



arawireless.org



ARA: Wireless Living Lab for Smart and Connected Rural Communities

Hongwei Zhang, Daji Qiao, Sarath Babu, Mohamed Selim, Mai Zheng, Yong Guan

Ozdal Boyraz, Anish Arora, Mike Luby et al.

e2@arawireless.org

IOWA STATE
UNIVERSITY

UCI
University of California, Irvine



Outline

- ARA Overview
- ARA User Community
- Looking Forward

Outline

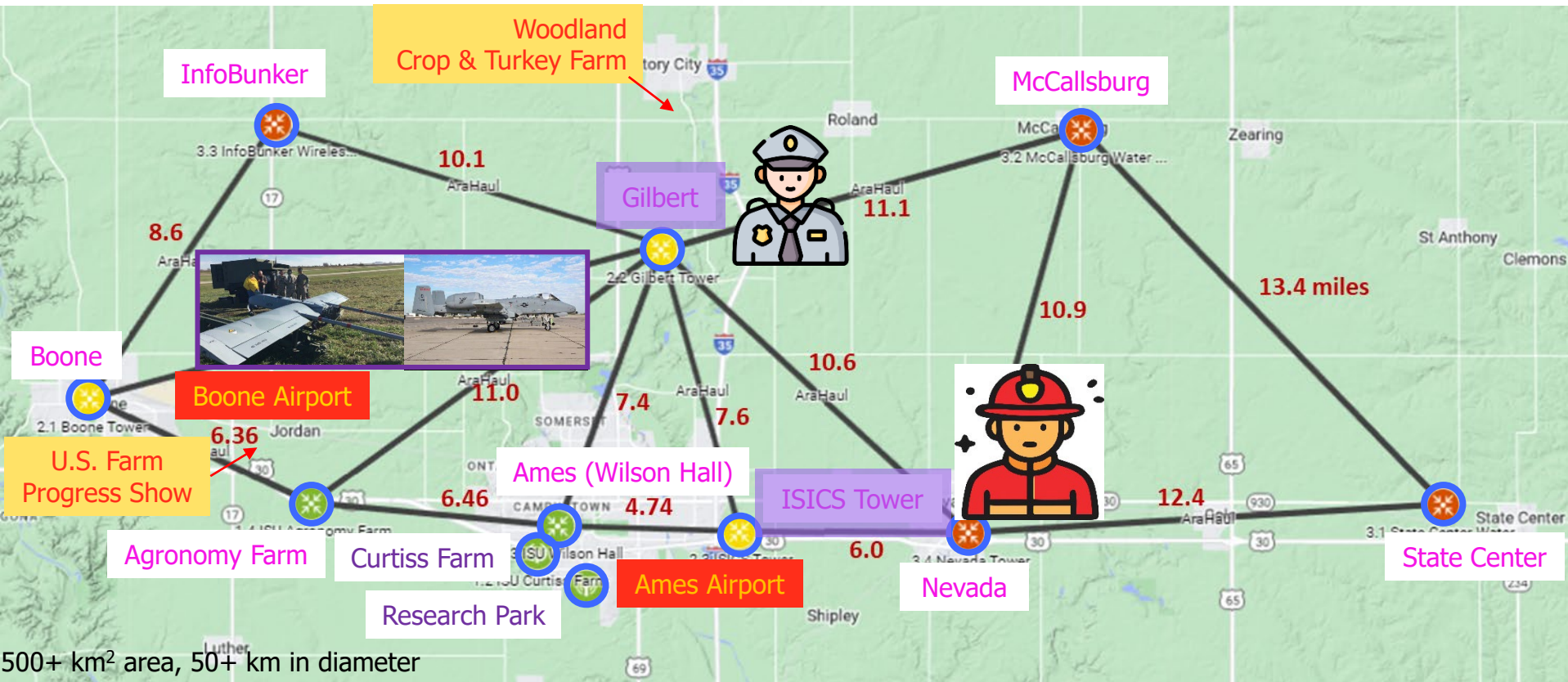
- ARA Overview
- ARA User Community
- Looking Forward

ARA as *Living Lab* for NextG and Agriculture/Rural Communities

- Real-world, at-scale testbed infrastructure
 - Terrestrial wireless access, x-haul, and edge compute
 - Satellite communications
- Ecosystem stakeholders
 - across NextG and AgTech
 - across academia, industry, government, and communities
- Research, innovation, education activities

ARA Deployment in Far-Edge Agriculture & Rural Settings

 AraHaul mesh sites, each with 1+ AraRANs



 AraRANs around Ames



Collins Aerospace

Long-Distance, High-Throughput Communications

- **AraHaul:** multi-modal, long-distance, high-throughput x-haul

- Terrestrial communications

- Optical (AraOptical)
 - mmWave (Aviat WTM 4800)
 - Microwave (Aviat WTM 4200)
 - Multi-band (Aviat WTM 4811)

194THz	100Gbps+	15km+
71-86GHz	20Gbps	15km+
11GHz	2.5Gbps	20km+
11, 71-86GHz	2.5-20Gbps	15km+
10-30GHz	100Mbps	across planet

- NTN / LEO satcom

- **AraRAN:** high-throughput COTS & SDR systems

- Low-UHF mMIMO (Skylark)
 - mid-band (Ericsson, NI)
 - mmWave (Ericsson, NI, InterDigital)

460-776MHz	100Mbps+	10km+
3.4-3.6GHz	600Mbps+	4km+
27.5-28.35GHz	2Gbps+	400m+

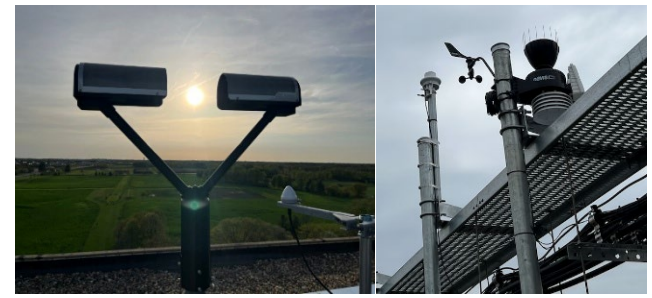
Diverse use cases

Spectral, temporal, spatial diversity for capacity, real-time, and robustness!

Cloud



ARA Base Station Sites



Weather Sensors



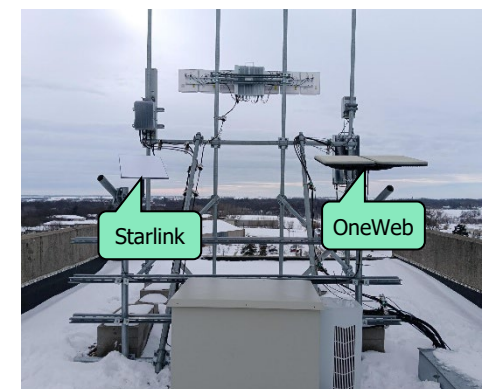
Wilson Hall BS



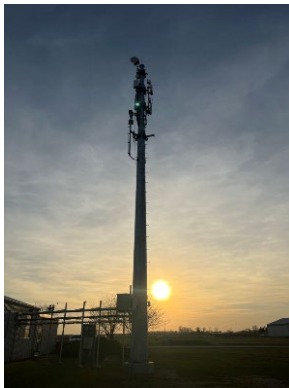
RAN Radios



X-Haul/FSOC



SatCom



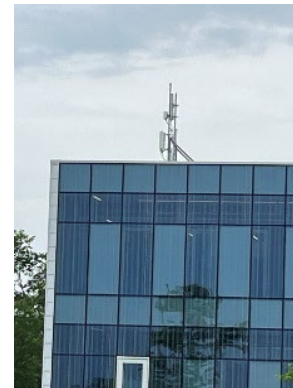
Ag Farm



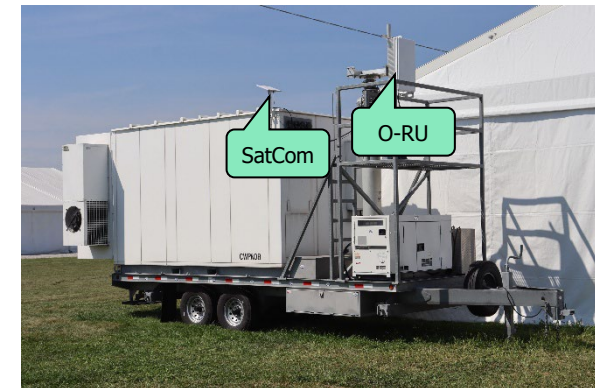
StoryComm



ISICS

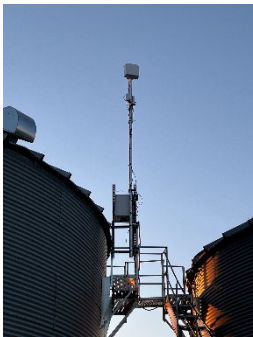


Research Park

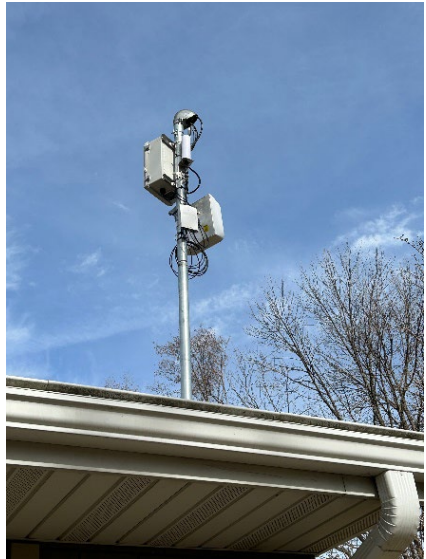


Portable BS Trailer
(TN & SatCom)

ARA UE Stations (selected)



Crop Farms & Livestock Facilities



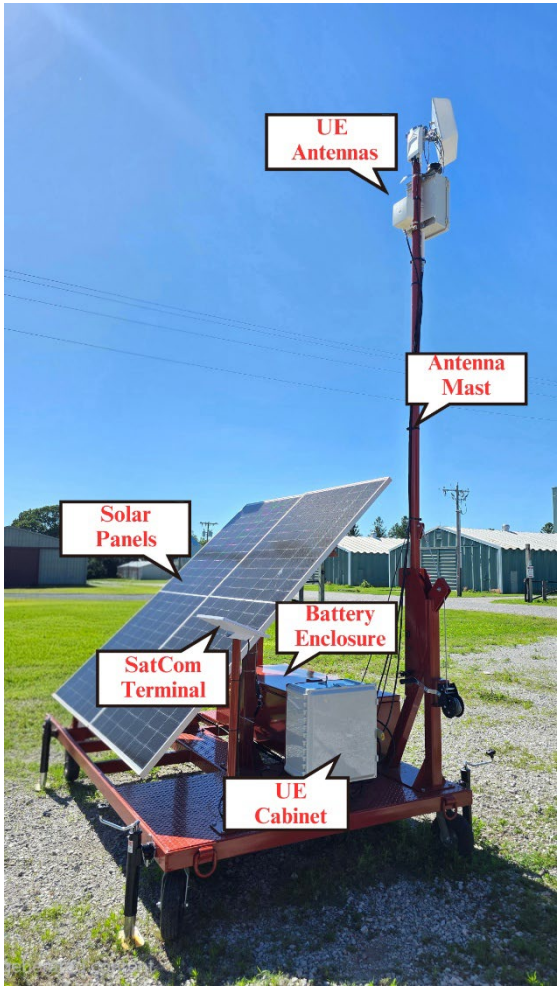
City & Residential Facilities

Feed Mill

Bioprocessing Plant

ARA BS and UE Sites

- 7 BSes deployed (circled in red)
- 30 UEs deployed
- 10+ solar-powered UE trailers in progress



Phase 1 UE Sites (20) - completed

AgronomyFarm-UE-000 (LEBRC Barn)

AgronomyFarm-UE-001 (Farm Field #1)

AgronomyFarm-UE-010 (Farm Field #2)

AgronomyFarm-UE-020 (Grain Bins)

... 13 more

Phase 2 UE Sites - Batch #1 (10) - compl...

AgronomyFarm-UE-030-035

Ames-UE-160

Ames-UE-140

FeedMill-UE-000-001

Phase 2 UE Sites - Batch #2 (11)

AgronomyFarm-UE-100

Ames-UE-161

KitchenFarm-UE-010

Gilbert-UE-020

... 6 more

Phase 2 UE Sites - Batch #3 (13)

AgronomyFarm-UE-036-038

Boone-UE-000

Boone-UE-001

Boone-UE-002

... 6 more

ARA Phase 2 Base Stations (3) - complet...

Boone-BS-000 (Tower)

Gilbert-BS-000 (Tower)

ISICS-BS-000 (Tower)

2,759 views
Published 1 hour ago

SHARE

EDIT

Phase 1 UE Sites (20) - completed

AgronomyFarm-UE-000 (LEBRC Barn)

AgronomyFarm-UE-001 (Farm Field #1)

AgronomyFarm-UE-010 (Farm Field #2)

AgronomyFarm-UE-020 (Grain Bins)

... 13 more

Phase 2 UE Sites - Batch #1 (10) - complet...

Phase 2 UE Sites - Batch #2 (11)

Phase 2 UE Sites - Batch #3 (13)

ARA Phase 2 Base Stations (3) - completed

ARA Phase 1 Base Stations (4) - completed

WilsonHall-BS-000 (Rooftop)

ResearchPark-BS-000 (Rooftop)

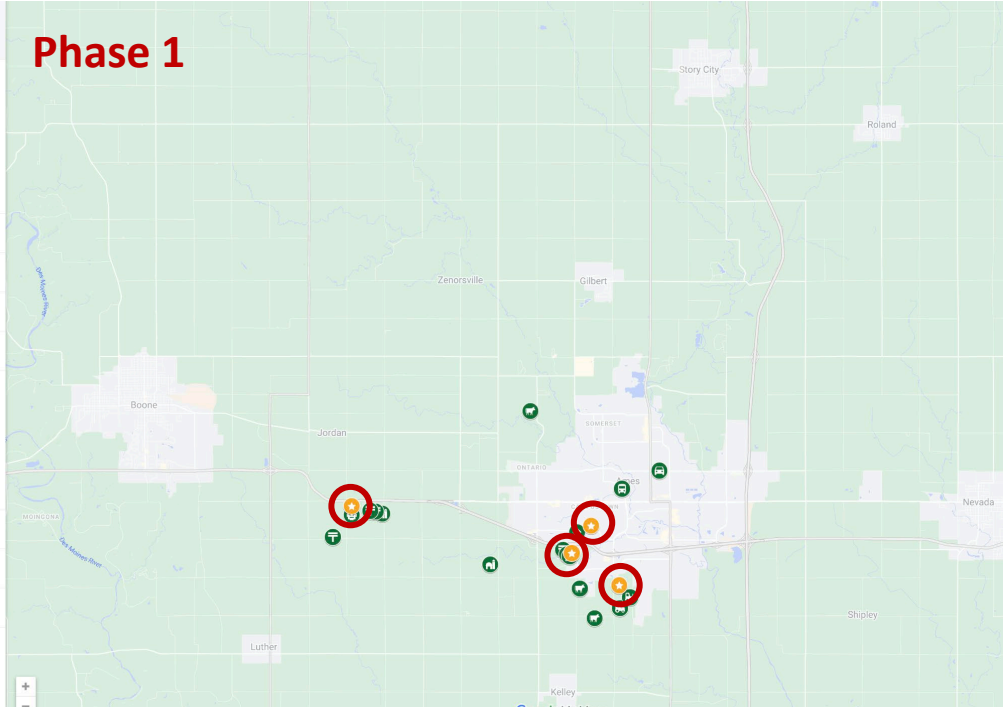
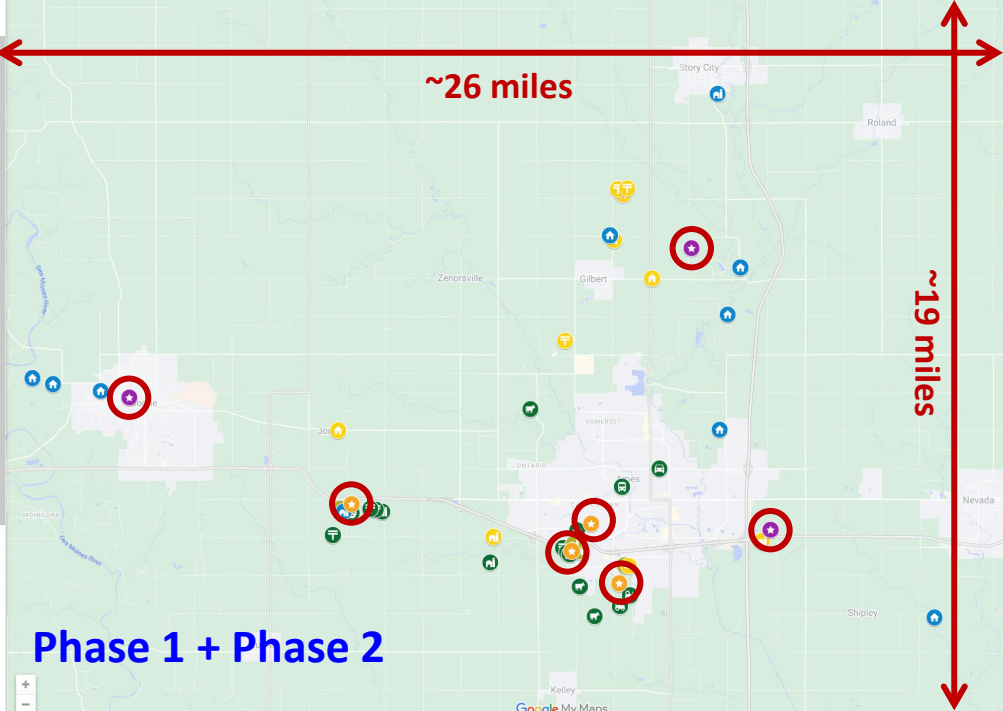
CurtissFarm-BS-000 (Pole)

AgronomyFarm-BS-000 (Pole)

Phase 2 UE sites - additional candidates

Phase 2 Hort sites

Heintz Farm

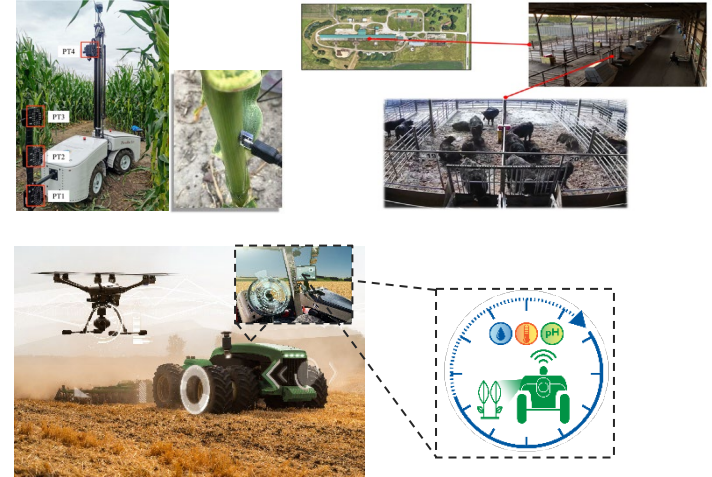


Wireless Research

- SatCom, x-haul & access channel and link measurement
 - *LEO satellite communications*: Starlink, OneWeb
 - *Long-distance, high-capacity x-haul* at 11GHz, 71-86GHz (& 194Thz)
 - *Heterogeneous access* at 460-776MHz, 3.4-3.6GHz, and 27.5-28.35GHz
- RAN & x-haul systems
 - 5G / NextG, Open RAN, AI RAN
 - Open source: OCUDU/srsRAN, Duranta/OAI, OSC, SD-Core etc
 - Programmable COTS
 - Massive MIMO
 - Ericsson 192/384-element arrays (64T64R)
 - Skylark Wireless
 - Dynamic spectrum sharing
- End-to-end real-time communications and computing

Applications Research

- Precision agriculture
 - ▣ Crop phenotyping
 - ▣ Livestock health monitoring
 - ▣ Agriculture automation



- Community services
 - ▣ Safe water
 - ▣ Smart transportation
 - ▣ Public safety

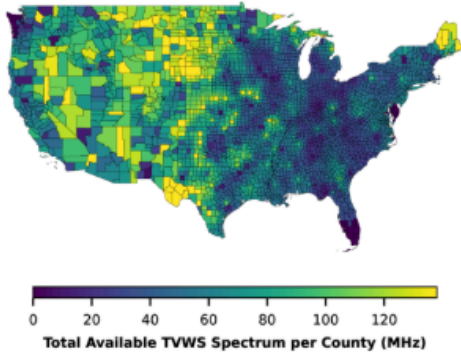


21 Exemplar Wireless Experiments

Resource Used	Experiment	Count
Compute nodes	Hello World, Edge	2
	OCUDU	2 (1 outdoor + 1 indoor)
	srsRAN	2 (1 outdoor + 1 indoor)
	OpenAirInterface (OAI)	2 (1 outdoor + 1 indoor)
	O-RAN with FlexRIC	2 (1 OCUDU, 1 OAI)
	GNURadio experiments	1
	Spectrum Sensing	1
	Skylark massive MIMO	3
	COTS 5G massive MIMO	2
	MmWave	1
AraHaul	LEO SatCom backhaul	1
	11 GHz & 80 GHz x-haul	2
	194 THz free-space optical	2
Weather sensors	Fine-grained weather info	1

ARA Datasets

Spectrum & Channel Behavior



TVWS Spectrum Availability: Discover how much spectrum may be hiding in plain sight! This dataset reveals the availability of TVWS (TV White Space) spectrum across the U.S., helping researchers explore rural broadband planning, dynamic spectrum sharing, and data-driven policies that could transform underused spectrum into meaningful connectivity.

Massive MIMO



AraMIMO TVWS Massive MIMO Dataset: Explore what happens when massive MIMO moves beyond the indoor lab into real rural and agricultural environments! The AraMIMO dataset opens opportunities to study beamforming, user scheduling, coverage, and network capacity, showing how TVWS and multi-user MIMO can work together to deliver long-range, high-capacity rural connectivity.

Long-Distance, High-Capacity Wireless X-Haul



AraHaul Outdoor Wireless X-Haul Link Performance with Weather Measurements: Analyze how long-range, high-capacity wireless x-haul links respond when the weather changes! By combining outdoor microwave and millimeter-wave performance data with detailed weather measurements, this dataset enables research into link reliability, weather-aware link prediction, adaptive networking, resilient wireless x-haul across long distances, and wireless-based weather sensing.

Outline

- ARA Overview
- ARA User Community
- Looking Forward

ARA Users and Experiments

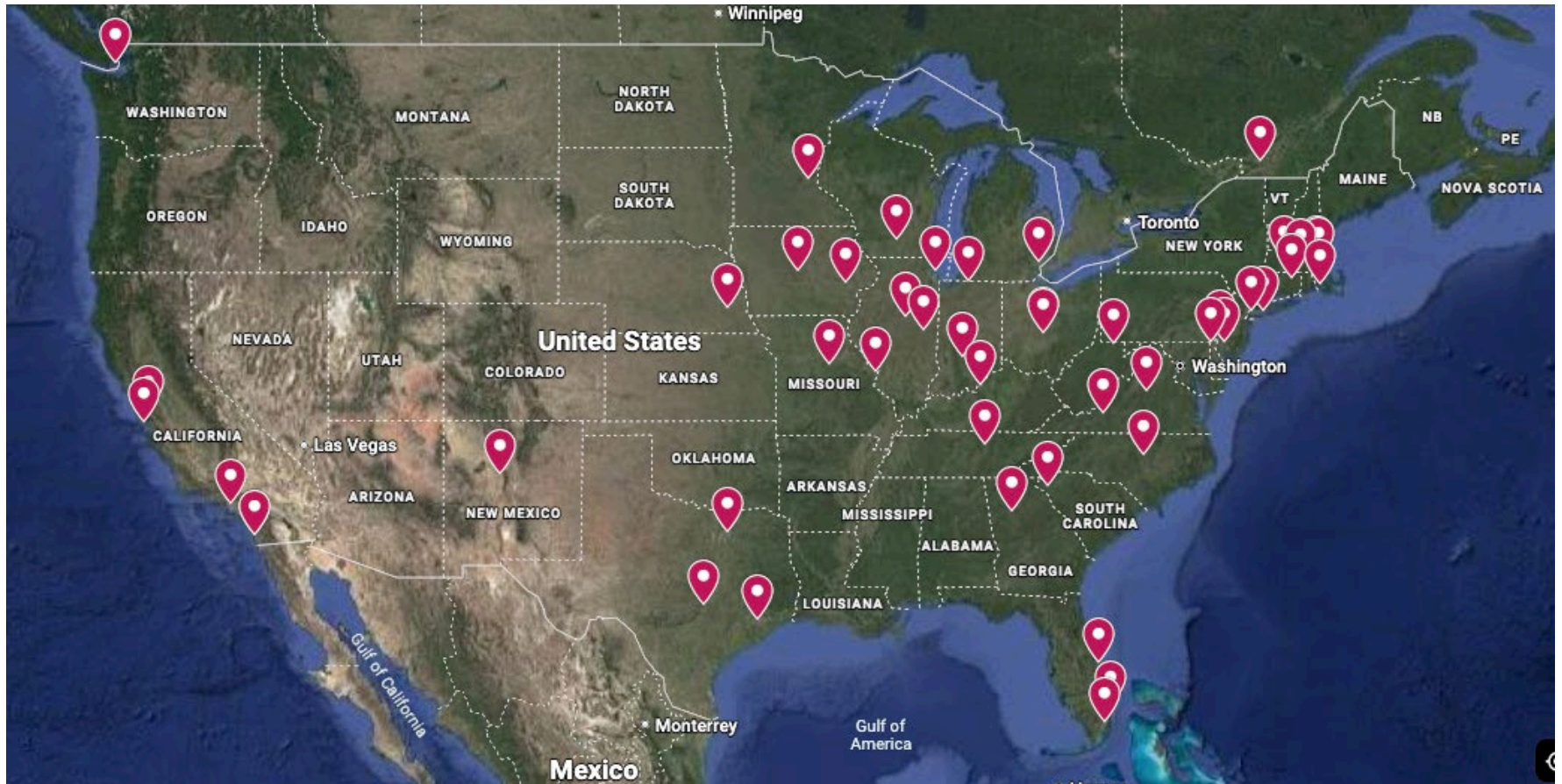
- 63 universities/organizations, 11 countries, 4 continents
 - ▣ 55 Universities, 6 non-profits, 2 industry
- 130 projects, 458 users
- 5,276 experiments



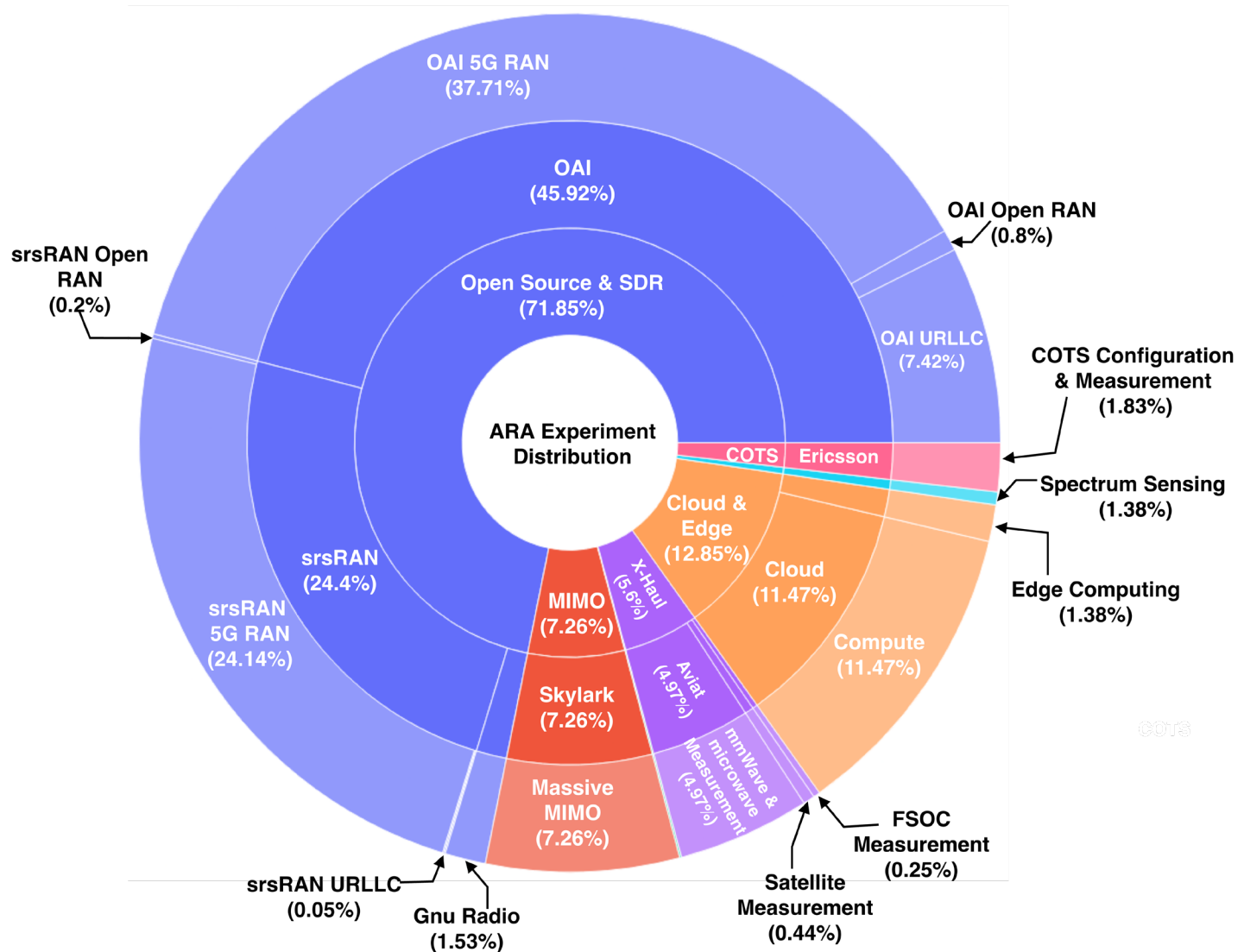
ARA Users by Regions

Region	Country	Organizations	Users
North America	USA	48	401
	Canada	2	3
South America	Brazil	1	1
Europe	France	1	3
	Austria	1	1
	Sweden	1	2
	Italy	1	1
Asia	Taiwan	2	4
	India	1	2
	Thailand	1	2
	Bangladesh	1	1

ARA Users in US & Canada



Types of Wireless Experiments



Projects using ARA (selected)

- NSF/USDA AI Institutes

- ICICLE: Intelligent CI with Computational Learning in the Environment (\$20M)
- AIIRA: AI Institute for Resilient Agriculture (\$20M)
- AI-EDGE: AI Institute for Future Edge Networks and Distributed Intelligence (\$20M)

- NTIA Innovation Fund

- ACCoRD: Acceleration of Compatibility and Commercialization for Open RAN Deployments (\$42M)
- ArMORED: Architecture for Massive-MIMO Open RAN Energy-efficient Devices (\$10M)

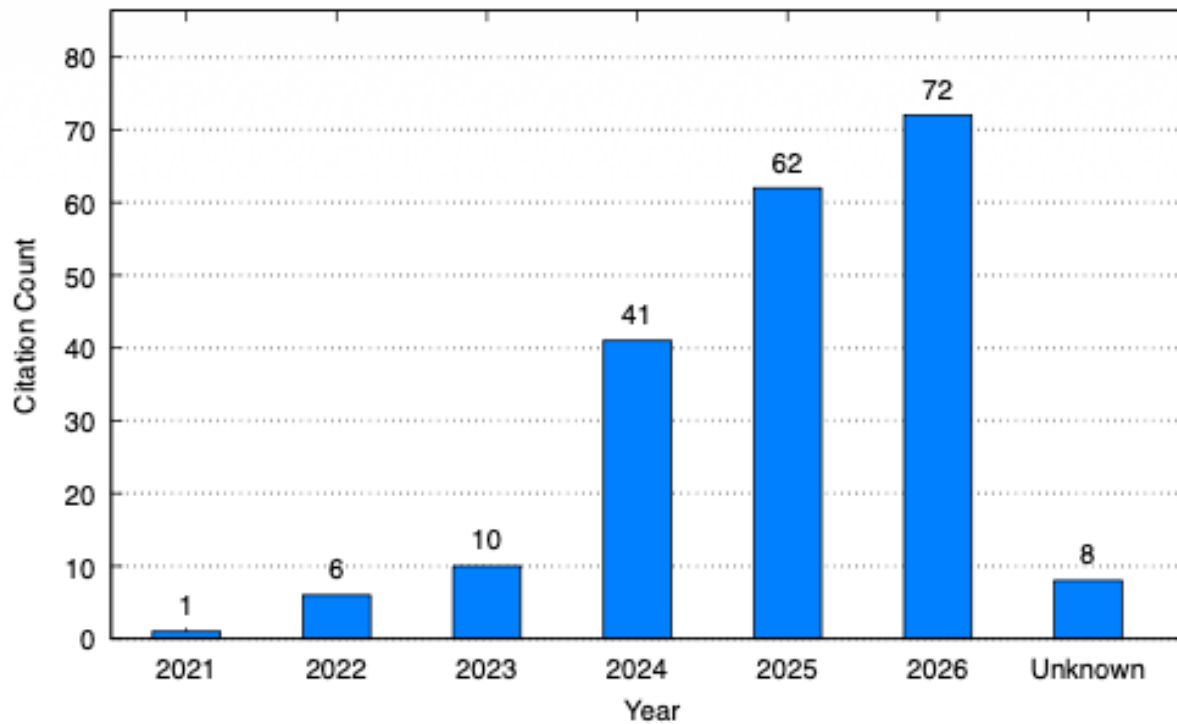
- Other NSF projects

- VINES Track 2 AgSlicing project
- COALESCE CPS Frontier project
- AI-AgARENA Project on Advancing AI for Climate-Smart Agriculture

- U.S. Army

ARA Publications

- ARA & components: 28
- Citation: 200



ARA Datasets

- 4 published datasets
- 2,499 downloads in past 5 months

Dataset	Number of Downloads
TVWS Massive MIMO	2,373
X-Haul	99
COTS 5G RSRP	15
TVWS Spectrum Availability	12

ARA-Enabled Research Publications

- Publications

- ACM CoNEXT, HotMobile, HotInfra, MHV etc
- IEEE DySPAN, ICNP, RTSS, NetSoft, MILCOM, TMA, ICCCN etc

- RTSS'2026

- T. Zhang, S. Balamurali, M., X. S. Hu, S. Han, *BWP-aware Real-Time Scheduling for Heterogeneous UEs in Industrial 5G Systems*, IEEE Real-Time Systems Symposium (RTSS), 2026

- HotMobile'26

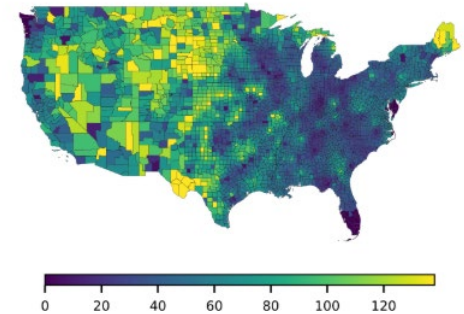
- J. Schellberg, S. Jog, V. Ranganathan, K. Chintalapudi, B. Priyantha, and B. Krishnaswamy. 2026. *Mirror in the Sky: Democratizing Continent-Scale IoT Connectivity via Amateur Satellites*. ACM HotMobile, 2026

2026 User Stories (selected)

Revisiting TV White Space for Rural Broadband: Nationwide Availability and ARA Field Validation

May 15, 2026

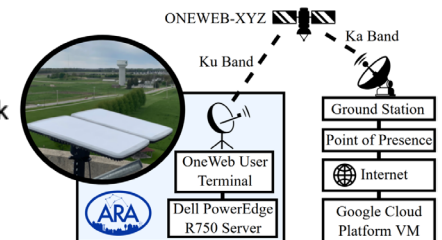
The TV White Space (TVWS) spectrum in the 470–608 MHz band travels far, penetrates well, and can cover large rural areas. The FCC authorized unlicensed secondary access more than a decade ago, yet rural deployments never took off. The framework collapsed in 2024. With broadcast license renewals approaching (US 2028–2031, UK 2034) and 6G renewing the framework, there is a narrow window to rethink how the band is governed. Across the country, the spectrum is available and concentrated in rural areas. About 89.4% of US counties have at least one open channel, with a national median of 100 channels per county. Tribal areas, among the most underserved, also skew toward high availability.



Measurement Study of Dynamics and Liquid Data Transport in OneWeb LEO Satellite Networks

April 15, 2026

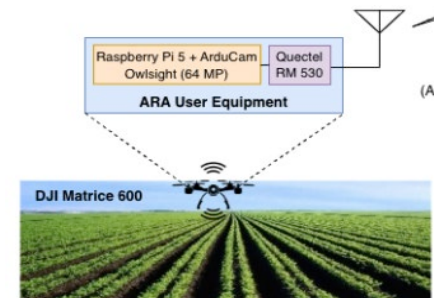
This study uses ARA's OneWeb backhaul terminal to characterize the performance of the OneWeb LEO satellite network and examines how liquid data transport can improve reliability under packet loss. The results show that, while OneWeb generally meets its service targets, liquid data transport can significantly reduce retransmissions and improve throughput stability for real time applications.



ARA-to-ICICLE: Remote Data Sourcing for Agricultural AI Processing

January 15, 2026

Modern agricultural AI relies on timely, high-quality field data. Yet collecting and processing this data in real time, especially in rural environments, remains a critical challenge. The ARA-to-ICICLE pipeline addresses this gap by enabling live agricultural data streaming from remote locations directly into an AI processing pipeline, unlocking faster insights and more responsive, data-driven farming.

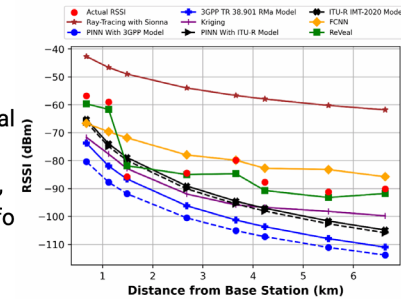


2025 User Stories (selected)

Physics-Informed Neural Network for Radio Environment Mapping

July 15, 2025

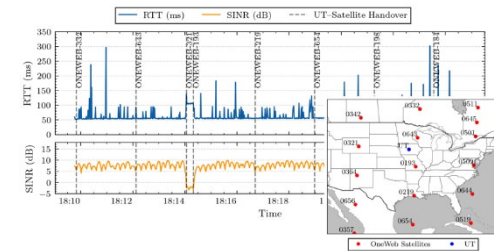
Prof. Hongwei Zhang and his team at Iowa State University (ISU) have made a leap in spectrum cartography with the development of ReVeal (Reconstructor and Visualizer of Spectrum Landscape), a Physics-Informed Neural Network (PINN) that enables high-accuracy Radio Environment Mapping (REM) using sparse data. This breakthrough, enabled in part by real-world data from the ARA rural wireless living lab, was recently reported at 2025 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN). Accurate REM is critical for dynamic spectrum sharing, especially in environments where traditional methods fall short due to shadowing and lack of precise information about transmitters (e.g., [...])



Measuring the OneWeb Satellite Network

June 15, 2025

Prof. Jianping Pan and his team at the University of Victoria (UVic), Canada, have leveraged the ARA platform to conduct studies on low-Earth orbit (LEO) satellite networks. Using ARA's user portal and with support from the ARA team, the UVic team was able to carry out experiments with a Hughes user terminal and the OneWeb satellite network. LEO satellite networks are characterized by dynamic behavior due to the high mobility of satellites. As these networks gain broader adoption, understanding their performance and effectively managing them becomes increasingly important. To address this, the UVic team has measured latency, throughput, and other [...]



"Amiga": Accelerating Field Scouting with ARA's FutureG Connectivity

November 15, 2025

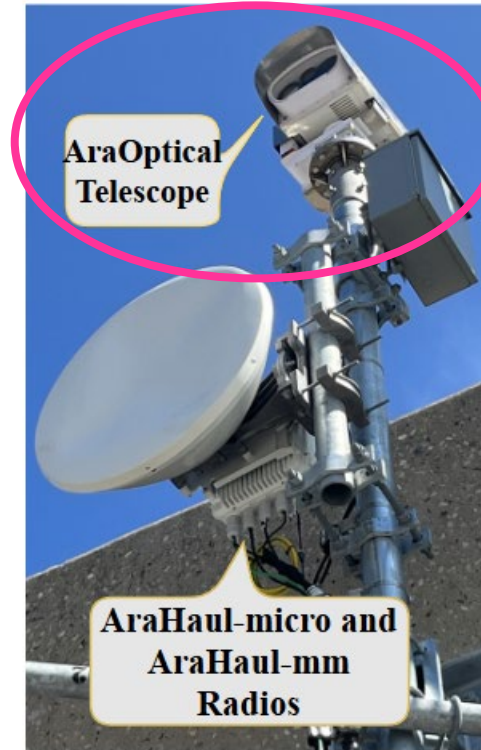
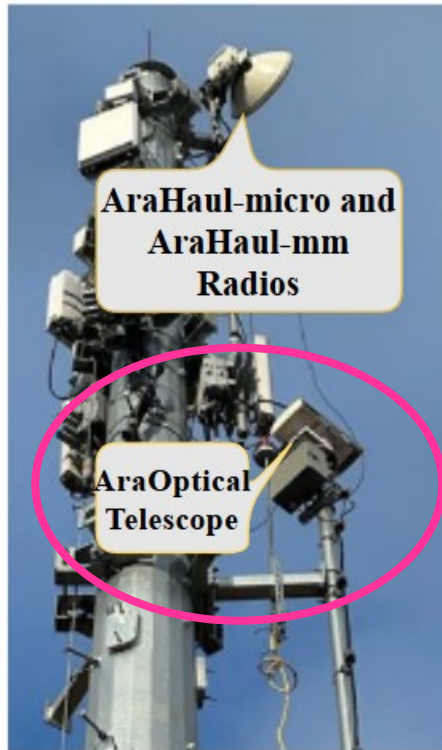
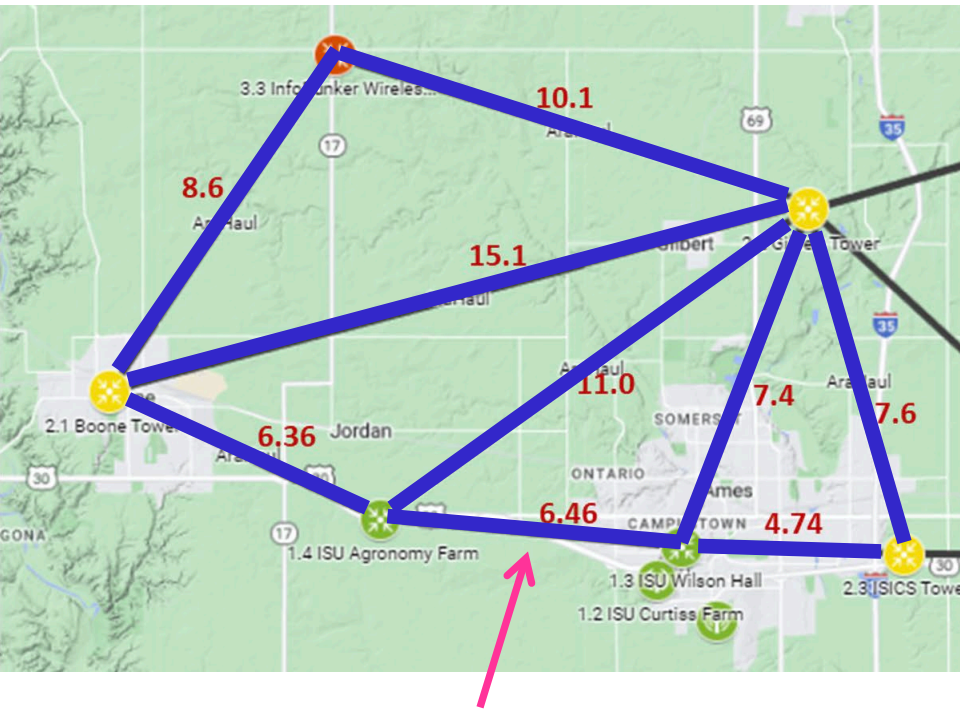
In the AIIRA national AI institute, Prof. Soumik Sarkar (Mechanical Engineering) and Prof. Asheesh "Danny" Singh (Agronomy) at Iowa State University leverages ARA to investigate how networked agricultural ground vehicles, remote sensing and computing, and machine learning can automate labor-intensive field scouting—transforming hours of manual assessment into near-real-time analysis and decision-making. Traditional field scouting and crop phenotyping are both time-consuming and labor-intensive. To address this challenge, the team is developing an integrated platform (shown in the picture below) that combines a highly customized, field-deployable "Amiga" platform (Bonsai Robotics, San Jose, CA), which can be equipped with a wide range of [...]



Outline

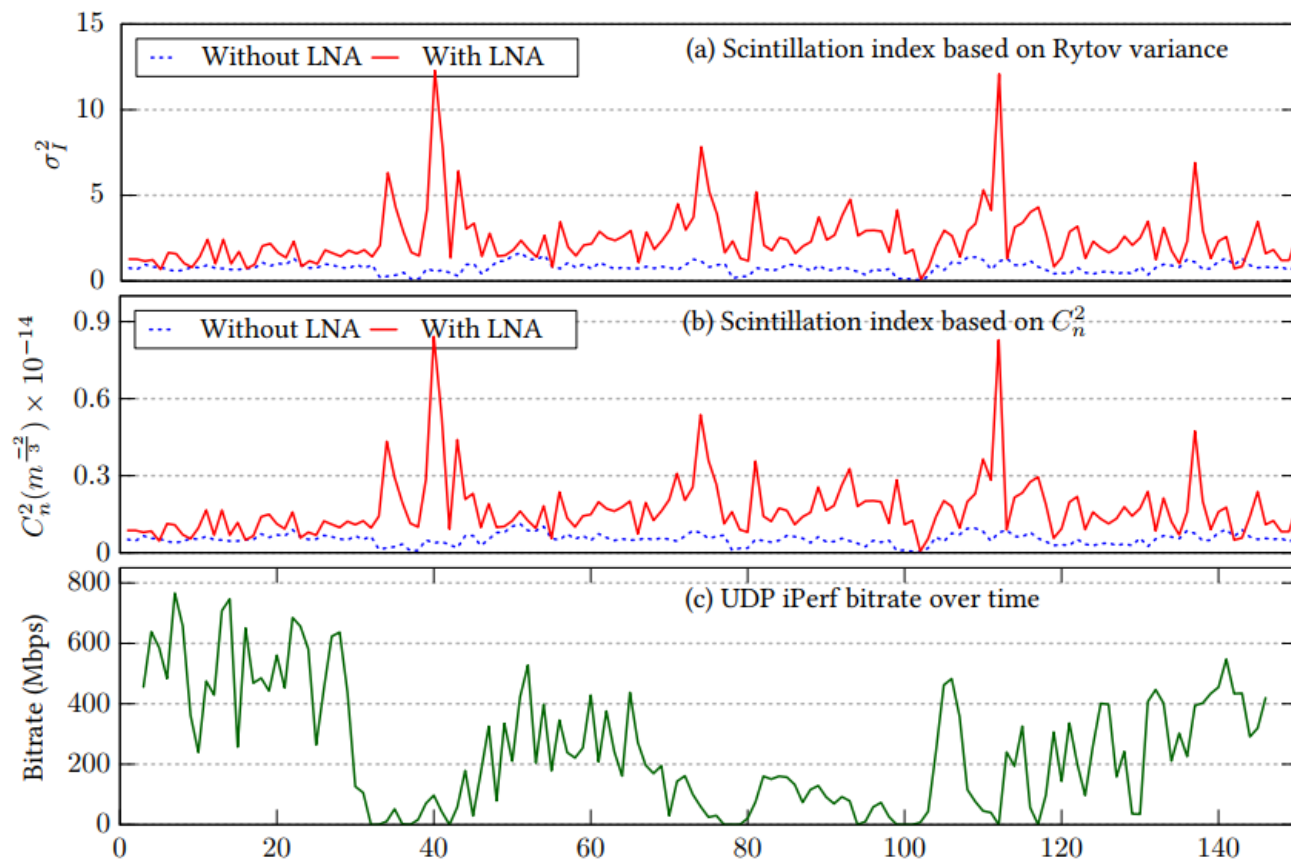
- ARA Overview
- ARA User Community
- Looking Forward

AraOptical: Phase 1



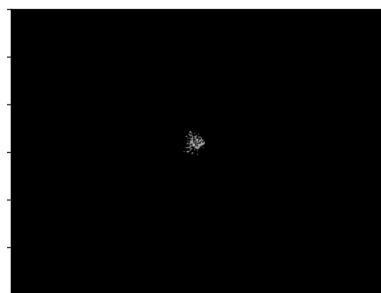
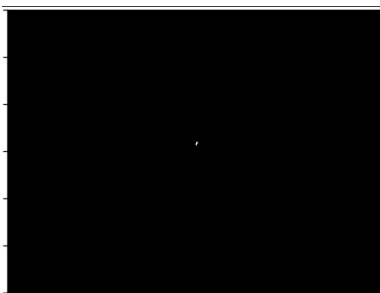
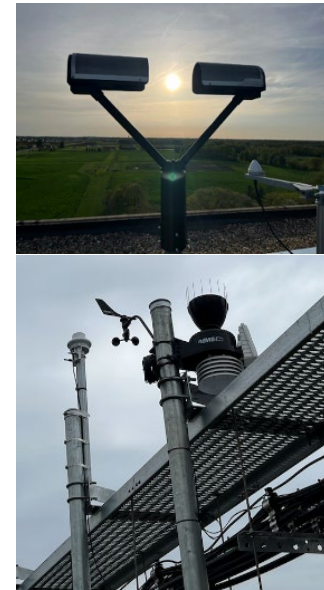
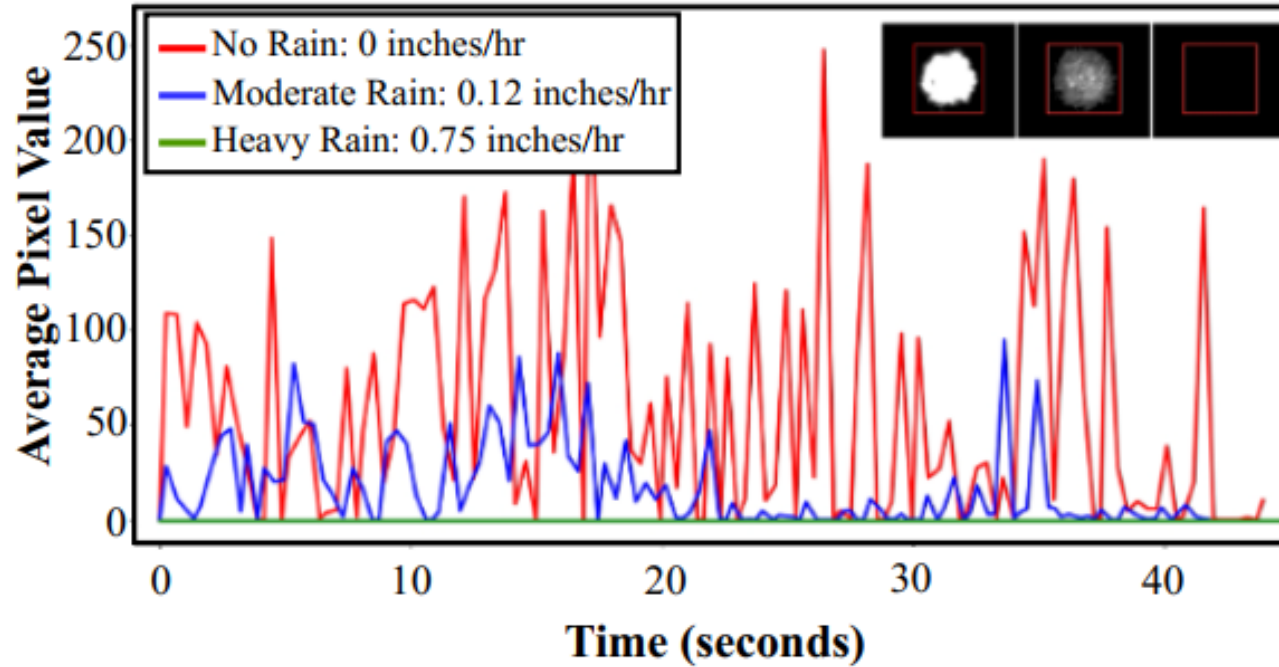
- First-of-its-kind 10+ km terrestrial FSOC (free-space optical comm) system
 - aggregate capacity of up to 160 Gbps
- Operating frequency: 191.7 - 194.8 THz

Scintillation Effect

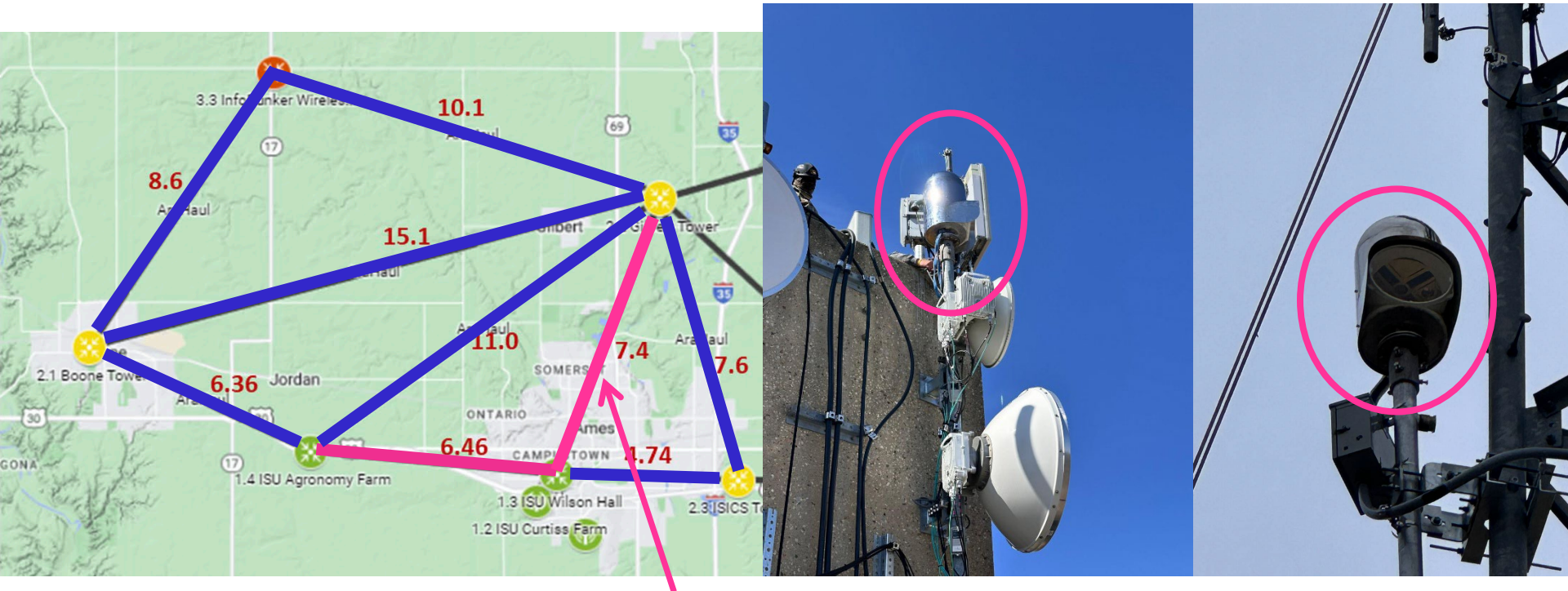


- LNA increases the dynamic range of power fluctuations
 - Amplifies the scintillation index
- Low bit rates correlate strongly with peaks in scintillation
- Adaptive gain control with LNA

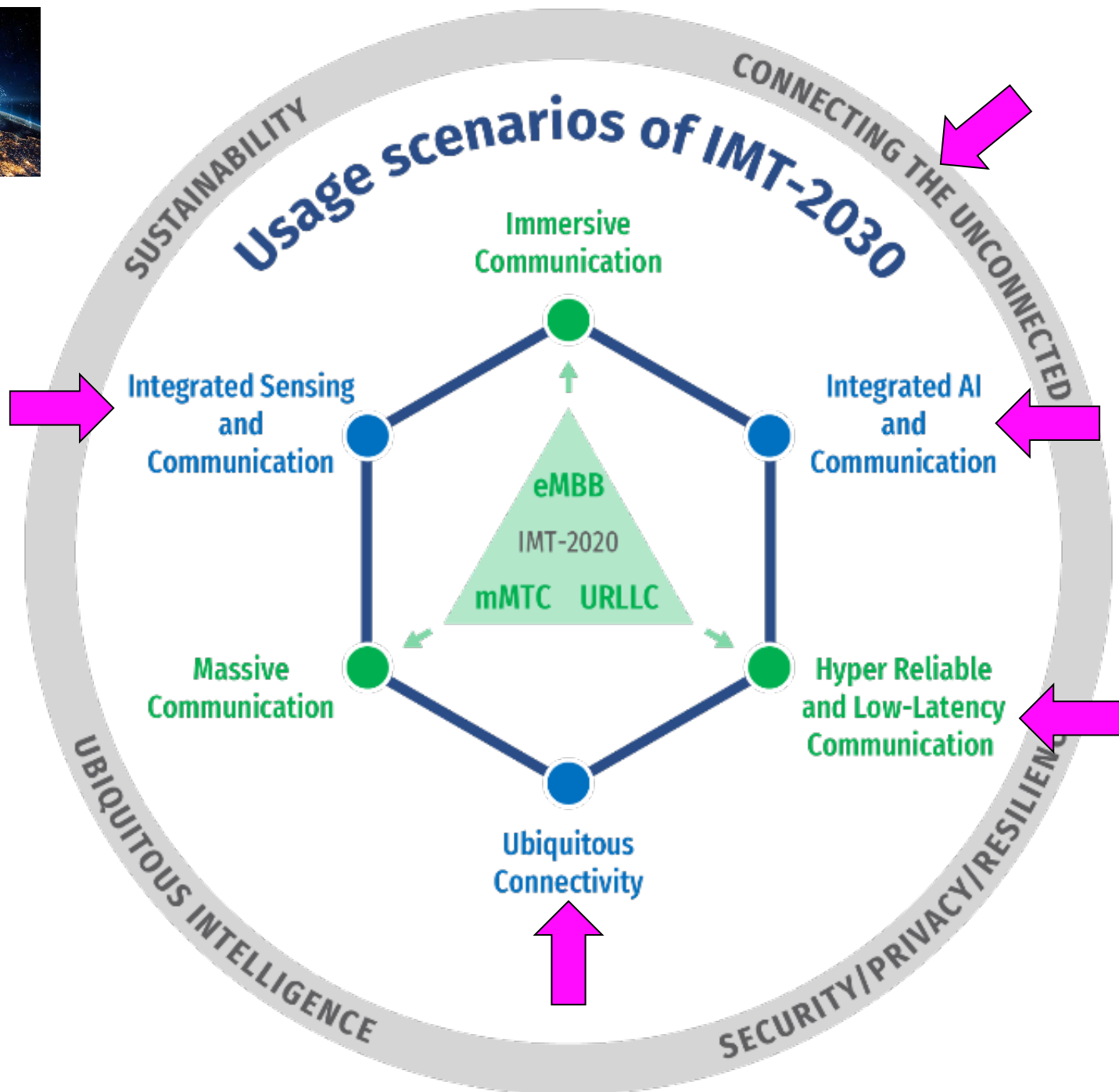
Rain Impact



AraOptical: Phase 2



- ❑ System re-design for long-range alignment and stability
 - Co-centric beacon and data beams
 - In-telescope mirror scanning vs. whole-telescope adjustment
 - Vibration sensor: vibration vs. scintillation
 - Multi-scale alignment and maintenance
- ❑ Up to 2.97 Gbps observed for up to 3+ hours
- ❑ From long-range terrestrial to *ground-satellite FSOC*



Research Support Priority

- Open RAN & AI RAN
 - End-to-end open-source support from UE to DUCU, RICs and core
 - E.g., OCUDU + Duranta / COTS UE
 - Energy-efficient massive MIMO O-RU
- Long-range massive MIMO
 - Skylark Faros v2 14TR (open source), Faros v3 & ArMORED 32TR (O-RAN)
 - Ericsson COTS 5G at 3.5 GHz (192 TR) and 28 GHz (256 TR)
- Long-range, high-capacity wireless x-haul
 - Free-space optical, mmWave, microwave links
 - AI-native liquid x-haul networking for robust and capacity-achieving real-time x-haul
- Satellite communications (& FR3 support)
 - Starlink, OneWeb, AST Space Mobile
 - 6G NTN (e.g., OCUDU)
- Integrated terrestrial and satellite communications
- Digital twin for NTN, network planning etc

NSF AgRuralG Workshop & AgWireless'26

Ag-inspired, rural-focused NextG research, innovation and partnerships





arawireless.org

Contact: e2@arawireless.org