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Application of 915 MHz Band LoRa for Agro-Informatics

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***Abstract*—Use of the LoRa low-power wide-area network modulation scheme with the LoRaWAN® (Long Range Wide Area Network) MAC layer is becoming popular for subterranean agro-informatics networking applications. LoRa uses chirp spread spectrum technology and is licensed by Semtech. Sensors with LoRa radios can be designed to detect and measure toxins that can leach into agricultural soils from industrial and storm water sources. Sensors can be buried with cameras that can detect and classify pathogens affecting the roots of plants. Sensor measurements and camera images can be sampled in situ and transmitted to an above-ground central LoRa concentrator (gateway) on a farm. LoRa devices can be buried at variable depth, however soil and water both attenuate the strength of a transmitted signal. In this work, we conduct experiments to measure the received signal strength indicator (RSSI) and signal-to-noise ratio (SNR) under different LoRa spreading factors, coding rates, and soil depths. Our results show LoRa transceiver burial depth should not exceed 50cm for agro-informatics applications.**

Keywords*—*LoRa, Signals in Soil, Agro-informatics.

I. Introduction

Water system runoff from streams, channels, and storms can damage agriculture water quality by transporting poisons, pesticides, drugs, supplements, salts (selenium and boron), pathogens, and heavy metals from developed areas into surface waters. To sense the soil contaminants and transmit the measured data to an above-ground base station (concentrator), LoRa (Long Range) low-power wide-area network (LPWAN) modulation can be used. Received signal strength indication (RSSI) and signal-to-noise ratio (SNR) can be used as the indicator of the contaminants. However, it is noted that both the parameters are affected by the depth.

In this paper, we present the results of evaluating how RSSI and SNR varies with depth in dry and saturated loam soil. In order to obtain wet soil, 13 L distilled water was added to reach the field capacity of 27% for the loam soil. The results show how RSSI is affected with the increase in depth. Typically, when RSSI reaches near -120 dBm, a LoRa transmission cannot be demodulated.

The rest of the paper is organized as follows: Section II presents the motivation behind the work. Section III discuss the various aspects of the experimental setup like the details of the soil container, LoRa device, transmitting and receiving antenna and the spectrum analyzer. Results are presented in Section IV while the conclusions are drawn in Section V.

II. Motivation

California is one of the largest tomato producing states in the United States. Phytophthora and fusarium root rot are the most common rot diseases in the tomato plant. Foliage turns yellow and wilt as the plant dies due to the fusarium infection while in case of the phytophthora infection the plants develop brown, necrotic lesions on the foliage that coalesce into larger lesions while the entire plant wilts. Early detection of the infection can be useful to save the plants from wilting.

We wish to develop a system for the early detection of the root rot as shown in Fig. 1. A camera will be placed near the root of the plant which will click the pictures of the roots periodically. The images will be sent to the signal processing module. The module will run a machine learning algorithm that will decide whether the root is rotting or not. The information will be passed to a LoRa transmitter buried in the soil. The transmitter will send the signal to the receiver located above the soil. The receiver will send the information to the farmer through the cloud. The farmer will be able to detect the rotting plant and can treat the plant in the early stage of the infection.

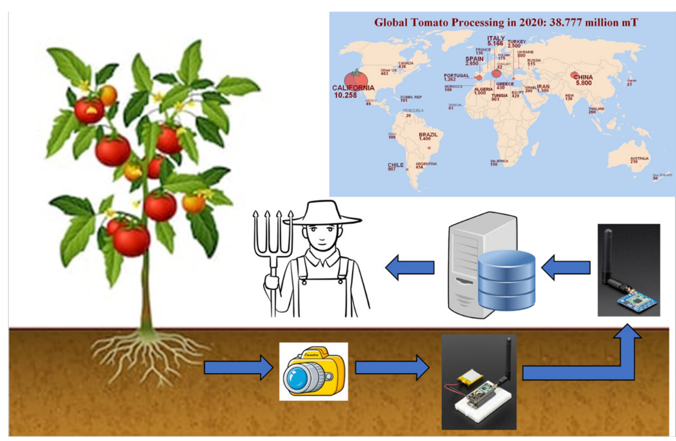

Fig. 1. Block diagram of the system for early root rot detection.

The current work aims to study the effect of soil on the signal transmitted by a LoRa device buried under the soil. Loam is best suited for tomato plant and hence the experiments were carried out with the loam soil. It was studied that the root of the tomato plant grow as deep as 2 feet (60.96 cm) and so the burial depth was varied from 0 to 60 cm.

III. Experimental Setup

A. Soil Container

A plastic bucket (Fig. 2) having radius 25 cm was filled with 60 cm of loam soil and the outside of the bucket was wrapped with aluminum foil. This was done to block the electromagnetic field travelling in the radial direction and thereby creating a Faraday shield enclosure. Using the equation of skin depth available in literature, it was found that the thickness of one layer of aluminum foil was enough to block the radiation.

Two sets of experiments were carried out. One with dry soil and another with wet soil. Around 13 L of the distilled water was added to the soil for reaching its field capacity of 27%.

Fig. 2. Photograph of the plastic bucket wrapped in one layer of aluminum foil to block electromagnetic fields.

B. LoRa Measurement Device

A peer-to-peer LoRa system for measuring RSSI and SNR at varying spreading factor and coding rate was build. In LoRa Spread Spectrum, the chipping signal is a linearly varying frequency chirp signal, while the information signal is modulated onto the chirp. Spreading factor, denoted *SF*, is the base-2 log of the chip rate R_{chip} to the symbol rate R_{symbol} ratio

$$SF = \log_2\left(\frac{R_{chip}}{R_{symbol}}\right) \tag{1}$$

SF is the number of bits encoded per symbol. LoRa supports code rates of k/n where $(n - k)$ = CR = [1, 2, 3, 4] are redundant bits for $k = 4$,

$$R_{code} = \frac{k}{n} = \frac{k}{k+CR} = \frac{4}{4+CR} \tag{2}$$

Since *SF* is the number of bits encoded per symbol, $SF \cdot R_{code}$ is the proportion of useful (non-redundant) bits encoded per symbol. The nominal, or predicted, bitrate is thus

$$R_{b,nom} = SF\ R_{code}\frac{BW}{2^{SF}},\ \text{bps} \tag{3}$$

where *BW* is 125 kHz. The peer-to-peer system we designed is composed of two Adafruit Feather M0 microcontrollers with a HOPE Microelectronics RFM95W 915 MHz (US) LoRa radio transceiver. We developed code to have one microcontroller continuously transmit a LoRaWAN packet to the other microcontroller at varying *SF* and *CR* values. We burry one microcontroller and place the other 3 meters away, above the soil. The buried microcontroller is powered by a rechargeable 3.7 V lithium polymer 500 mAh battery. A Taoglas ISPC.91A 915 MHz 5 dBi ceramic patch antenna was connected to the buried microcontroller as shown in Fig. 3.

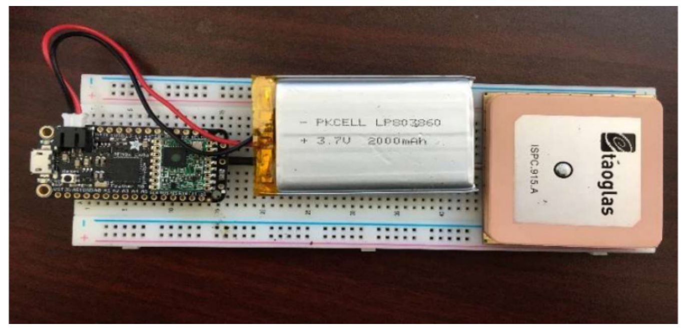

Fig. 3. Photograph of the buried microcontroller device. This device was placed in a sealed plastic bag prior to burial in loam soil.

C. Tranmsitting and Receiving Antenna

The choice of antenna was an important criteria while setting up the experiment. Two different types of antennas were used for the experimental setup, one for the transmitter and one for the receiver. Since the transmitting antenna was supposed to buried under the soil, it should be printed, small in size, have omni-directional radiation pattern and low profile. An antenna that protrudes out from the structure cannot be used as the soil would change its orientation leading to change in the radiation pattern. Hence, Taoglas ISPC.91A ceramic patch antenna was used. It provided a gain of 5 dBi and an efficiency of 71% with a ground plane. Even without a ground plane, it provided a gain of 1 dBi and an efficiency of 50-60%. There was no constraint of size and shape of the receiving antenna and so a monopole antenna was utilized.

D. Tektronix RSA306B Spectrum Analyzer

A Tektronix RSA306B spectrum analyzer was used to verify the SNR and RSSI measurements reported by the outside (non-buried) microcontroller. The RSA306B has a range of 9 kHz to 6.2 GHz.

A block diagram for the experimental setup is shown in Fig. 4.

IV. Results & Analysis

In a double-nested loop, for each value of *SF* and *CR*, the buried microcontroller transmits 10 packets to the outside microcontroller and the RSSI and SNR is recorded. Fig. 5

shows a plot of the averaging of all 10 measurements for each *SF*-*CR* tuple measured in dry soil. From the figure, it can be seen that RSSI remains above -120 dBm down to a depth of 60 cm. The dry soil measurements were made under conditions of room temperature and relative humidity. We then performed a wet soil experiment where we added 13L of distilled water to the bucket to reach the field capacity θ_{fc} of 27% for loam. Field Capacity θ_{fc} is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased [1, 2].

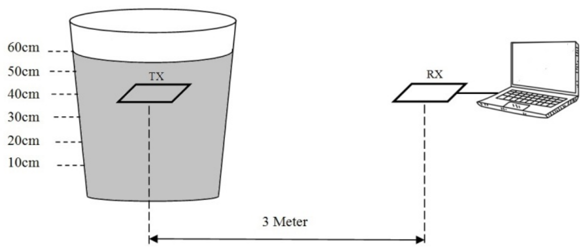

Fig. 4. Block diagram of the experimental set-up.

Fig. 6 shows the effect saturated soil has on RSSI. At 50cm, use of a 4/7 ▲ and 4/8 ■ code rate, and a code rate of 4/6 with a spreading factor of 8, resulted in received transmissions with an RSSI less than -120 dBm.

Fig. 7 shows surface plots of measured SNR as a function of code rate and spreading factor under dry conditions at depths of 0, 30, and 60 cm. The 0cm measurement is taken with the transmitter is resting on the top of the soil. The surface plots show how SNR degrades with depth. A spreading factor of 10 was shown to typically yield the highest SNR.

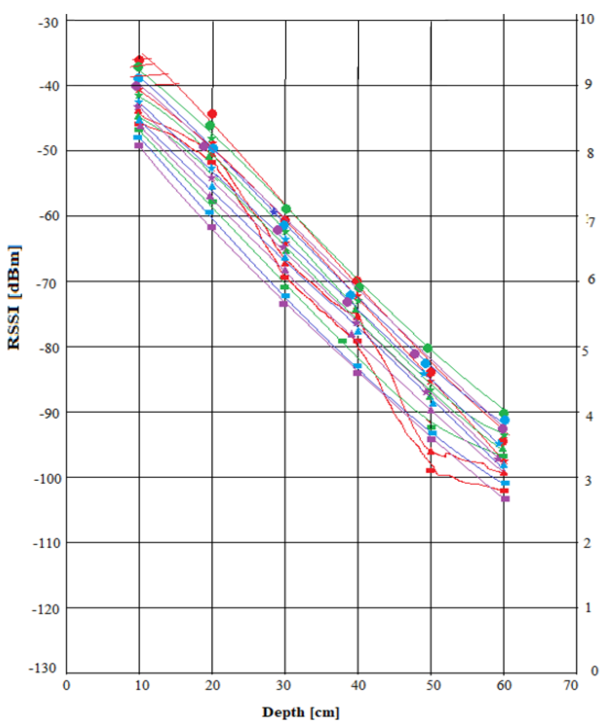

Fig. 5. Legend: CR 4/5 ●, CR 4/6 ★, CR 4/7 ▲, CR 4/8 ■; SF7, SF8, SF9, SF10. RSSI vs burial depth at diferent values of *SF* and *CR* in dry soil.

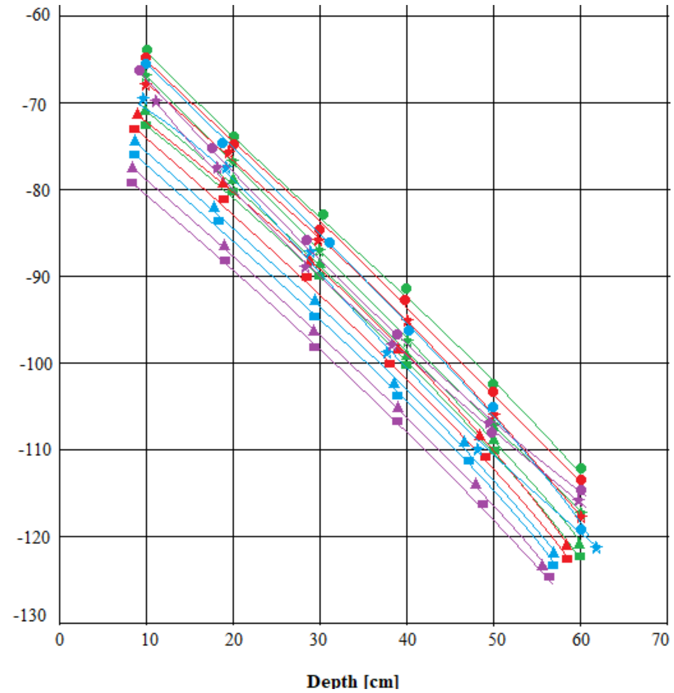

Fig. 6. RSSI vs burial depth at diferent values of SF and CR in wet soil.

V. Conclusions

Use of the LoRa physical layer in subterranean applications for transmitting sensor measurements is becoming an active research area in agroinformatics [3-8]. Research by Wan et al. [5] showed LoRa packet success rate (PSR) markedly decreases as water volume increases from 9% to 25% in loam type soil at 50cm depth. In LoRa, each spreading factor is constrained by a unique Signal-to-Noise ratio (SNR) limit, or minimum $(S/N)_{min}$. If received signal power reaches or falls below $(S/N)_{min}$ a LoRa receiver will be unable to demodulate the signal. $(S/N)_{min}$ is the ratio of receiver sensitivity S_{min} to noise floor power level,

$$\left(S/N\right)_{\min} = \frac{S_{\min}}{k_B T_0 \; BW \; 1000\,\mathrm{mW/W} \; NF} \tag{4}$$

where k_B is the Boltzmann constant, T_0 is the absolute temperature of the receiver input (e.g. 293 K), *BW* is the receiver bandwidth in Hz (e.g. 125000 Hz), and *NF* is the LoRa receiver architecture noise figure (e.g. 6 dB). A relationship between S_{min} and spreading factor is shown in Fig. 8.

Our results show in dry conditions, LoRa transceiver burial within 60cm is able to transmit LoRaWAN packets to an outside receiver where RSSI does not fall below Smin. However, in saturated conditions at Field Capacity θ_{fc}, RSSI falls below -120 dBm, and approaches Smin at 60 cm. We recommend LoRa transceiver burial depth does not exceed 50 cm for agro-informatics applications. Our microcontroller code for the Adafruit Feather M0 is publicly available from GitHub [9].

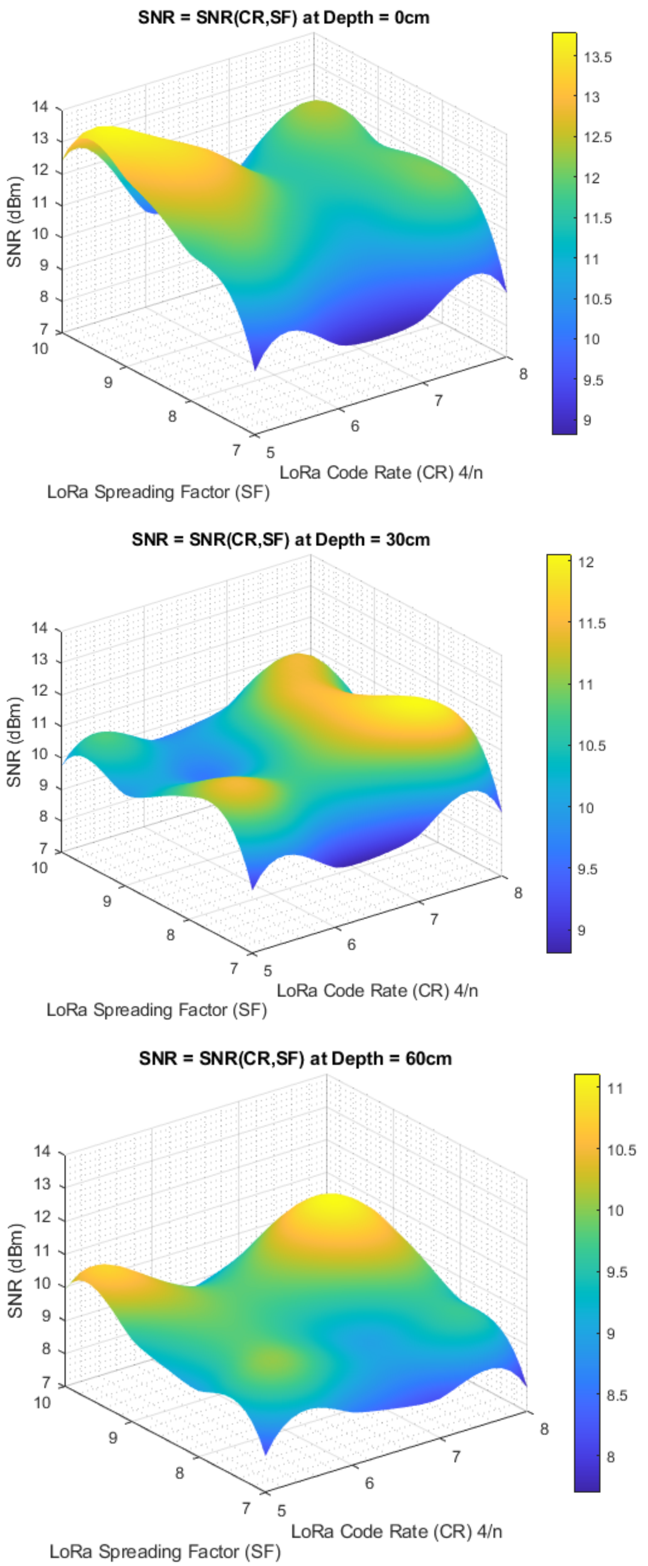

Fig. 7. Signal-to-noise ratio as a fuction of code rate and spreading factor for dry soil conditions.

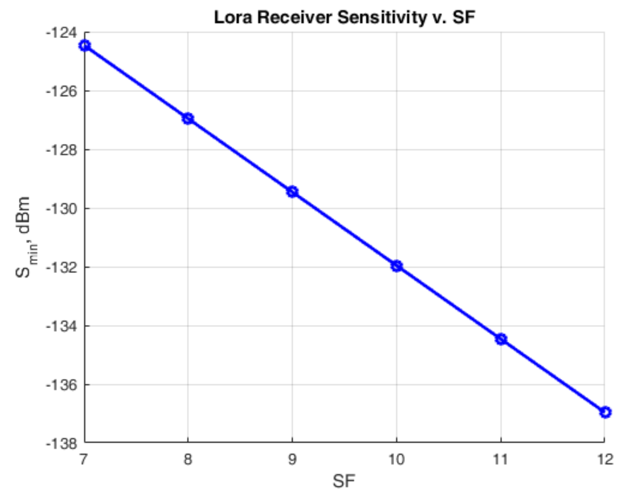

Fig. 8. LoRa receiver sensitivity S_{min} as a function of spreading factor *SF*.

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