications are intelligent irrigation, real-time environment monitoring, assisted navigation, and sports field maintenance [2]. Previous related works used special nodes with higher transmit power levels and aimed long-range distances (>15m) [4, 3]. In this work, the results of experiments at the frequency of 433MHz using commodity sensors are presented. To the best of our knowledge, this is the first work that reports experimental data for a typical Hybrid WUSN scenario involving short-range distances. The main contribution of this work is to highlight the challenges and open research aspects related to the development of a wireless underground-to-aboveground communication channel model.

2 Experiments Setup and Results

The underground experiments were carried out in University of Nebraska-Lincoln City Campus during Aug08-May09 period [2]. For the experiments, MICA2 nodes that operate at 433MHz, with vertically polarized antennae, are used [5]. The following symbols are used here: $d_{bg}$ is the burial depth of the sender node,
Fig. 1. Results from the underground-to-aboveground communication experiments. $d_h$ is the horizontal inter-node distance between the nodes, and $d_{ag}^r$ is the height of the receiver node. In Figs. 1(a) and 1(b), the Received Signal Strength (RSS) and Packet Error Rate (PER) values are shown, respectively, as a function of the horizontal inter-node distance, $d_h$, considering a fixed $d_{bg}^r = 40\text{cm}$. The receiver is placed above the soil surface ($d_{ag}^r = 0$). Each line in the figures shows the
results for different transmit power levels and one special case is also analyzed: the combination of the transmit power $+10 dBm$ and wet soil conditions (in this case, 11% and 18% are the VWC for normal and wet soil, respectively). As shown in Figs. 1(a) and 1(b), an increase in the $d_h$, decreases the signal strength, as expected. It is observed that below 2m, the communication has good quality for all transmit power levels. However, a drop of almost $20 dB$ on the RSS and a PER increase from almost 0 to 20% occurs when the VWC increases.

The Figs. 1(c) and 1(d) also evaluate RSS and PER values as a function of $d_h$, considering a fixed $d_{ag}^s = 13 cm$ and a transmit power level of $+10 dBm$. Each line in the figures shows the results for different heights of the receiver. An increase in the $d_{ag}^s$, increases the signal strength and, in general, decreases the PER. It can also be observed that, with $d_h \geq 9 m$ the behavior of the communication is unstable. Finally, in the Figs. 1(e) and 1(f), it is investigated how the RSS and PER are affected by small changes in the deployment of the sensors. Both tests, A and B, were realized at the same local. The experiment B only changed the hole of the sender and the position of the receiver. However, these small changes drastically modified the communication range. For instance, in the experiment A, no communication is possible at $d_h = 3 m$ and $d_{ag}^s = 30 cm$. For the new locations, the results of the experiment B shows a high quality communication for $d_h = 3 m$ and $d_{ag}^s = 50 cm$. Moreover, the values of RSS and PER in the Figs. 1(e) and 1(f) do not present a monotonic behavior.

3 Conclusion

The results proved the feasibility of the use of commodity WSN sensors for some Hybrid WUSNs scenarios. However, changes in the soil moisture can potentially stop the communication. The temporary use of a higher transmit power level can be a solution for this issue. Moreover, the non-monotonic behavior of the RSS and PER must be fully explained aiming the development of a wireless underground-to-aboveground channel model for short-range distances.

References