Enabling Field-Level Connectivity in Rural Digital Agriculture with Cloud-Based LoRaWAN

Joshua K. Bailey, Yaguang Zhang, Andrew Balmos, Fabio A. Castiblanco, Jingwen Zhang, Dennis Buckmaster, James Krogmeier, and Mark G. Allen

International Conference for Precision Agriculture, 7/23/24

Abstract #10784

PURDUE UNIVERSITY®

Introduction

- Digital agriculture has the potential to connect farmers to the land through data
- Farming is becoming more expensive, making it more important than ever for farmers to analyze each decision daily
- This requires reliable data across operations
- Internet of Things (IoT) can help achieve this by providing site-specific, real-time data
  - e.g., soil sensors, weather stations, livestock monitoring systems, GPS trackers, fuel monitors, energy meters, storage metrics, smart irrigation valves, automated feeders
- There are several challenges to widespread adoption, however, with connectivity being a major issue
- Low-cost, field-level connectivity at scale is essential and must be accessible in a variety of environments and regions

Objectives

1. Explain principles of LoRaWAN as a connectivity solution and the benefits for sensing in agricultural production systems.
2. Provide hardware design plans for remote LoRaWAN applications.
3. Propose a cost-effective open-source software stack enabling data flow and insights.
4. Illustrate case studies for LoRaWAN applications deployed in orchards and fields.

PURDUE UNIVERSITY®

Objectives

1. Explain principles of LoRaWAN as a connectivity solution and the benefits for sensing in agricultural production systems.
2. Provide hardware design plans for remote LoRaWAN applications.
3. Propose a cost-effective open-source software stack enabling data flow and insights.
4. Illustrate case studies for LoRaWAN applications deployed in orchards and fields.

PURDUE UNIVERSITY®

LoRa (Long Range)

- Spread spectrum modulation technique developed by Semtech utilizing chirp spread spectrum (CSS) technology
- Constitutes the device layer and physical layer responsible for modulating data collected (i.e., from a sensor), converting it to digital (RF) signals, and transmitting the data to a central point or gateway
- As a Low Power Wide Area Network (LPWAN) technology, some key features include its low-power consumption and long-distance connectivity (up to 10 km), albeit at a reduced data rate

Comparison of six wireless connectivity options	Cellular	Wi-Fi	Cat-M1	NB-IoT	Bluetooth	LoRa
Range	Long	Short	Medium	Long	Very Short	Long
Power (Battery usage)	High	High	Medium	Medium	Low	Low
Capacity (Devices per gateway)	Medium	Medium	High	High	Medium	Low
Cost	High	Low	Medium	Medium	Low	Low
Data Rate	Very High	Very High	Medium	Low	Low	Very Low

LoRaWAN (Long Range Wide Area Network)

- Developed by the LoRa Alliance to increase capacity
- Communication protocol built on top of the LoRa physical layer specifically for IoT applications
- Good selection for many agricultural settings:
  - Covers vast amounts of land
  - Can potentially connect thousands of sensors per gateway
  - Tradeoff of lower data rate for lower power end devices means LoRaWAN sensors can achieve long lifespans
- Operates in the unlicensed radio spectrum enabling LoRaWAN gateways to be deployed as a private network
- Costs to operate LoRaWAN are on the same order of magnitude as other unlicensed networks (e.g. WiFi)
- The LoRaWAN protocol connects sensors to gateways, then to cloud or edge devices, and finally to applications (focus of this work is gateways to cloud or edge devices)

Objectives

1. Explain principles of LoRaWAN as a connectivity solution and the benefits for sensing in agricultural production systems.
2. **Provide hardware** design plans **for remote LoRaWAN applications.**
3. Propose a cost-effective open-source software stack enabling data flow and insights.
4. Illustrate case studies for LoRaWAN applications deployed in orchards and fields.

PURDUE UNIVERSITY

LoRaWAN Hardware for Cloud-Based Systems

- Goal is to efficiently provide data on the go for modern farming operations
- Advantages of cloud-based systems:
  - Reduce the risk of both physical and cyber vulnerabilities, which can cause the loss of important historical data and network configuration settings
  - Less hands-on requirements with automated backups and easier maintenance (i.e., server hardware doesn't become outdated/run out of storage)
  - Flexible cost structures where the user only needs to pay for the amount of resources they use
- The following subsections detail reference hardware design plans for cloud-based LoRaWAN infrastructure that take advantage of existing farm resources:

Internet Service-Connected	Cellular-Connected	Low Orbit Satellite Internet-Connected	Hybrid Approach
Existing Internet service is accessible, e.g., home, office, shop	Pre-existing Internet is not an option but cellular coverage is available	Traditional internet access methods such as cable, fiber, or cellular are not readily available	More than one of these hardware design plans is needed

Internet Service-Connected LoRaWAN Gateways

Existing Internet service is accessible, e.g., home, office, shop

- LoRaWAN gateways can be connected to the Wi-Fi source either direct connect to an ethernet source or wireless via Wi-Fi
- Gateway is placed inside with the antenna outside, mounted on an accessible area
- 10 ft cable length or less is ideal
- If a metal roof is present, the antenna should be mounted two times the antenna height
- Consulting with a local contractor could be beneficial

PURDUE UNIVERSITY

Internet Service-Connected LoRaWAN Gateway Costs (North America)

Manufacturer	Component	Description	Approximate Cost
RAKwireless	LoRaWAN Gateway	Channel: 8 Channels, LTE: With LTE Cat4 (EG95-NA) for North America, Frequency: US915	$372.00
RAKwireless	8dBi Antenna	Connector Type: N-Type Male, Frequency: 900-930MHz	$60.00
PackYard	Sealing Tape	0.8mm Thickness	$12.98
MOOKEERF	Antenna Cable	10FT	$17.99
MOOKEERF	Lightning Arrester	N-Type Male to N-Type Female	$16.99
MAXLIN CABLE	Fence Post	50FT (can be more or less)	$24.99
Vabogu	Tripod	1.5FT (can be more or less)	$3.99
		Total	**$508.94**

PURDUE UNIVERSITY

Cellular-Connected LoRaWAN Gateways

Pre-existing Internet is not an option but cellular coverage is available

- LoRaWAN gateways can be connected via a data plan (such as those offered by SixFab)
- In applications where PoE can't be used, we configured and deployed Solar Powered IoT4Ag Network Gateways (SPRINGs)
- RAKwireless solar panel and battery kit are good options as they're not solely used for backup power
- SPRINGs are mobile, enabling
  - Data collection during most important times of the year (e.g., planting, growing, harvesting)
  - The ability to protect equipment in others (e.g., winter)

Cellular-Connected LoRaWAN Gateway Costs (United States)

Manufacturer	Component	Description	Approximate Cost
RAKwireless	LoRaWAN Gateway	Channel: 8 Channels, LTE: With LTE Cat4 (EG95-NA) for North America, Frequency: US915	$402.00
RAKwireless	8dBi Antenna	Connector Type: N-Type Male, Frequency: 900-930MHz	$60.00
National Hardware	U-Bolt (2)	5/16" x 2" x 3-1/4" Zinc	$3.00
PackYard	Sealing Tape	0.8mm Thickness	$12.98
MOOKEERF	Antenna Cable	6FT	$15.99
RAKwireless	RAK Battery Plus	Variant: RAK Battery Plus & Solar Panel Kit, Country: United States	$817.00
YardGard	Fence Post	Steel Chain Link Fence Post, 8’ H 1-5/8” W	$26.99
WiMo	Tripod	Mast Tripod, 7FT Spread	$279.99
WiMo	Tripod Feet	Tripod Foot Plates	$89.99
American Earth Anchors	Tripod Anchor (3)	9-inch Penetrator	$21.51
American Ground Screw Mfg & Supply Store	Ground Screw	22” Ground Anchor	$39.99
		Total	**$1,769.44**

PURDUE UNIVERSITY

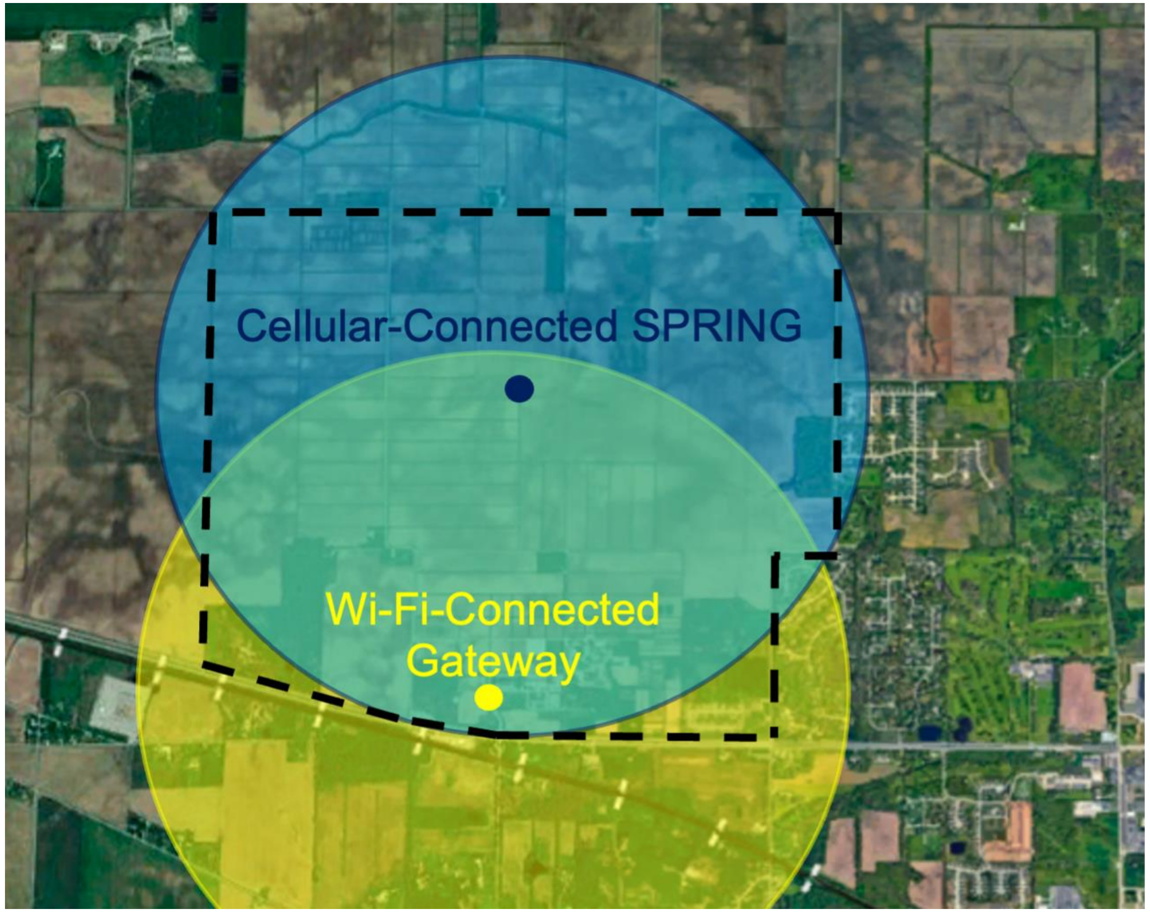
Low Orbit Satellite Internet-Connected Solutions

Traditional internet access methods such as cable, fiber, or cellular are not readily available

- Emerging satellite communication technology exemplified by the low orbit satellite connections offered by Starlink can provide backhaul communication
- A variety of wireless communication technologies, including Wi-Fi, private 5G, and LoRa/LoRaWAN can be deployed to establish a local area network managed by farmers, thereby facilitating field-level connectivity

Hybrid Approach

More than one of these hardware design plans are needed



- What if…
  - A farm has a gateway connected to a Wi-Fi router, but the signal is unable to reach beyond a forest line to further acreage?
  - A farm has multiple locations, some with cellular coverage and some without?
- A scalable and cost-effective combination of the three hardware design plans can be used, considering accessibility and LoRaWAN coverage distance
- Simple range testing can be conducted to evaluate LoRaWAN coverage distance
  - e.g., moving sensors further from gateways and monitoring SNR and RSSI

PURDUE UNIVERSITY

Hardware Resiliency and Risk Considerations

- Scenarios that can affect system stability and methods for preventing and/or dealing with them:
  - **Loss of power to gateway:** A backup power supply, such as a generator, can be used until the power source is restored or replaced.
  - **Loss of Internet service:** Specific to the Internet-connected gateway design plan, a gateway with LTE can be purchased instead
  - **Gateway and/or antenna damage:** Hold a backup gateway, antenna, and cabling to allow for swift replacement
- The nature of LoRaWAN itself provides robustness for upholding communication even when facing challenging scenarios:
  - LoRa-based sensors “blindly” broadcast messages, and all gateways within range will receive them for processing
  - Sensor data can continue to be received once the issue is fixed without having to reconfigure each individual sensor
  - Sensors within range of other gateways will also collect the broadcasted message, providing resiliency against any particular gateway failing

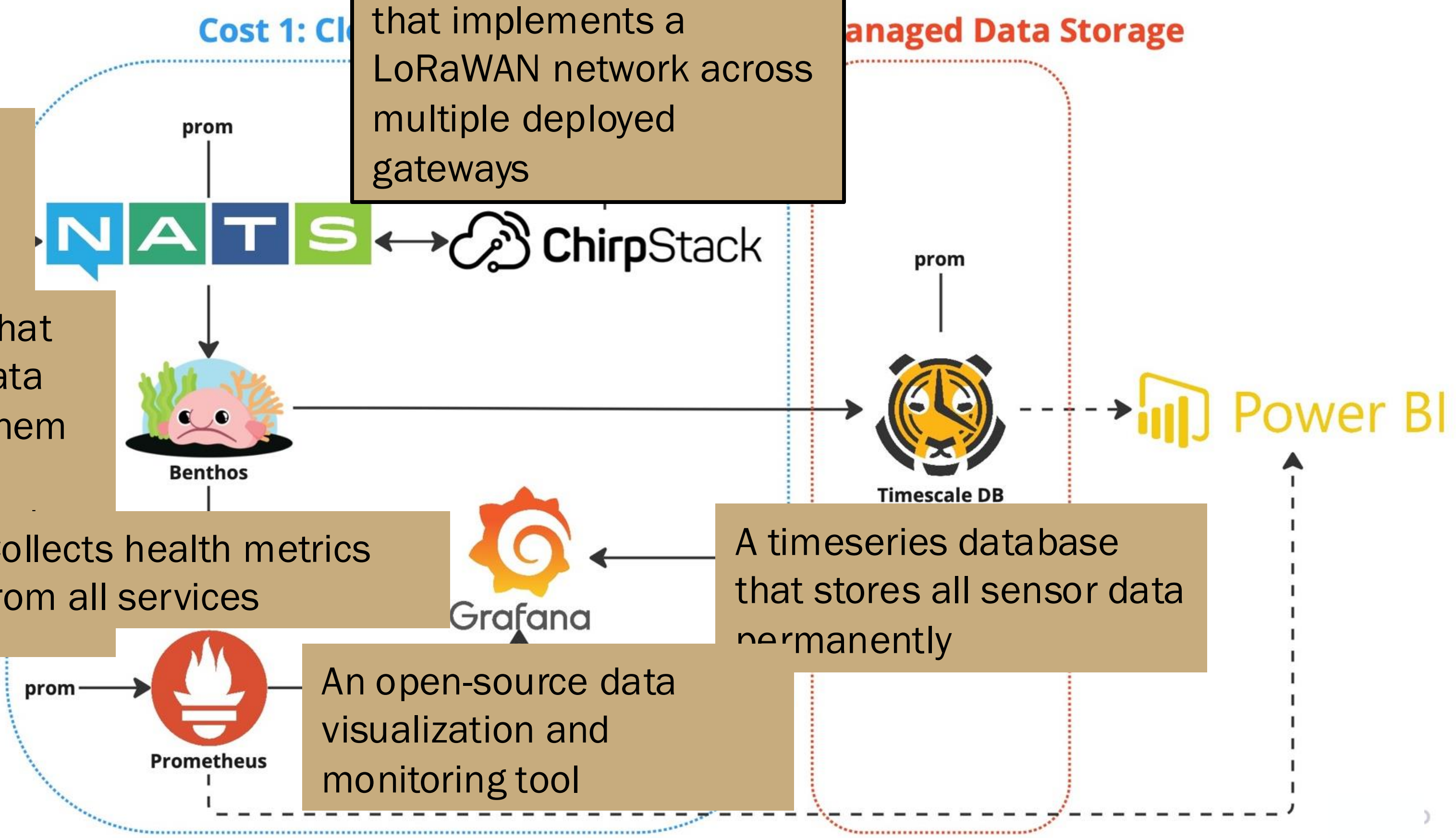
Objectives

1. Explain principles of LoRaWAN as a connectivity solution and the benefits for sensing in agricultural production systems.
2. Provide hardware design plans for remote LoRaWAN applications.
3. **Propose a cost-effective open-source software stack enabling data flow and insights.**
4. Illustrate case studies for LoRaWAN applications deployed in orchards and fields.

PURDUE UNIVERSITY®

Software Stack for Efficient Data Flow

Avena: An open-source software framework



An open-source LoRaWAN gateway network server that implements a LoRaWAN network across multiple deployed gateways

A messaging system that implements interest-based communications between software serv

A system integrator that transforms sensor data streams, preparing them for storage, applying calibration factors, any other processi required

Collects health metrics from all services

A timeseries database that stores all sensor data permanently

An open-source data visualization and monitoring tool

PURDUE UNIVERSITY

Software Resiliency and Risk Considerations

Methods for preventing or dealing with software reliability and security issues:

- **Issues with data pipeline components:** Grafana promptly sends alerts allowing for timely action
- **Cyber threats of data sniffing:** In general, all things within the Avena architecture are connected via a WireGuard network, ensuring that all communication is secure
- **Cyber threats to data pipeline components:** Secure passwords should be used and regularly updated for accounts

Objectives

1. Explain principles of LoRaWAN as a connectivity solution and the benefits for sensing in agricultural production systems.
2. Provide hardware design plans for remote LoRaWAN applications.
3. Propose a cost-effective open-source software stack enabling data flow and insights.
4. **Illustrate case studies for LoRaWAN applications deployed in orchards and fields.**

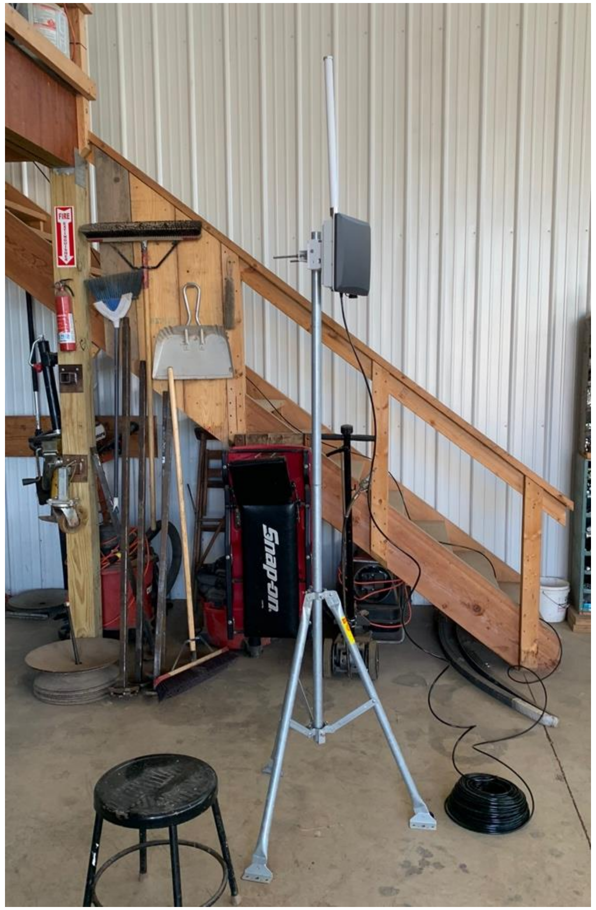
PURDUE UNIVERSITY®

Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage (Summer 2022)

Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage (Summer 2022)

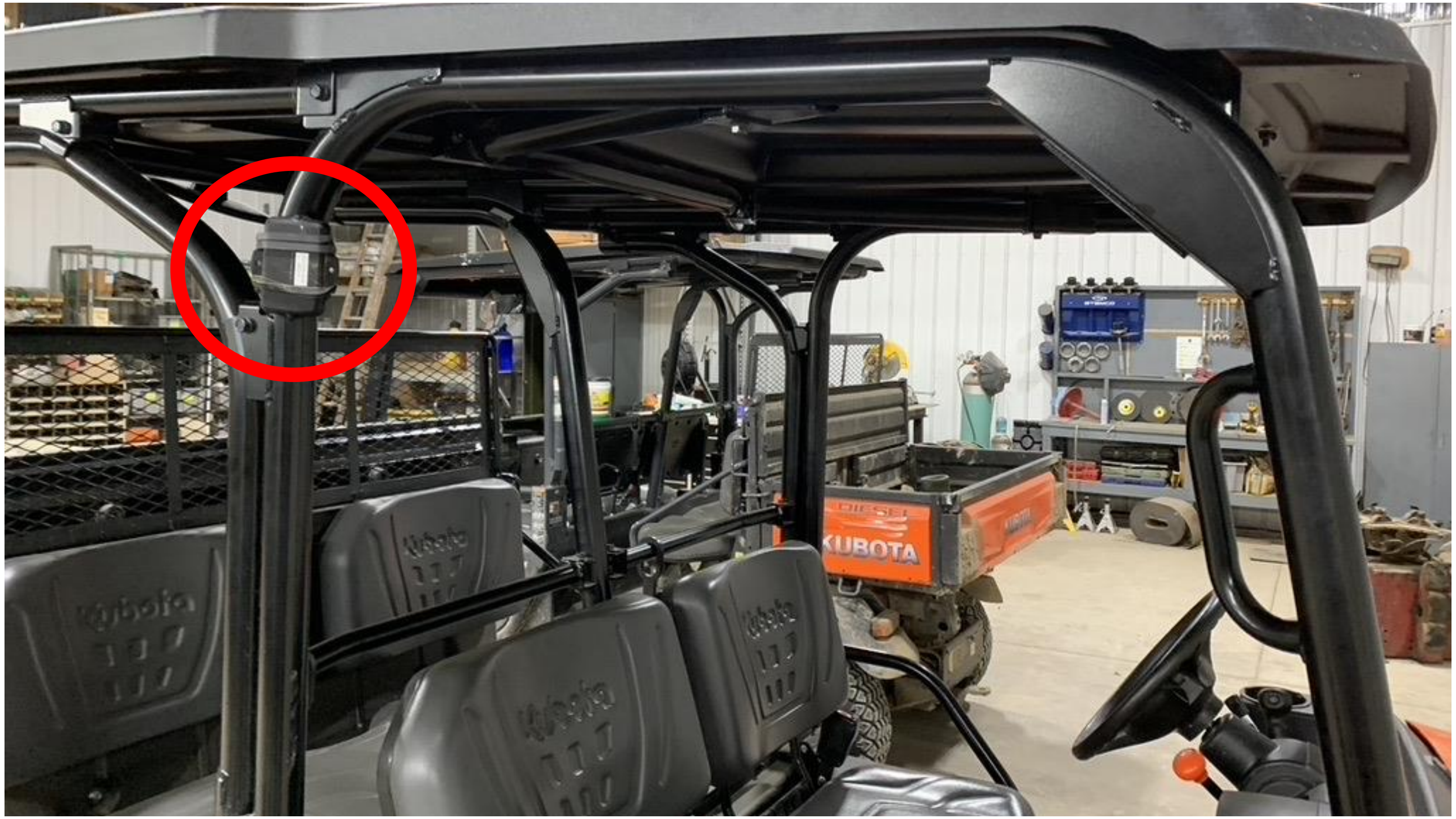


Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage (Summer 2022)

Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage (Summer 2022)



PURDUE UNIVERSITY

Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage (Summer 2022)

PURDUE UNIVERSITY

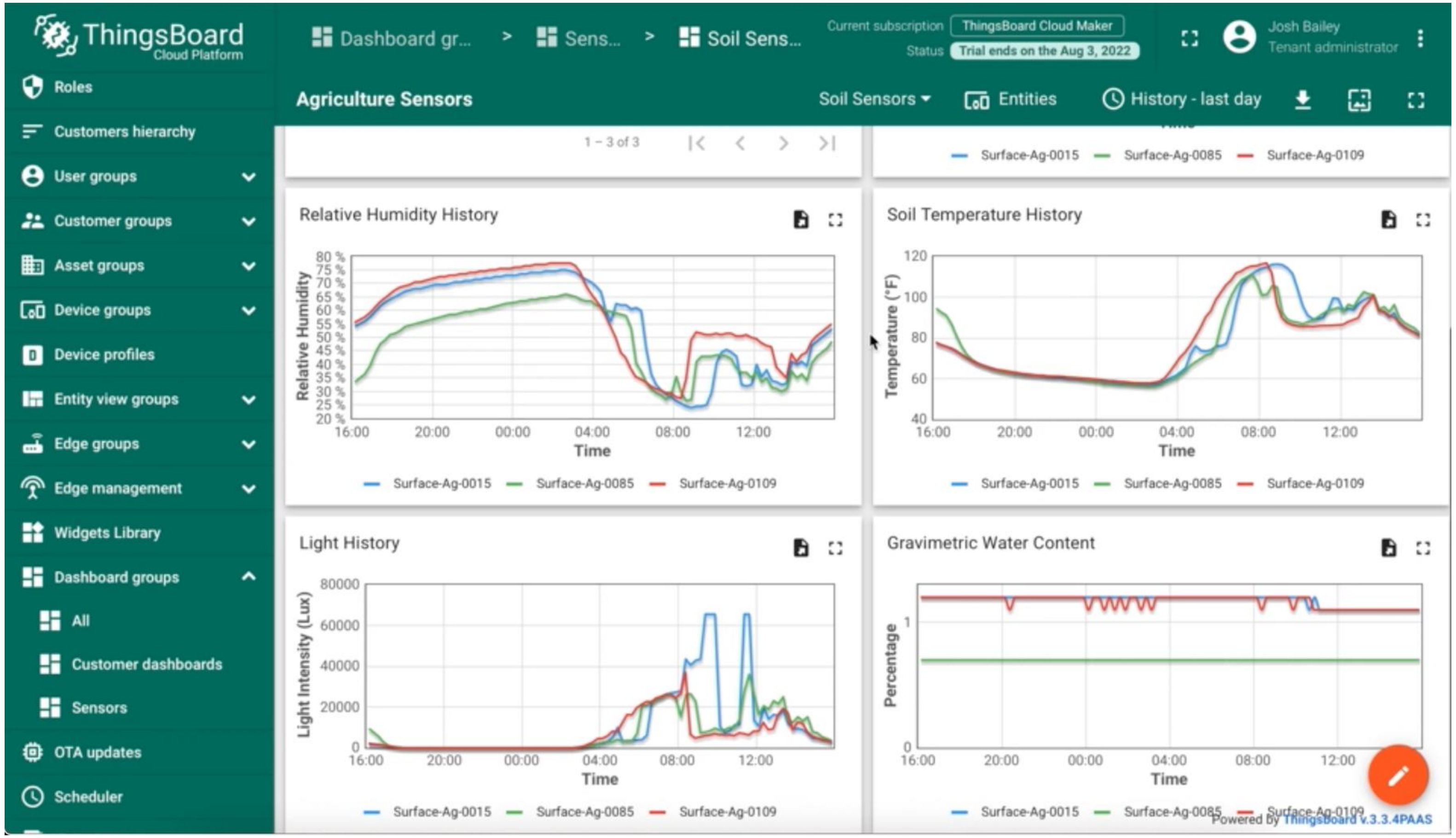
Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage (Summer 2022)

PURDUE UNIVERSITY

Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage (Summer 2022)



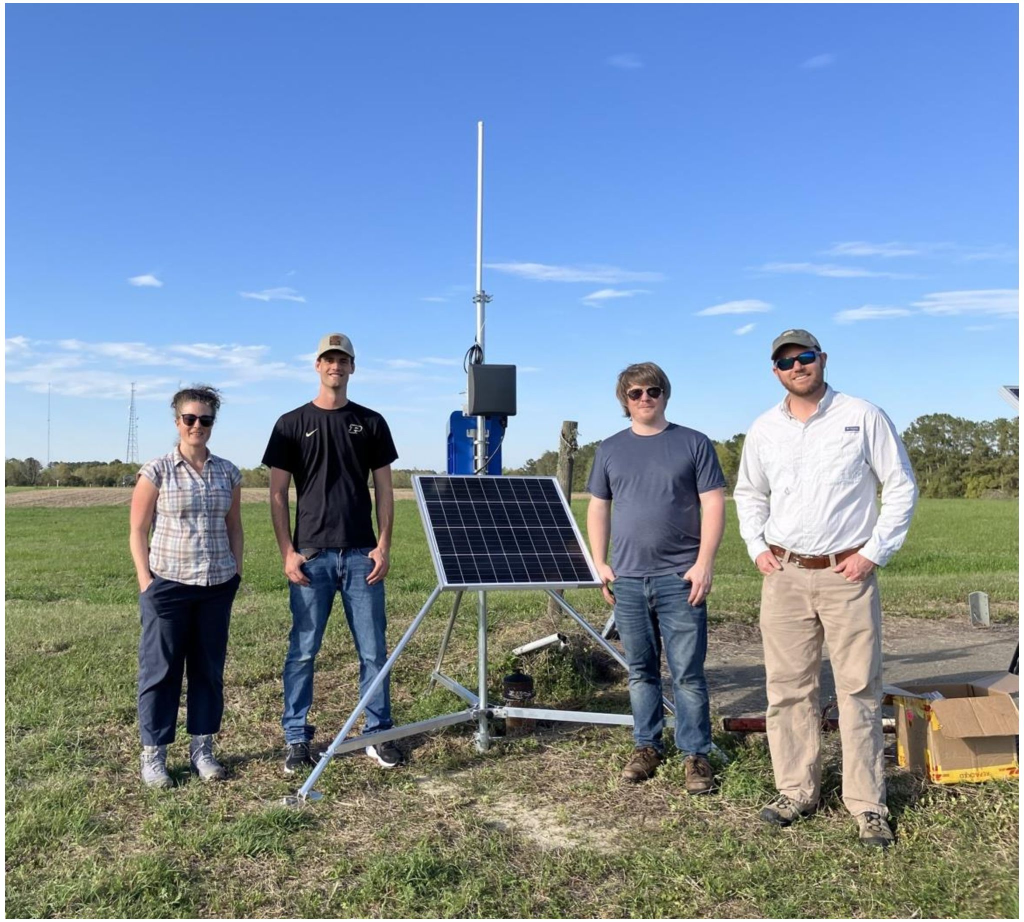
Wi-Fi-Connected LoRaWAN Gateway at Commercial NY Apple Orchard

Purpose: Testing basic LoRaWAN coverage and implementing devices (Summer 2024)

PURDUE UNIVERSITY

Cellular Data-Connected LoRaWAN Gateway at University of Florida Research Farm

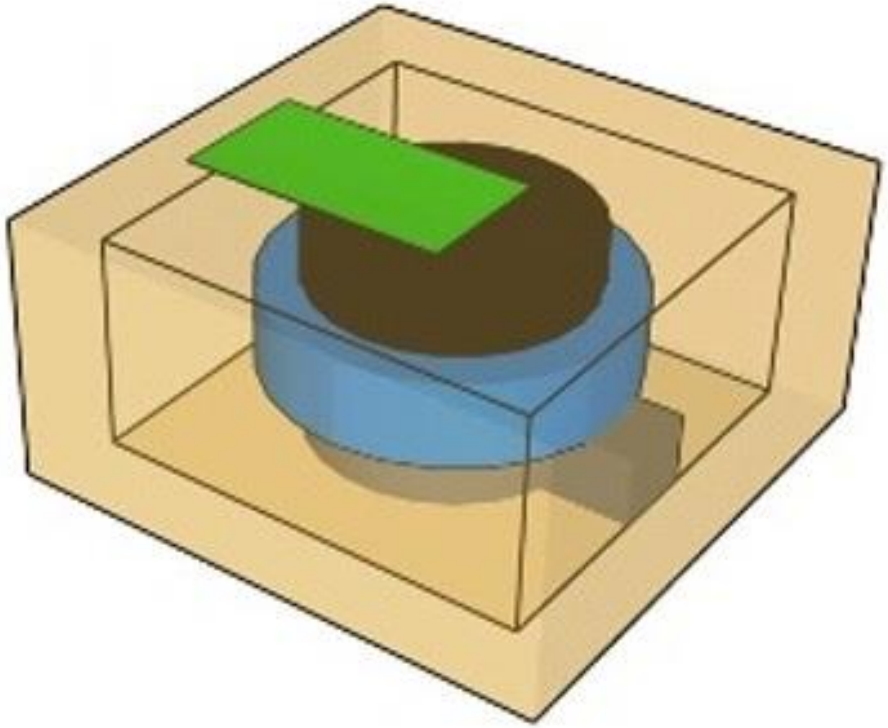
Purpose: Supporting the testing of air batteries as a power source for subsurface sensors



PURDUE UNIVERSITY

Cellular Data-Connected LoRaWAN Gateway at University of Florida Research Farm

Purpose: Supporting the testing of air batteries as a power source for subsurface sensors



(a)

(b)

Future Work

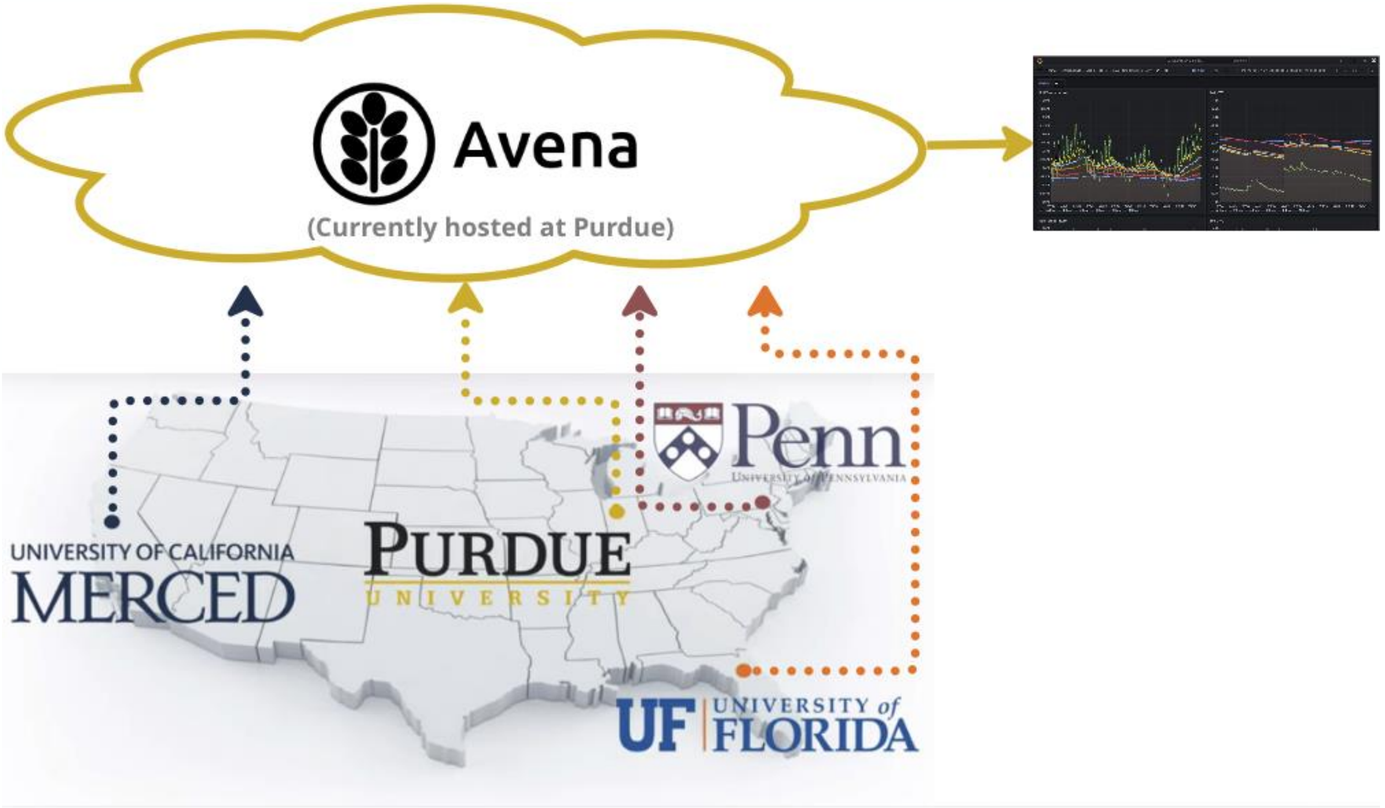
Additional LoRaWAN deployments across IoT4Ag research farms

Creation of extensive build guides for each design plan on GitHub

Design of custom components to support local data storage

Refinement of the dashboards

Integration of artificial intelligence for interpreting the work



Thank You

Acknowledgements

This work was supported in part by the NSF-funded IoT4Ag project (EEC-1941529). Partners are University of Pennsylvania, University of Florida, University of California – Merced, and University of Arizona.

This material is based upon work supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, through the Northeast Sustainable Agriculture Research and Education program under subaward number FNE23-034.

Thank you to Ian Small and Rebecca Barocco for assisting with deploying and testing of the SPRING modules at Quincy and Live Oak, Florida.

PURDUE UNIVERSITY®