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

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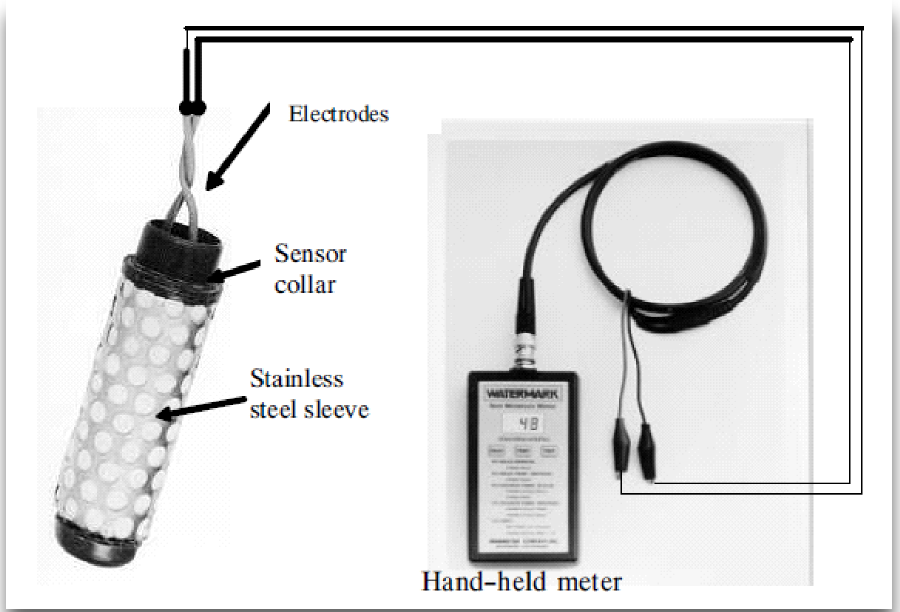
Sensor-guided Irrigation Management



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

[1] S. Irmak, et.al., ``Watermark granular matrix sensor to measure soil matric potential for irrigation management,'' University of Nebraska-Lincoln Extension Circular, EC783, 2006.

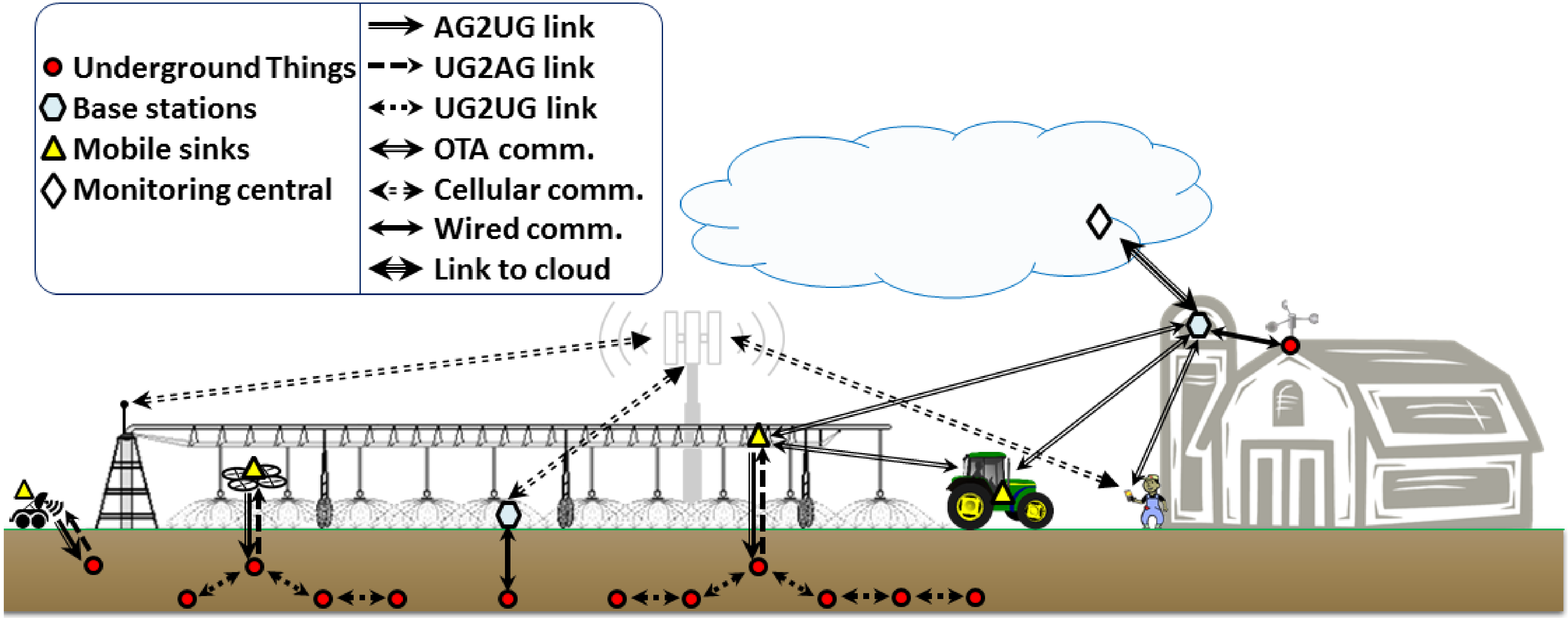
Making Soil Talk

1. Understand (sensors)
2. Communicate (wireless)
3. Decide (irrigation)

How do we get information… OUT?

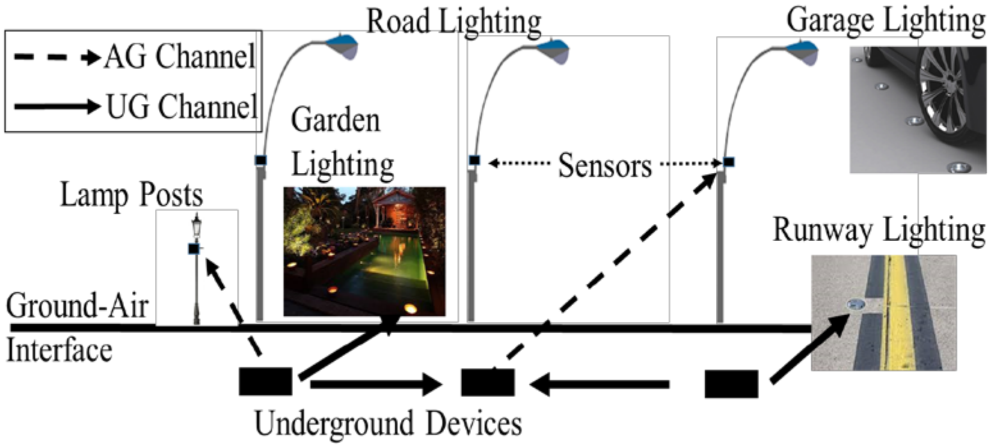
IOUT

IOUT



[2] I.F. Ayildiz, and E.P. Stuntebeck, "Wireless Underground Sensor Networks: Research Challenges," Ad Hoc Networks Journal (Elsevier), vol. 4, no. 6, pp. 669-686, November 2006
[3] Z. Sun and I.F. Akyildiz. "Channel modeling and analysis for wireless networks in underground mines and road tunnels," IEEE Transactions on Communications, vol. 58, no. 6, pp. 1758–1768, June 2010.
[4] X. Dong, M. C. Vuran, and S. Irmak. "Autonomous Precision Agricultrue Through Integration of Wireless Underground Sensor Networks with Center Pivot Irrigation Systems". Ad Hoc Networks (Elsevier) (2012).
[5] I. F. Akyildiz, Z. Sun, and M. C. Vuran, "Signal propagation techniques for wireless underground communication networks," Physical Communication Journal (Elsevier), vol. 2, no. 3, pp. 167–183, Sept. 2009.
[6] A. Salam, and M.C. Vuran, ``Impacts of Soil Type and Moisture on the Capacity of Multi-Carrier Modulation in Internet of Underground Things ,'' in Proc. ICCCN'16, Waikoloa, HI, Aug. 2016 (Best Student Paper Award).

IOUT Applications



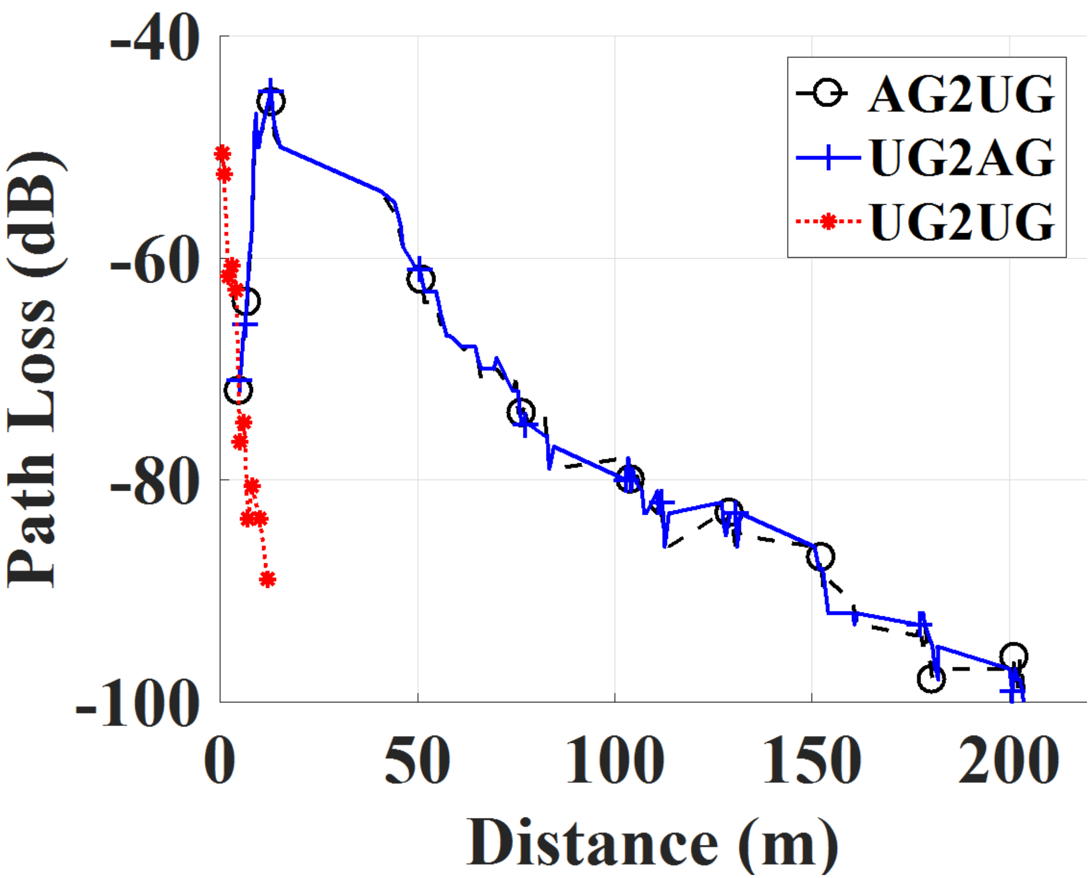
[2] I. F. Akyildiz and E. P. Stuntebeck, "Wireless underground sensor networks: research challenges," Ad Hoc Networks (Elsevier), vol. 4, pp. 669–686, July 2006
[7] A. Salam, M.C. Vuran, and S. Irmak, "Towards IOUT in smart lighting: A statistical model of wireless underground channel," to appear in Proc. 14th IEEE International Conference on Networking, Sensing and Control (IEEE ICNSC), Calabria, Italy, May 2017.

Nebraska IOUT Sensing and Communication Testbeds

[8] A. Silva and M. C. Vuran, ``Development of a Testbed for Wireless Underground Sensor Networks, '' EURASIP Journal on Wireless Communications and Networking, 2010.
[9] A. Salam, M.C. Vuran, and S. Irmak, ``Pulses in the Soil: Impulse Response Analysis of Wireless Underground Channel,'' in Proc. IEEE INFOCOM '16, San Francisco, CA, Apr. 2016.

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

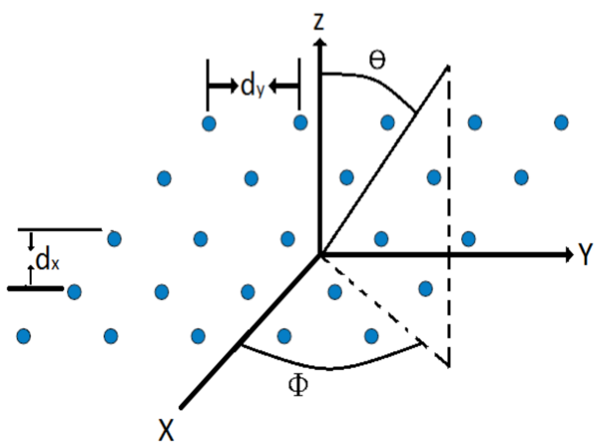
Soil moisture adaptive beamforming [10]

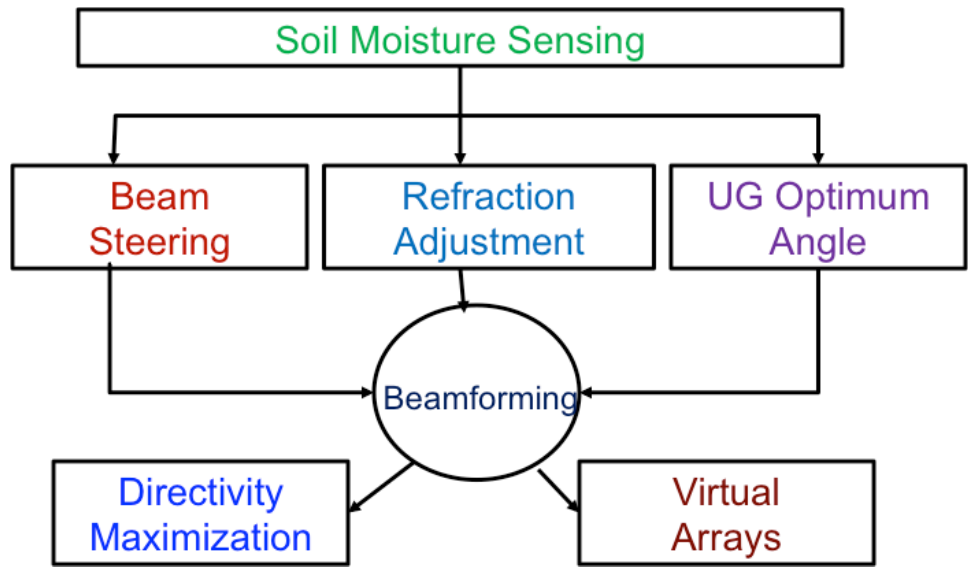
[9] A. Salam, M.C. Vuran, and S. Irmak, ``Pulses in the Soil: Impulse Response Analysis of Wireless Underground Channel,'' in Proc. IEEE INFOCOM ‘16, San Francisco, CA, Apr. 2016.
[10] A. Salam, M.C. Vuran, `Smart Underground Antenna Arrays: A Soil Moisture Adaptive Beamforming Approach`,'' in Proc. IEEE INFOCOM ‘17, Atlanta, GA, May 2017.

SMABF – A MISO Approach

A. Salam, M.C. Vuran, `Smart Underground Antenna Arrays: A Soil Moisture Adaptive Beamforming Approach`,'' in Proc. IEEE INFOCOM '17, Atlanta, GA, May 2017.

- 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

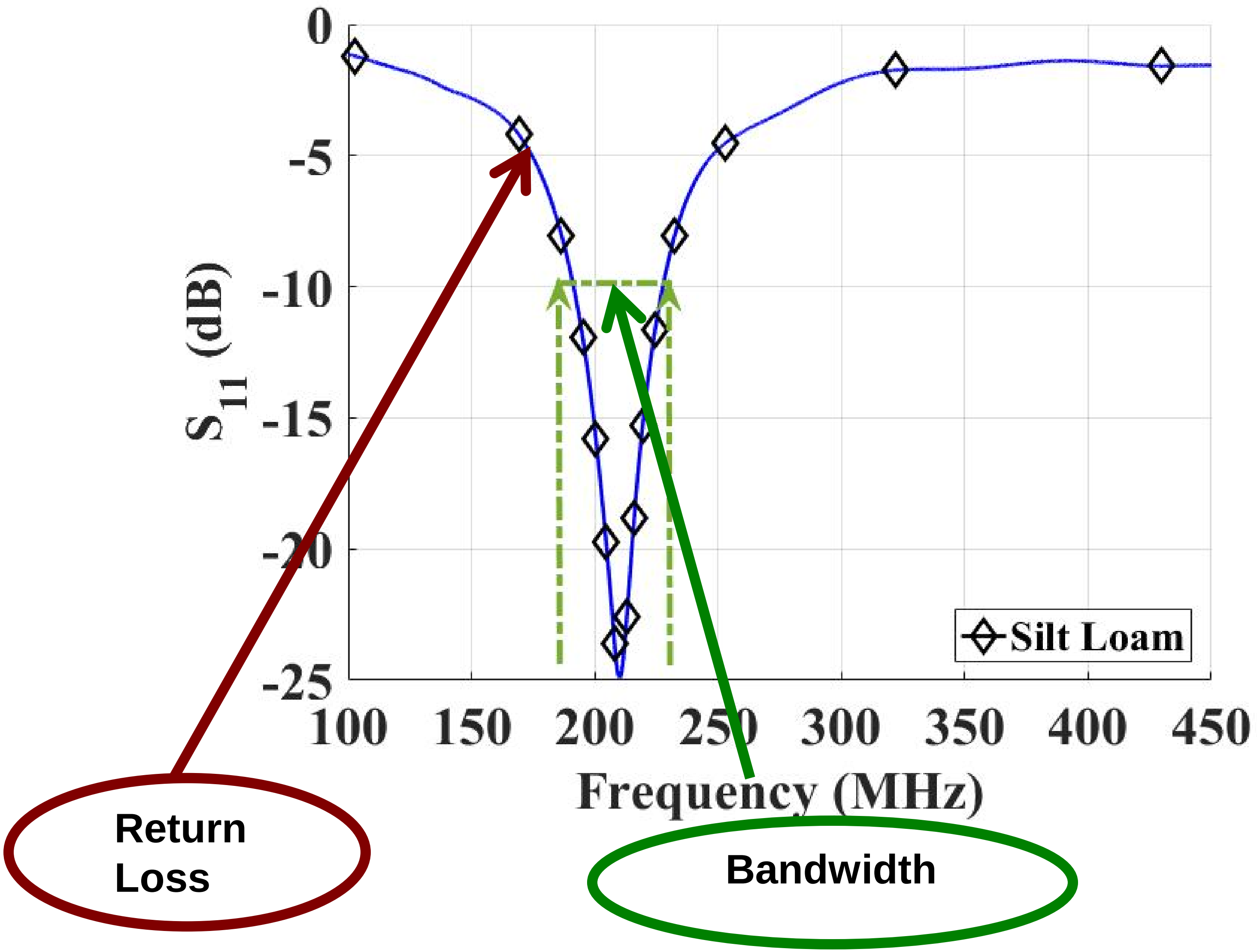
- Communication range enhancement up to 35m through SMABF
- Network of UG nodes can be formed
- Less number of nodes required
- IOUT Center Pivot Integration for bigger farms

Antennas in Soil

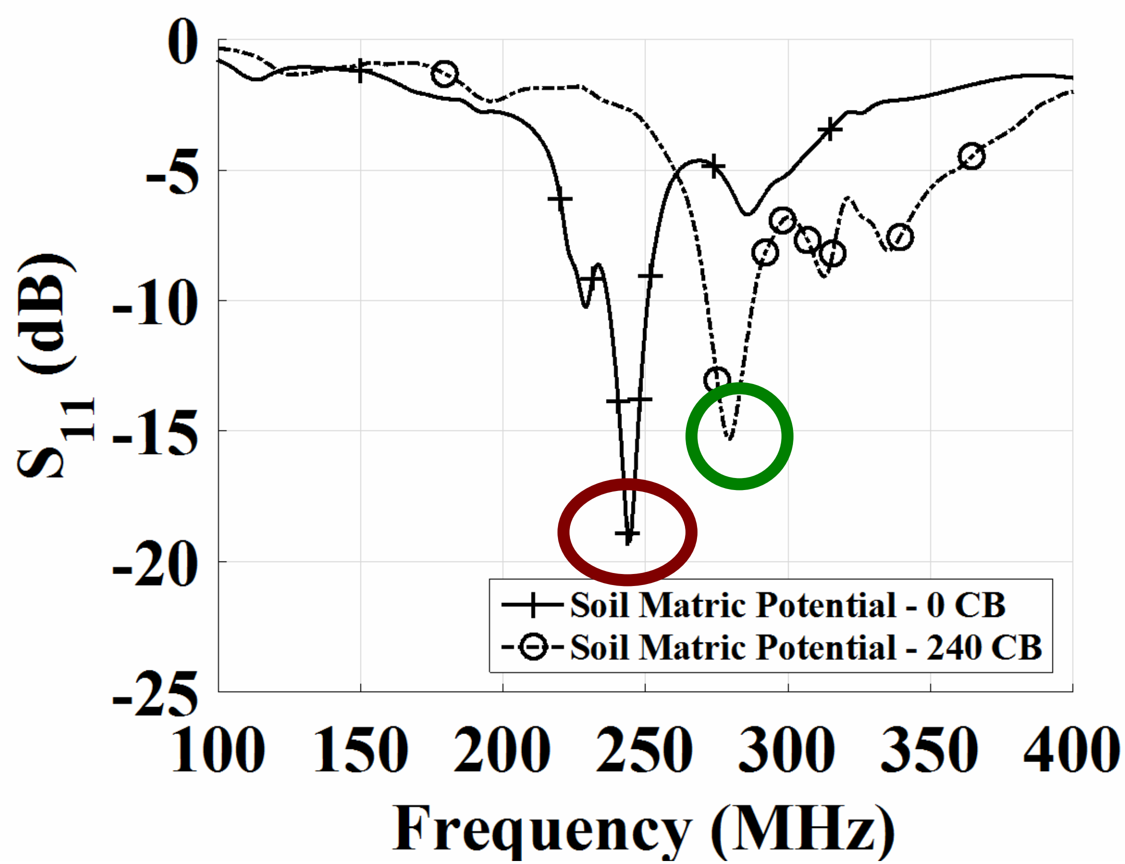


Antenna Return Loss and System Bandwidth

System (Antenna) Bandwidth



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)

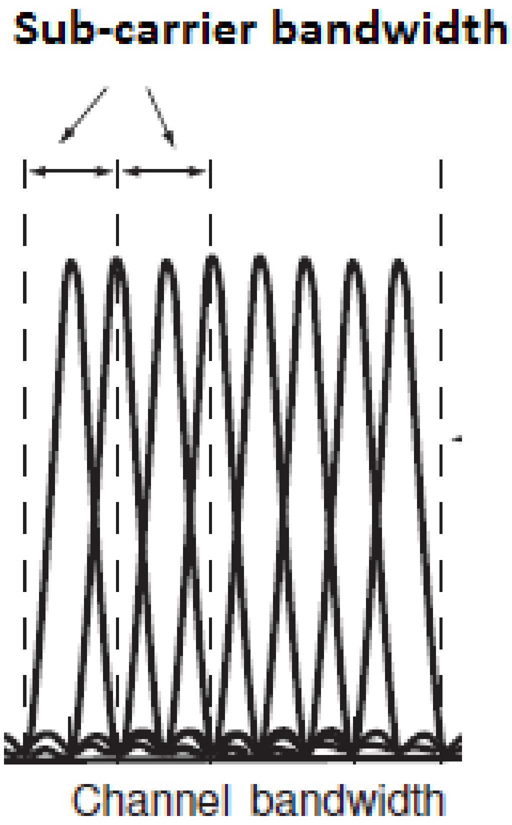
Where does it lead to in IOUT communications?

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

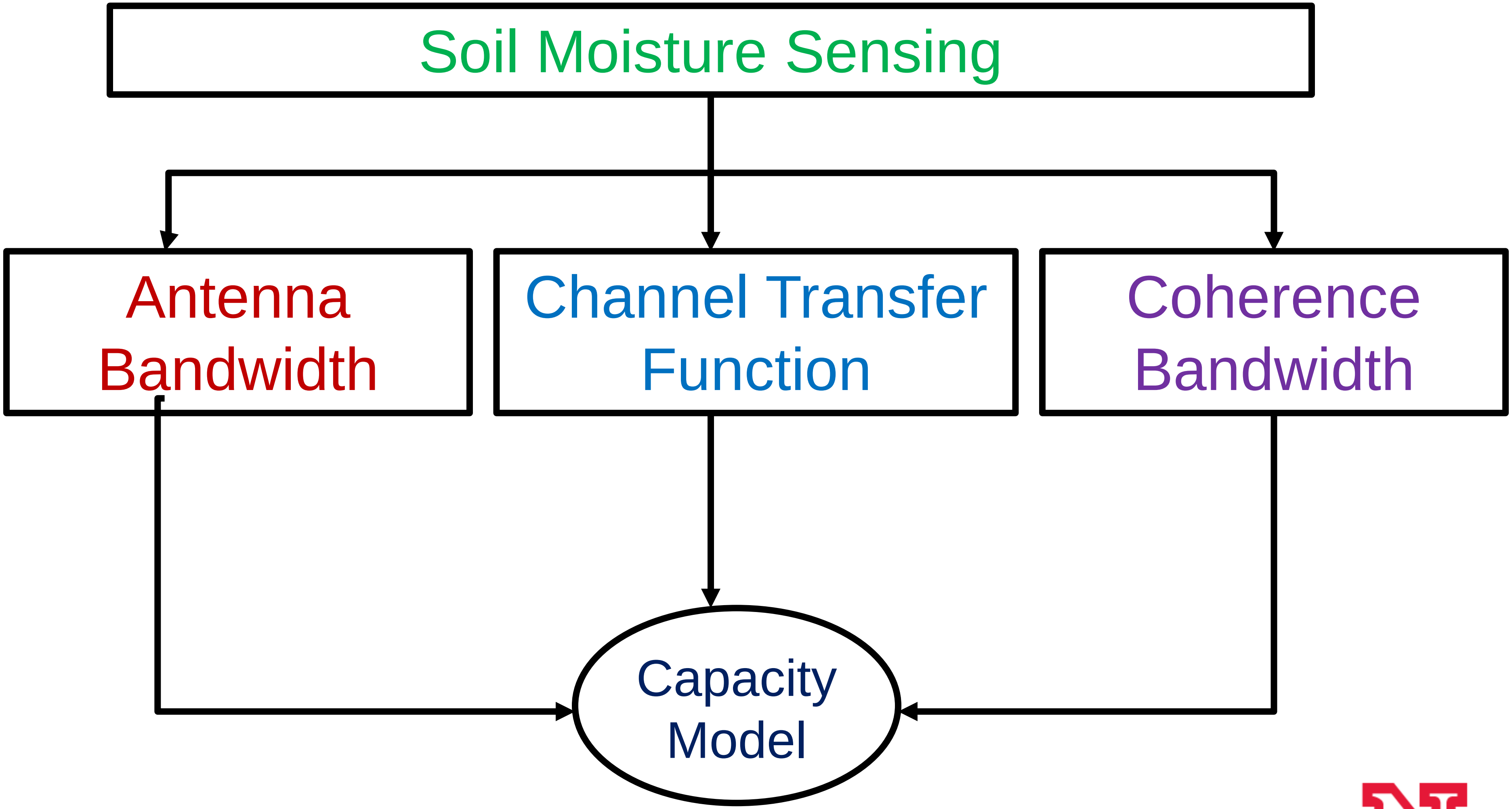
UG Multicarrier Design - Overview

- 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



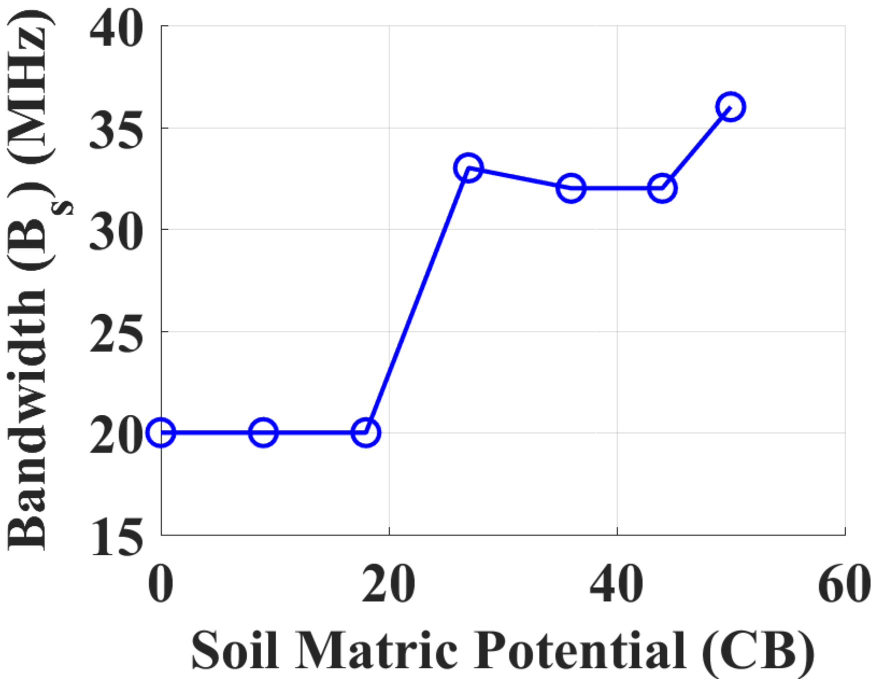
Overview of the Compound Capacity Model

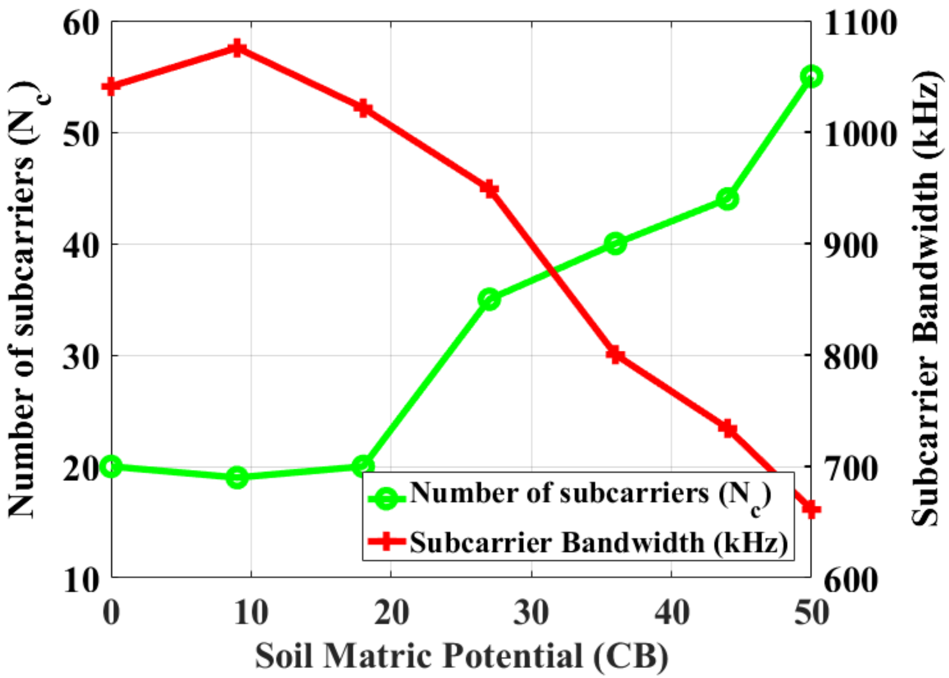
A. Salam, and M.C. Vuran, ``Impacts of Soil Type and Moisture on the Capacity of Multi-Carrier Modulation ,'' in Proc. ICCCN'16, Waikoloa, HI, Aug. 2016 (**Best Student Paper Award**).



Impact of Soil Moisture on Channel Capacity

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

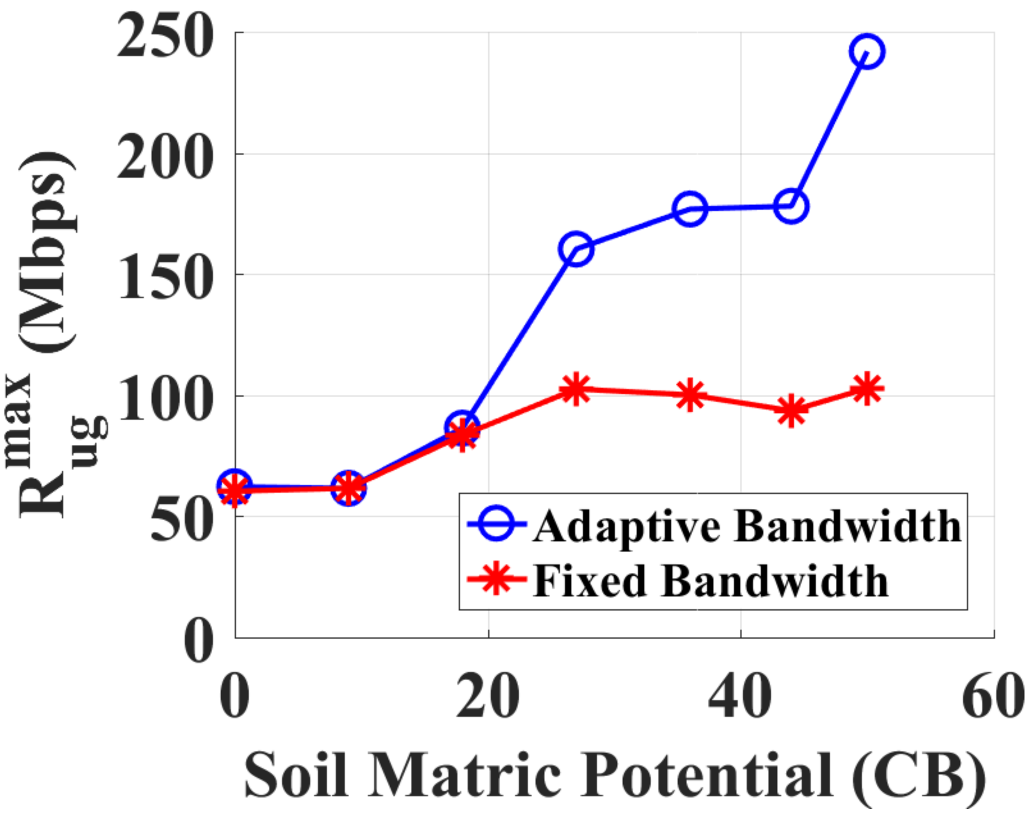
A. Salam, and M.C. Vuran, ``Impacts of Soil Type and Moisture on the Capacity of Multi-Carrier Modulation ,'' in Proc. ICCCN'16, Waikoloa, HI, Aug. 2016 (**Best Student Paper Award**).

- 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 Solutio

Adjust subcarrier BW with change in soil moisture

Where does it lead to in IOUT communications?

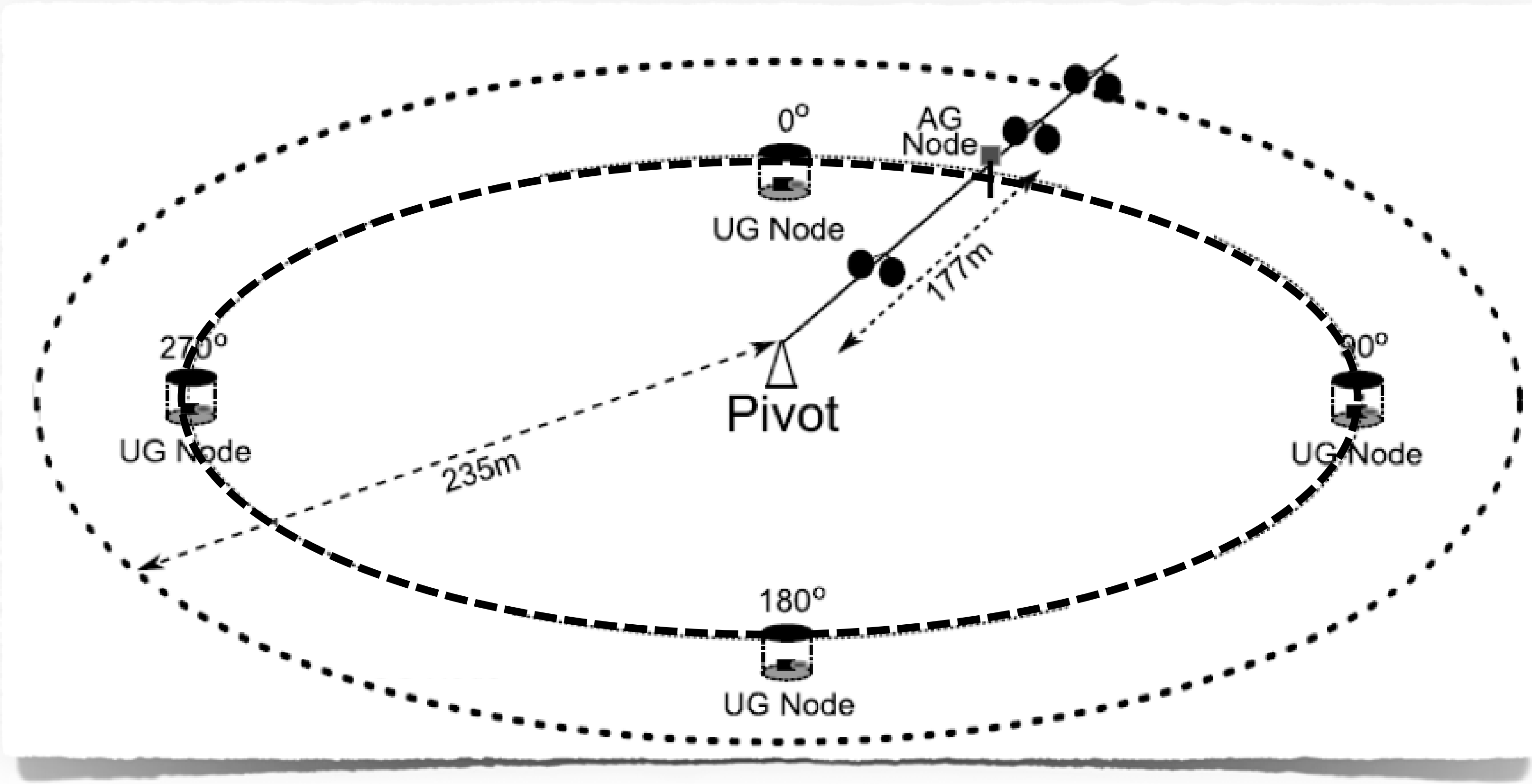
High Data Rate Communications

- More information out of soil
- Support for multitude of sensors with fewer radios
- Multimedia data transfer

IOUT Center Pivot Integration

X. Dong, M. C. Vuran, and S. Irmak, “Autonomous Precision Agriculture Through Integration of Wireless Underground Sensor Networks with Center Pivot Irrigation Systems,” Ad Hoc Networks Journal, vol. 11, no. 7, pp. 1975-1987, Sept. 2013.

IOUT Center Pivot Integration



J. Tooker, X. Dong, M. C. Vuran, and S. Irmak, "Connecting Soil to the Cloud: A Wireless Underground Sensor Network Testbed," demo presentation in IEEE SECON '12, Seoul, Korea, June, 2012.

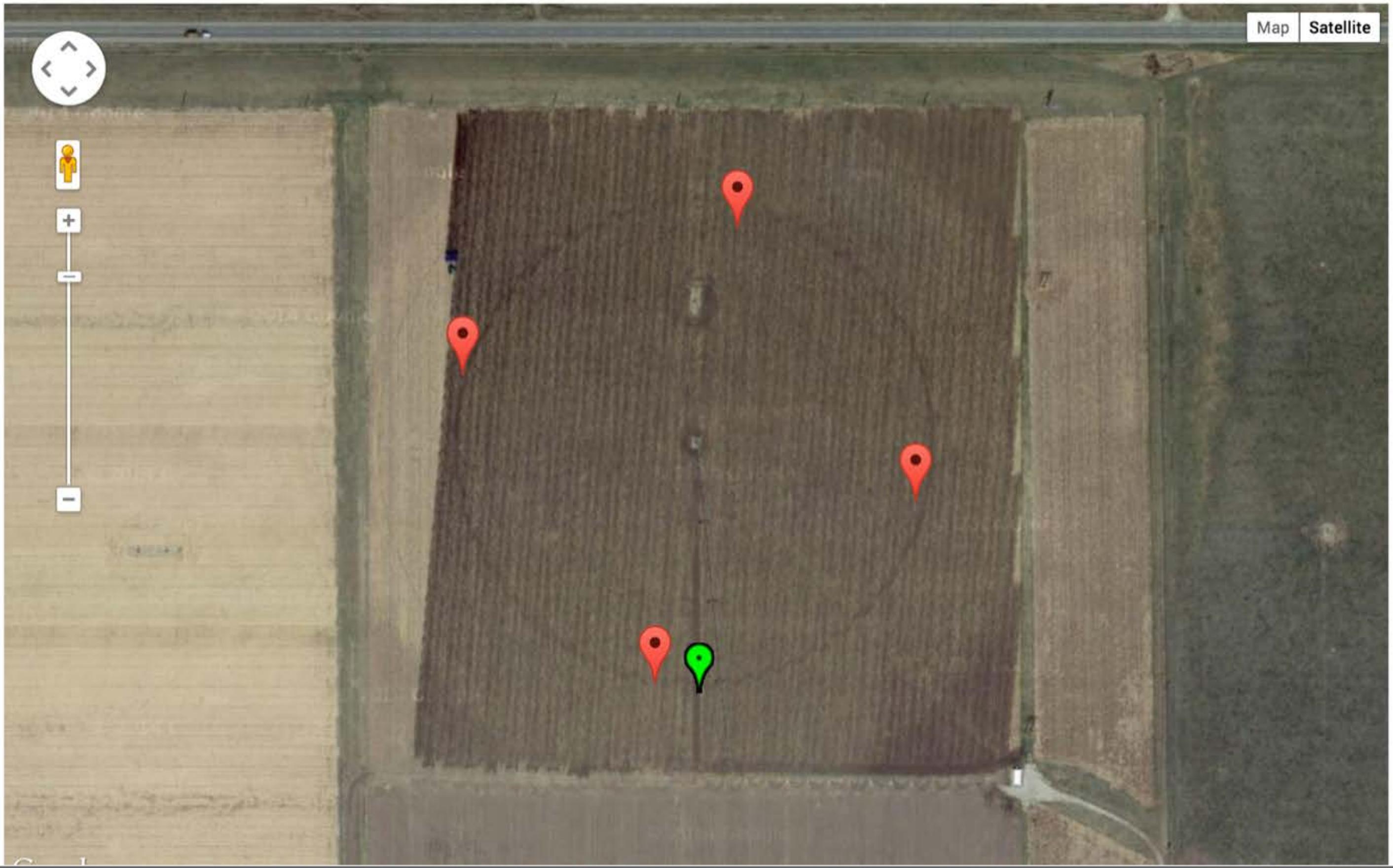
2011-2013 Deployments

CPN WUSN Viewer GPS View Data View

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.

Node 1: East Node 2: North Node 3: West Node 4: South



2014 Deployment

2014 Deployment

CPN WUSN Viewer   GPS View   Data View

Agriculture 2.0

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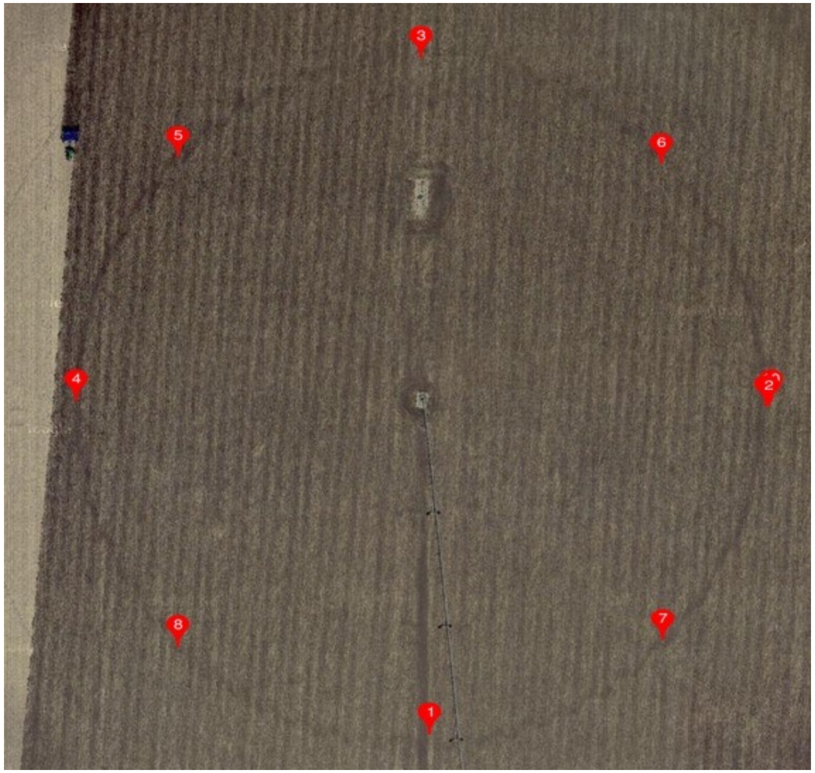
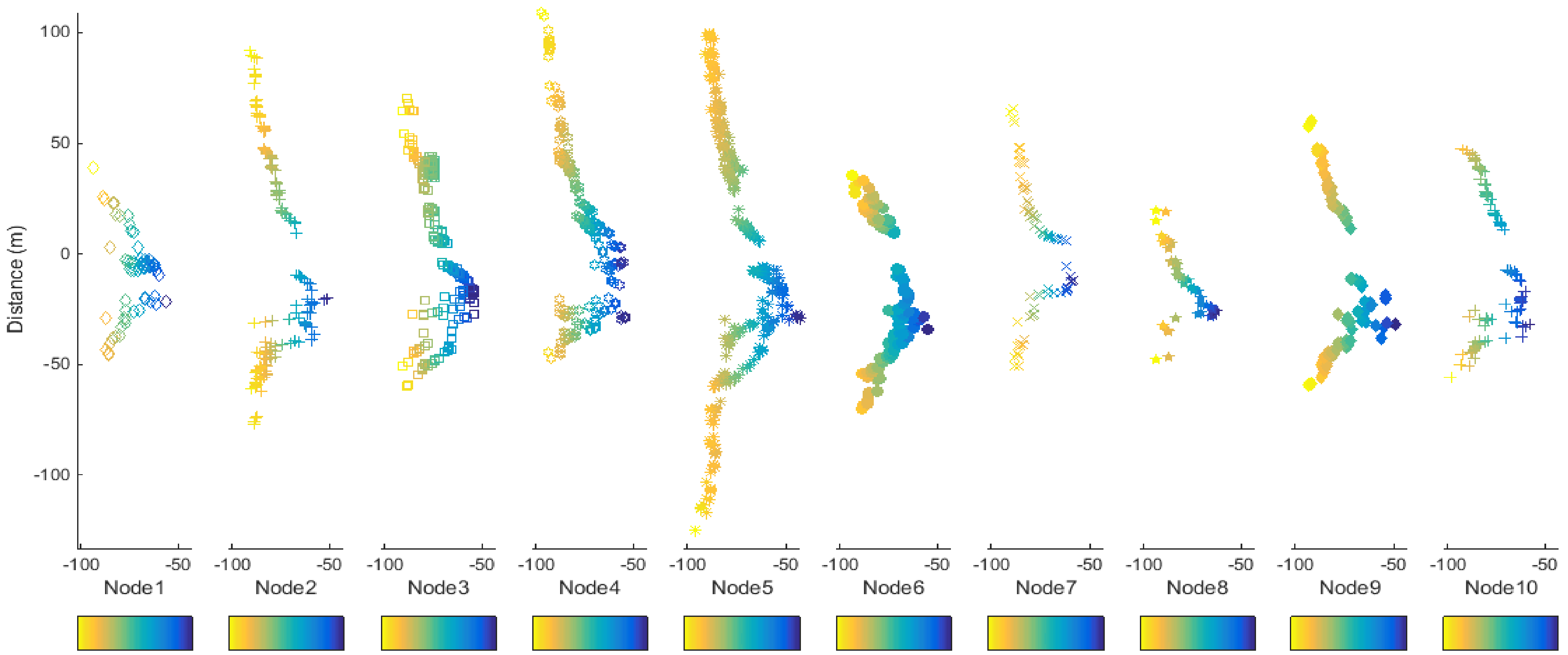
2015 Deployment

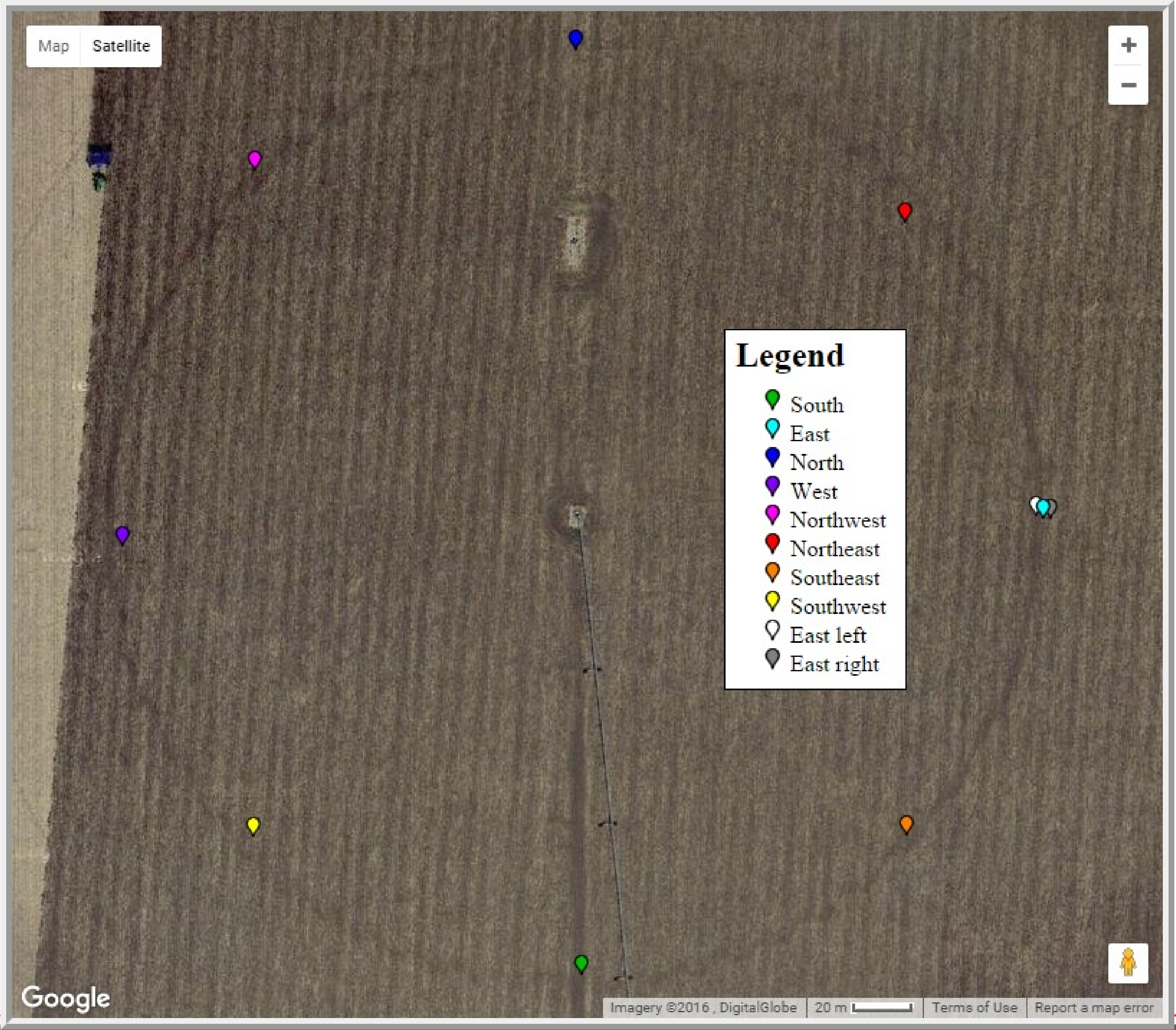
2015 Deployment



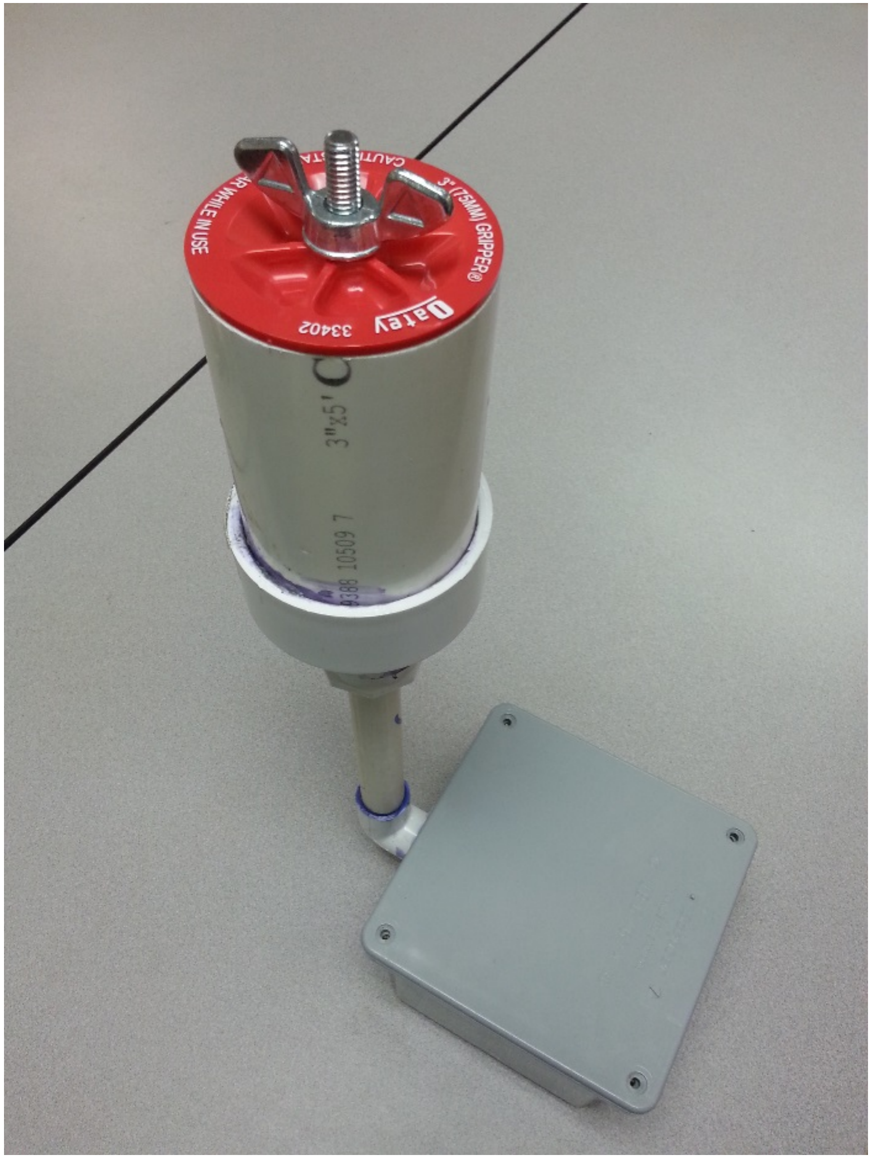
2015 Deployment



2016 Deployment



2016 Deployment - UG Node

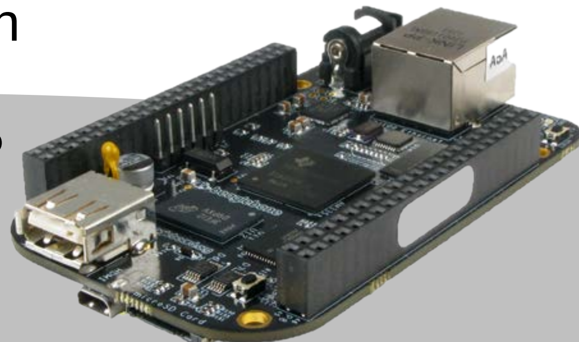


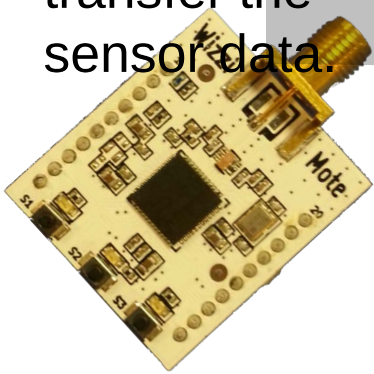
2016 Deployment - AG Node

- 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

- Long-range communication allow us to send an HTTP request to transfer the sensor data.





- A web application hosted on a server or the cloud trigger Selenium.

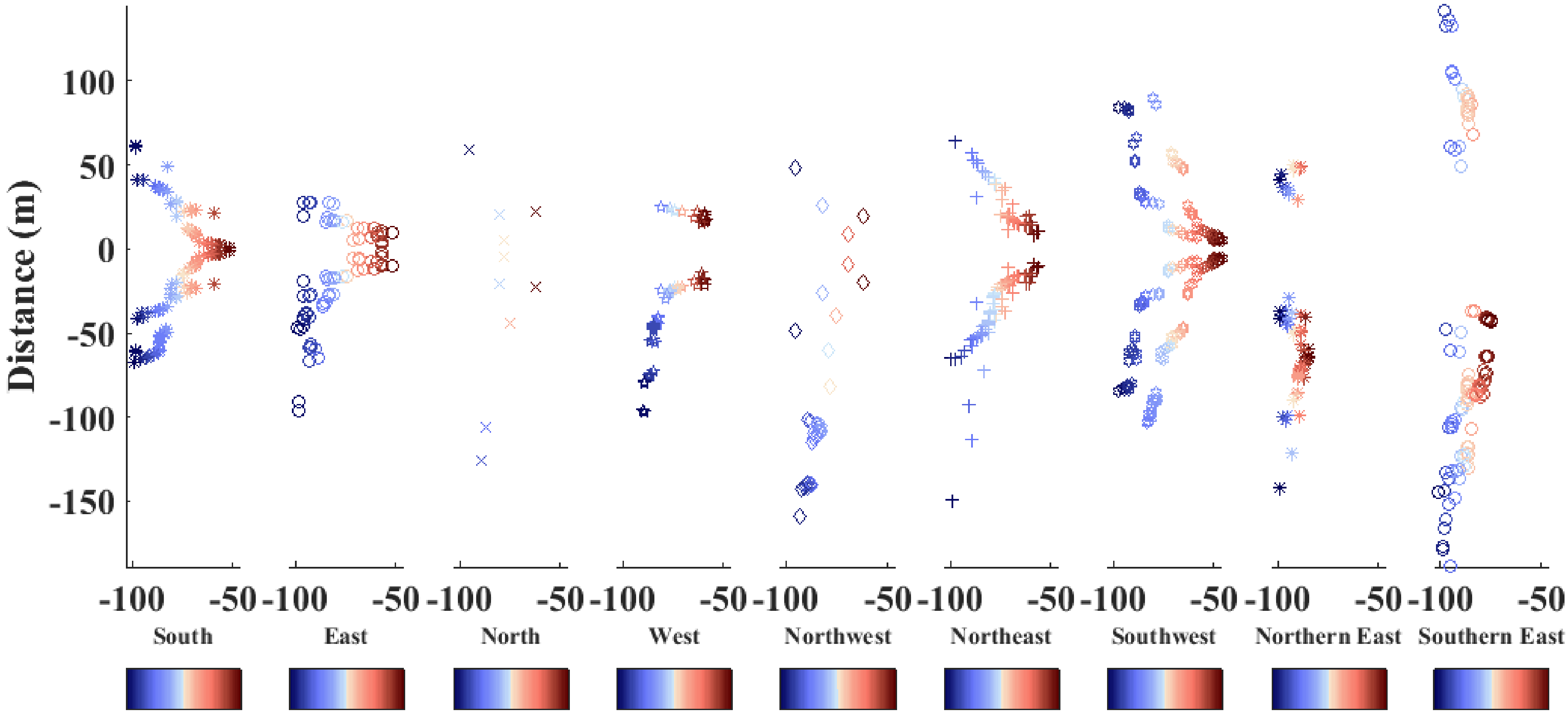
GlassFish

- With Selenium, commands can be issued to control the pivot.
- Information can also be extracted from web pages like GPS coordinates.

- Selenium can be used to control the most popular web browsers or a headless browser.

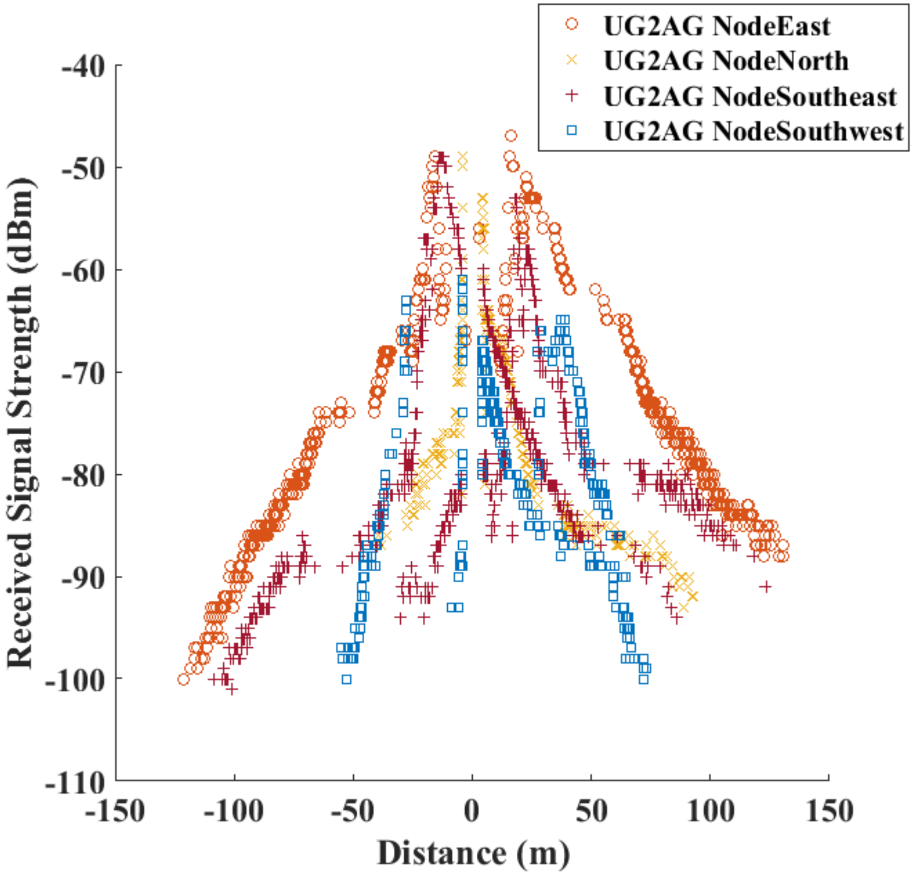
- PrecisionLink is connected to Precision Point Control III, which is used to control the pivot.

Communication Range

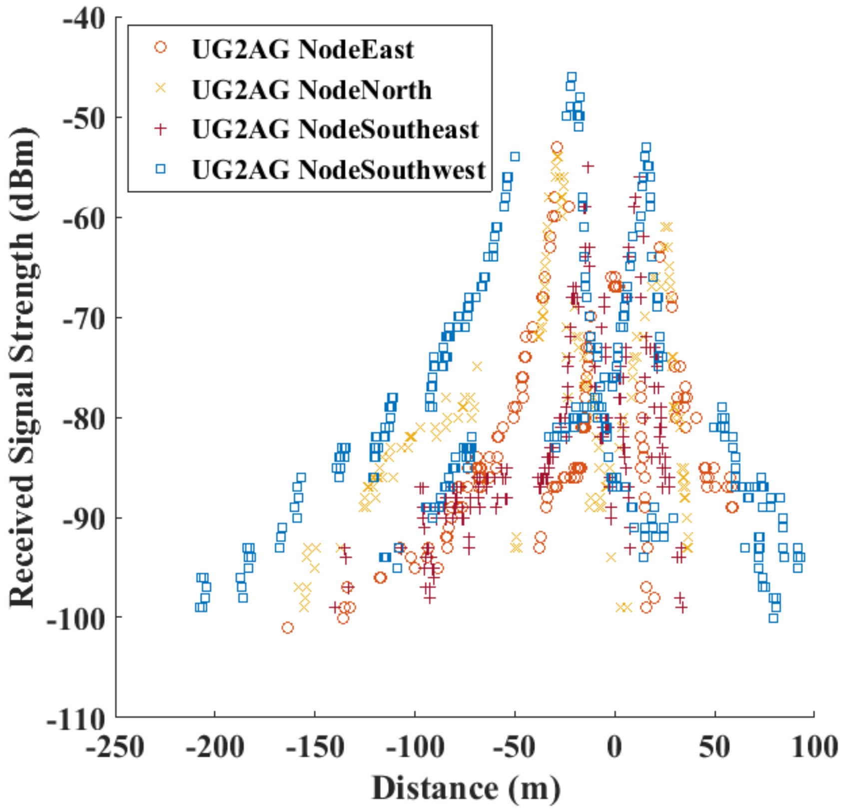


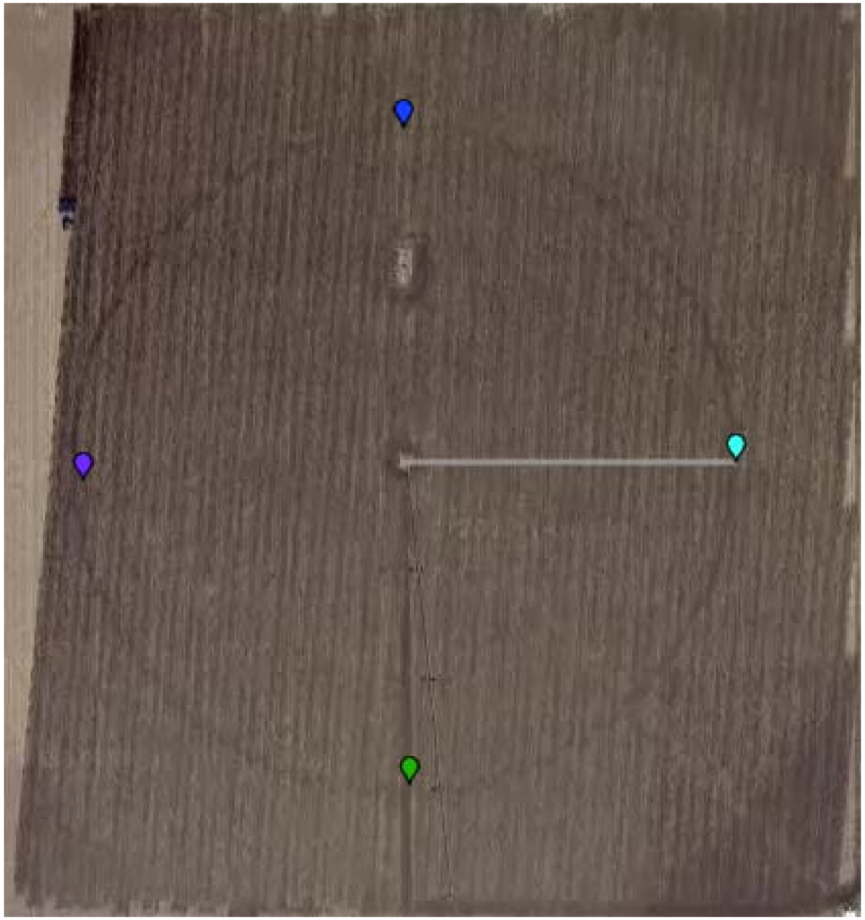
Communication Range

October 28, 2015

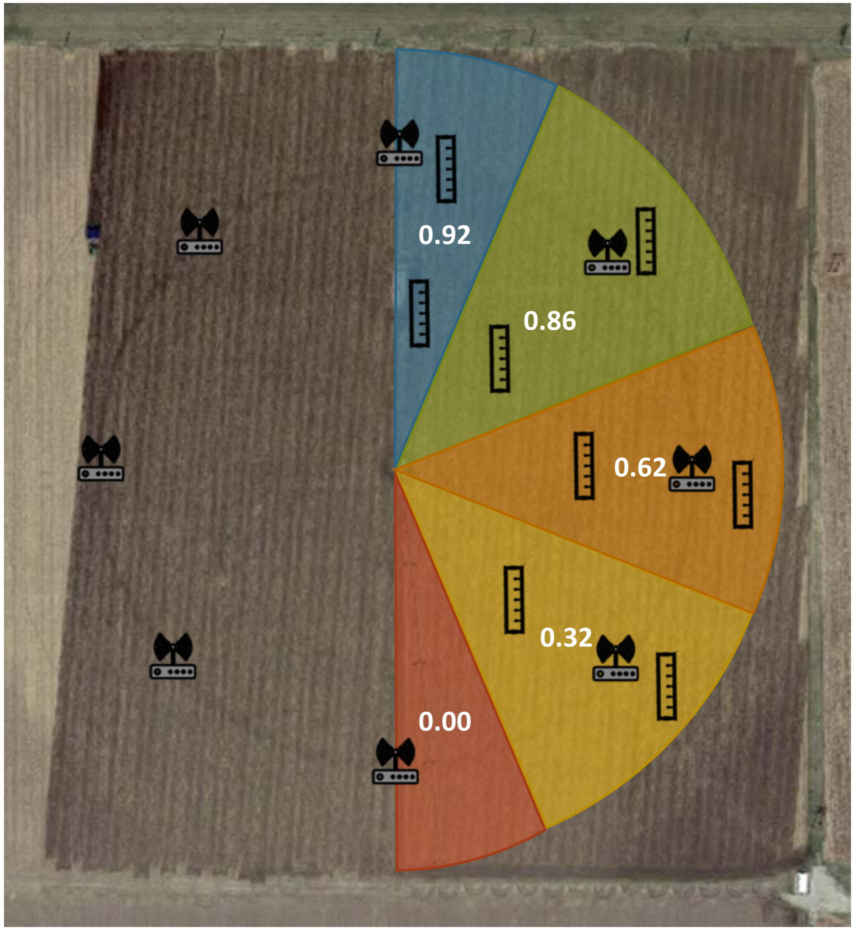


October 18, 2016





Controls System Experiment Setup



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

Water for Food
Robert B. Daugherty Institute
at the University of Nebraska

NSF

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Questions

THANKS

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