

The following are the presentation slides presented by Joshua K. Bailey on 4/17/25 for the first half of the master's thesis defense titled IoT and Generative AI for Enhanced Data-Driven Agriculture

Cloud-Based LoRaWAN for IoT in Agriculture

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Content in this chapter is to be submitted for review for publication in ASABE Applied Engineering in Agriculture



Introduction

- Internet of Things (IoT) can provide site-specific, real-time data across operations
 - 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

Wireless Connectivity Options

	Zigbee	ANT	Sigfox	HaLow	TV White Space	NB-IoT	LTE-M	LoRa/LoRa WAN
Range	Up to 100 m	Up to 30 m	Up to 40 km	Up to 1 km	Up to 10 km	Up to 15 km	Up to 15 km	Up to 20 km
Data rate	Up to 250 kbps	Up to 20 kbps	Up to 100 bps	Up to 15 Mbps	Up to 16 Mbps ^a	Up to 200 kbps	Up to 1 Mbps	Up to 50 kbps
Power consumption^b	Low	Low	Ultra-low	Moderate	Moderate	Moderate	Moderate	Ultra-low
Network architecture^c	Private networks	Private networks	Public networks	Private and public networks	Private and public networks	Public networks	Private and public networks	Private and public networks
License	Unlicensed (ISM)	Unlicensed (ISM)	Unlicensed (ISM)	Unlicensed (ISM)	Unlicensed ^d	Licensed	Licensed	Unlicensed (ISM)
Hardware cost^e	Low	Low	Low	Moderate	Moderate	High	High	Low
Scalability^f	Moderate (with mesh)	Low	Low	Moderate	Moderate	High	High	High (LoRaWAN)

^a TV white spaces can use multiple channels which allow for up to 16 Mbps per channel

^b Typical maximum transmit power at the node side, can vary based on frequency of data

^c Most common methods for given network deployments

^d Conditional use of the licensed TV band based on FCC Part 15 Rules for Unlicensed White Space Devices

^e Cost of required user owned equipment plus any required access/subscription fees

^f Relative ability for the network to grow in size to support additional nodes and/or additional range

Objectives

1. Provide sample gateway hardware configurations for remote LoRaWAN applications.
2. Propose a cost-effective open-source software stack enabling data flow and insights.
3. Present case studies for LoRaWAN applications in orchards and fields.
4. Provide a cost evaluation framework for proposed hardware and software.

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LoRaWAN Hardware for Cloud-Based Systems

- Goal is to efficiently provide data on the go for modern farming operations
- Advantages of cloud-based systems:
 - Protect against data loss from physical or cyber incidents
 - Enable automated backups for easier maintenance
 - Offer flexible, pay-as-you-go pricing that scales with actual usage
- 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	Hybrid Approach
Existing internet service is accessible, e.g., home, office, shop	Pre-existing internet is not an option but cellular coverage is 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

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	Long Ethernet Cable	50FT (can be more or less)	\$16.79
Vabogu	Short Ethernet Cable	1.5FT (can be more or less)	\$3.99
		Total	\$500.74

Cellular-Connected LoRaWAN Gateways

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



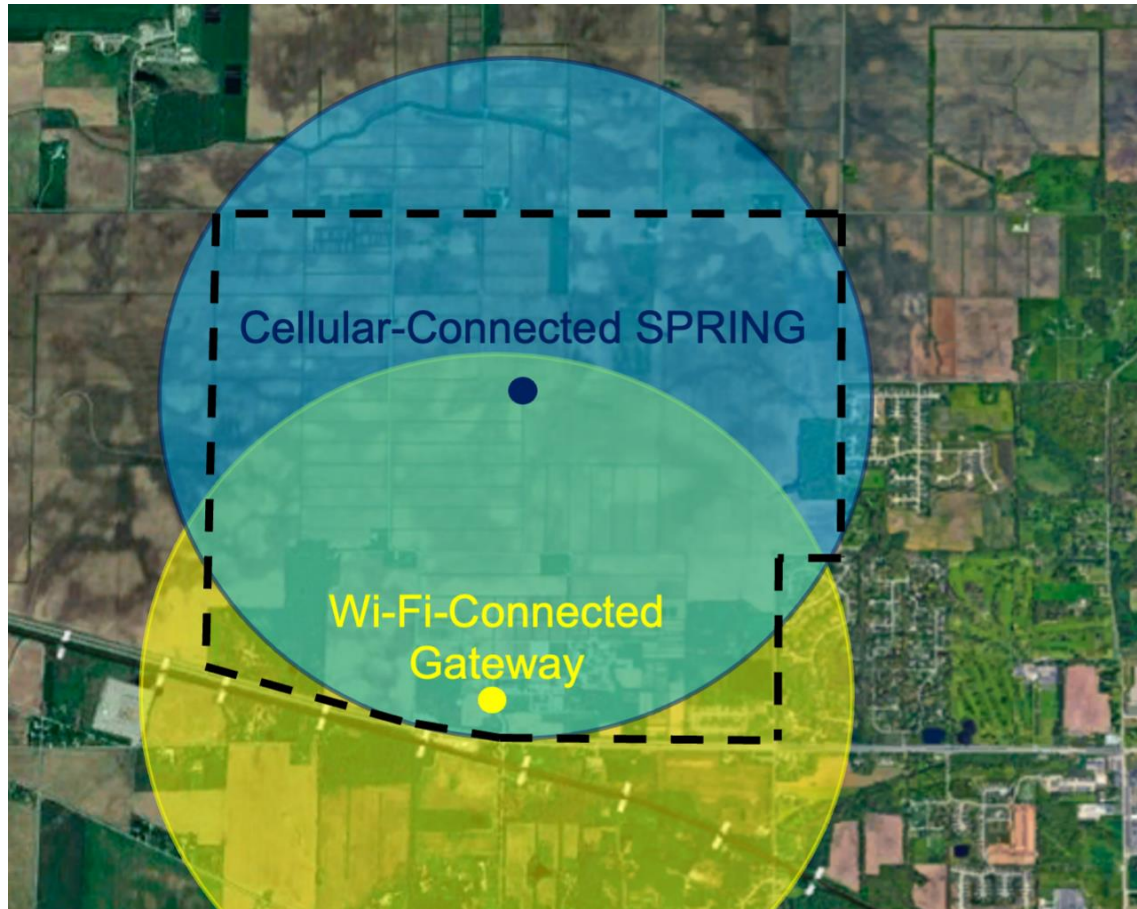
- LoRaWAN gateways can be connected via a data plan (such as those offered by SixFab)
- In applications where PoE can't be used, we configured and deployed Solar-Powered IoT4Ag Network Gateways (SPRINGs)
- RAKwireless solar panel and battery kit are good options as they're not solely used for backup 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	\$19.99
WiMo	Tripod	Mast Tripod, 7FT Spread	\$281.99
WiMo	Tripod Feet	Tripod Foot Plates	\$95.99
American Earth Anchors	Tripod Anchor (3)	9-inch Penetrator	\$7.17
American Ground Screw Mfg & Supply Store	Ground Screw	22" Ground Anchor	\$39.99
		Total	\$1,716.11

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 two 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

Hardware Resiliency and Risk Considerations

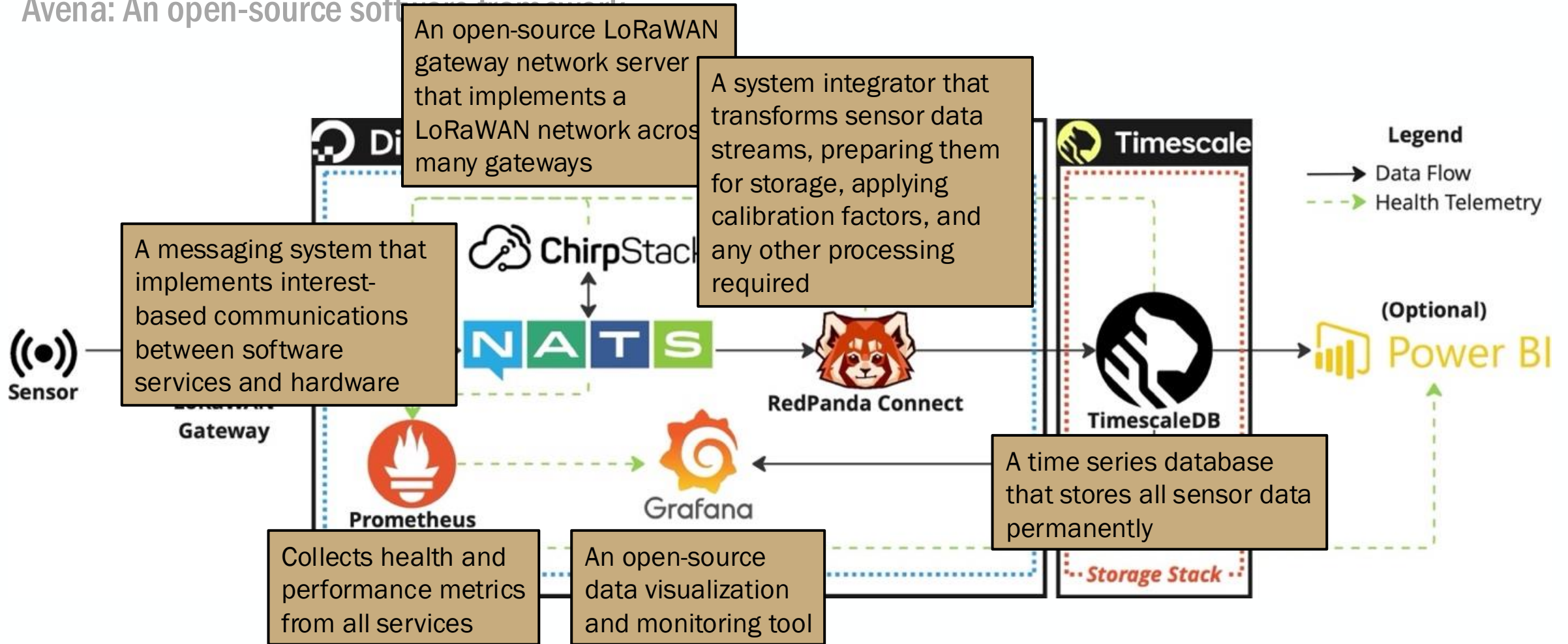
- Scenarios that can affect system stability and methods for preventing and/or dealing with them:
 - **Loss of power to gateway:** A backup power supply can be temporarily used
 - **Loss of internet service:** Specific to the internet-connected gateway design plan, a gateway with LTE can be purchased 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:
 - Deploying overlapping gateways strengthens coverage—failures or interference at one gateway are offset by others in different environments
 - Gateways can de-duplicate messages, reducing redundancy and lowering network load
 - In case of cyber-attacks or outages, gateways can be physically disabled, and manual overrides should be in place for critical automated systems

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Software Stack for Efficient Data Flow

Avena: An open-source software framework



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

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

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



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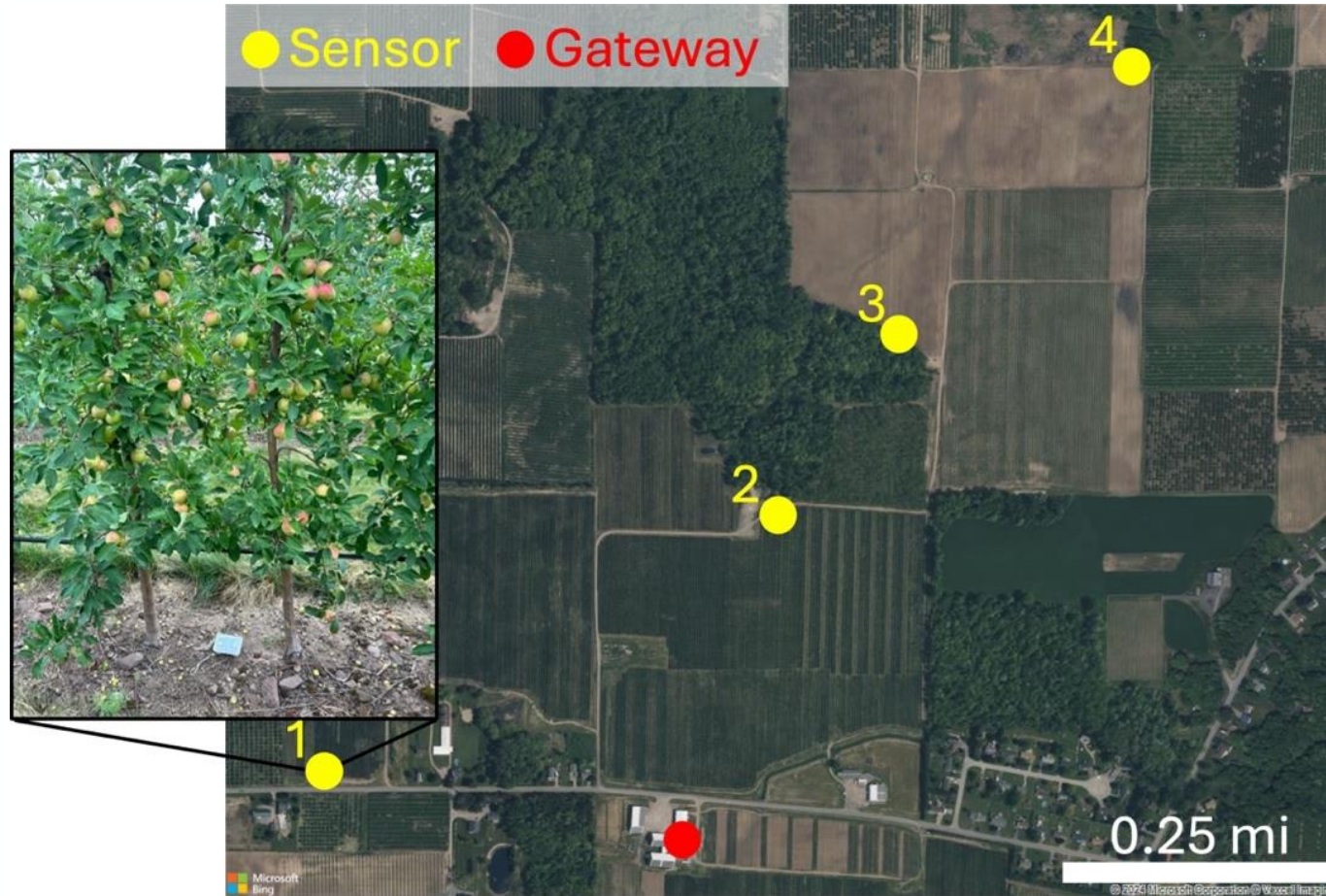
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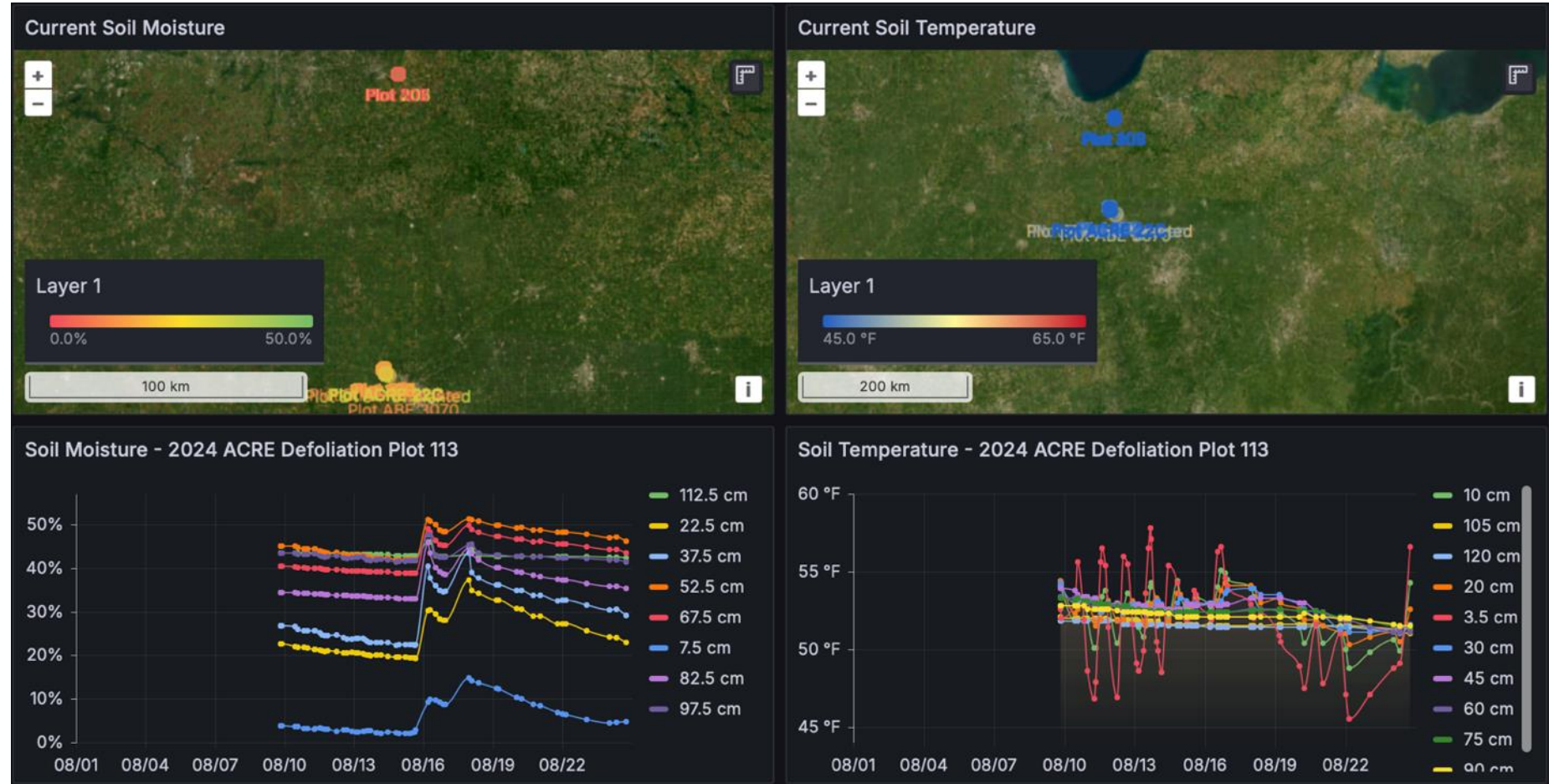
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- Sensor 2
 - Average RSSI: -110.9 dBm
 - Average SNR: -2.795 dB
- Sensor 3
 - Average RSSI: -113.1 dBm
 - Average SNR: -12.65 dB

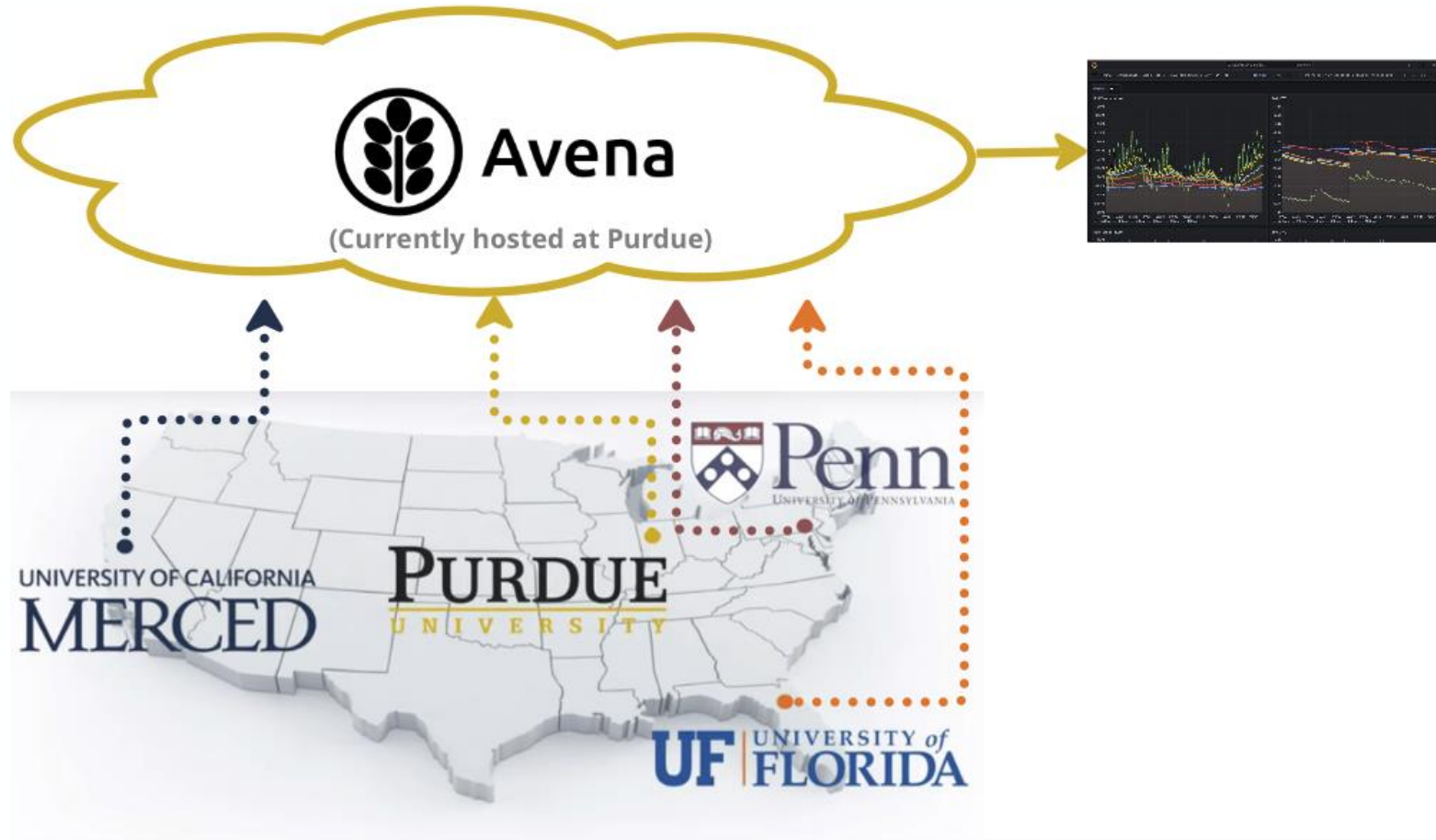
Cellular Data-Connected LoRaWAN Gateway at Purdue ACRE Farm

Purpose: Supporting additional LoRaWAN coverage at Purdue ACRE



SPRINGS for IoT4Ag

Purpose: Research data collection standardization across the IoT4Ag ERC



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Cost Evaluation Framework

Cost plans overview

- Cellular data plan costs (Sixfab):
 - 500MB per month: \$9
 - 2GB per month: \$29
 - Additional plans available for users with large data needs
- Data processing and storage costs:
 - DigitalOcean's Basic Droplets:
 - 512 MiB memory: \$4 per month
 - 1 GiB memory: \$6 per month
 - Timescale offers two main solutions:
 - Performance tier: \$30 per month for Compute, \$0.177 per GB-month for storage (up to 8 CPU and 32 GB memory)
 - Scale tier: \$36 per month for Compute, \$0.212 per GB-month for storage (up to 32 CPU and 128 GB memory)

Cost Evaluation Framework

Data rate per month calculation example assuming thirty-day months

	Device type	Periodic uplinkers	Conditional uplinkers	Periodic uplinking with conditional downlinking	Conditional uplinking with conditional downlinking	
	Example sensor	Soil moisture sensors	GPS trackers	Smart irrigation valves	Smart feeders	
	LoRaWAN class	A	A	B	A	
INPUTS						
ND	Number of devices	100	15	100	100	
UDR	Uplink data rate	85	70	65	68	B/event
UPP	Uplinks per period	4	356400	4	1	
UPU	Uplink period units	hour	month	hour	day	
DDR	Downlink data rate			35	40	B/event
DPP	Downlinks per period			5	1	
DPU	Downlink period units			week	day	
INTERMEDIATE CALCS						
UM	Uplink messages	288000	5346000	288000	3000	per month
DM	Downlink messages			2143	3000	per month
OUTPUT						
UDA	Uplink data amount	23.3	356.9	17.9	0.2	MB/month
DDA	Downlink data amount			0.1	0.1	MB/month
TDA	Total data amount	23.3	356.9	17.9	0.3	MB/month
	Total for all sensors (sum of TDAs)	398				MB/month

Cost Evaluation Framework

Storage cost calculation example at various time intervals

INPUTS						
DA	Data amount	0.40	0.40	0.40	0.40	GB/month
CTF	Cumulative timeframe	12	24	60	120	month(s)
CC	Compute cost	30	30	30	30	\$/month
SC	Storage cost	0.177	0.177	0.177	0.177	\$/GB-month
OUTPUT						
CS	Cumulative storage	31.2	120	732	2904	GB
TC	Total cost	366	741	1930	4114	\$

Conclusions

- Limitations:
 - Lack of implementation assistance for farmers beyond GitHub build guides
 - Requirement for Wi-Fi and/or cellular connectivity to utilize cloud-based LoRaWAN systems
 - High cost of IoT sensors and the need to demonstrate value for full system adoption
- Future improvements:
 - Simplifying guides and updating them with software changes
 - Exploring low-orbit satellite connectivity options as LoRaWAN gateway backhauls
 - Continuing to search for cost-effective reference sensors
 - Emphasizing the economic value that IoT technologies and data bring to farms

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.

