Internet of Underground Things in Smart Agriculture: Communication Principles and Soil Moisture Sensing Experiences from the Field

Abdul Salam  Rigoberto Wong  Mehmet C. Vuran

Cyber-Physical Networking Laboratory,
Department of Computer Science & Engineering
University of Nebraska-Lincoln, Lincoln, NE

{asalam, wong, mcvuran}@cse.unl.edu
Sensor-guided Irrigation Management

Up to 40% improvement in water use efficiency is possible with in-situ soil water content measurements.

Making Soil Talk

1. Understand (sensors)
2. Communicate (wireless)
3. Decide (irrigation)
How do we get information... OUT?

IOUT


IOUT Applications


Nebraska IOUT Sensing and Communication Testbeds

What is Next for UG wireless?
Long Range UG Communications

How can we increase UG communications range and form a network with UG nodes?

IEEE INFOCOM’16
High-gain lateral wave [9]

IEEE INFOCOM’17
Soil moisture adaptive beamforming [10]

SMABF – A MISO Approach


- Underground antenna arrays at the transmitter
- Omni-directional antenna at the receiver
- Soil moisture adaptive beamforming
- Leads to higher directivity

- Beam patterns for UG and AG devices
- Refraction from soil-air interface
- UG Optimum Angle
Where does it lead to in IOUT communications?
Long Range Communications

- Communication range enhancement up to 35m through SMABF
- Network of UG nodes can be formed
- Less number of nodes required
- IOUT Center Pivot Integration for bigger farms
Antennas in Soil

Antenna Return Loss and System Bandwidth
System (Antenna) Bandwidth

Return Loss Bandwidth

S\textsubscript{11} (dB)

Frequency (MHz)

Silt Loam

Bandwidth
Impact of the Soil Moisture – Empirical Results

- Antenna bandwidth increased from 14MHz to 20MHz
- Resonant frequency changes from 244MHz to 289MHz when soil matric potential changes from 0CB -> 240CB (45 MHz change)
Where does it lead to in IOUT communications?
Antennas in Soil

• A model to predict resonance frequency of UG antenna under different soil moisture levels
• Software defines radio operation
• Design of wideband antennas
UG Multicarrier Design - Overview

• Background on multicarrier design
  – Divides spectrum into many small, partially overlapping subcarriers
  – Subcarrier frequencies “orthogonal” to each other

• System (Antenna) Bandwidth

• Subcarrier Bandwidth
  – Coherence bandwidth, function of soil type and moisture

• Number of subcarriers

• Fixed or adaptive, time-dependent soil moisture
Overview of the Compound Capacity Model

A. Salam, and M.C. Vuran, “Impacts of Soil Type and Moisture on the Capacity of Multi-Carrier Modulation,” in Proc. ICCCN’16, Waikoloa, HI, Aug. 2016 (Best Student Paper Award).
• Antenna bandwidth increases from 20 MHz to 36 MHz (80 % increase)

• Number of subcarriers has increased from 20 to 55 when soil moisture changes from 0 CB to 50 CB
Adaptive System and Subcarrier Bandwidth

A. Salam, and M.C. Vuran, “Impacts of Soil Type and Moisture on the Capacity of Multi-Carrier Modulation,” in Proc. ICCCN’16, Waikoloa, HI, Aug. 2016 (Best Student Paper Award).

- Fixed system bandwidth (20MHz)
- Fixed subcarrier bandwidth
- (411 kHz)

- At 27CB soil moisture, fixed bandwidth capacity is 102 Mpbs

- Adaptive technique results in 56% higher capacity (161 Mpbs)

- At 50CB -> 241 Mpbs

Adaptive Bandwidth Solution

Adjust subcarrier BW with change in soil moisture
Where does it lead to in IOUT communications?
High Data Rate Communications

- More information out of soil
- Support for multitude of sensors with fewer radios
- Multimedia data transfer
Agriculture 2.0
Use the above menu to navigate between the GPS and Data views. The GPS view depicts the location of the underground nodes. In addition, the GPS view marks the node on the center pivot. Furthermore, the green marker denotes the currently connected underground node. The data view illustrates the soil moisture collected by the underground nodes over time.
2014 Deployment
2014 Deployment

Agriculture 2.0
Use the above menu to navigate between the GPS and Data views. The GPS view depicts the location of the underground nodes. In addition, the GPS view marks the node on the center pivot. Furthermore, the green marker denotes the currently connected underground node. The data view illustrates the soil moisture collected by the underground nodes over time.
2015 Deployment
2015 Deployment
2015 Deployment
2016 Deployment - AG Node

- Transceivers for short-range communication
- 4G dongle for long-range communication
- Development platform for processing and logging
- GPS for localization
- Solar panel as power source
System Architecture

- PrecisionLink is connected to Precision Point Control III, which is used to control the pivot.
- Long-range communication allows us to send an HTTP request to transfer the sensor data.
- With Selenium, commands can be issued to control the pivot.
- Information can also be extracted from web pages like GPS coordinates.
- A web application hosted on a server or the cloud triggers Selenium.
- Selenium can be used to control the most popular web browsers or a headless browser.
Communication Range
Communication Range

October 28, 2015

October 18, 2016
Controls System Experiment Setup

![Diagram with percentages](image1)

![Photo of irrigation system](image2)
Overall Prospects

- **Permanent** underground sensor installation
  - Lifetime >5 yrs
- **Monitoring Anytime / Anywhere:** Spatial and temporal monitoring with I-OUT
- Integrate sensors, systems, networks with the smart grid – environment-aware networking
- Lab experiments... field experiments... deployment experiments...
Acknowledgement
Questions

THANKS

http://cpn.unl.edu  mcvuran@cse.unl.edu