

ARA Living Lab for Connecting the Unconnected

– from wireless & application co-evolution to ecosystem building

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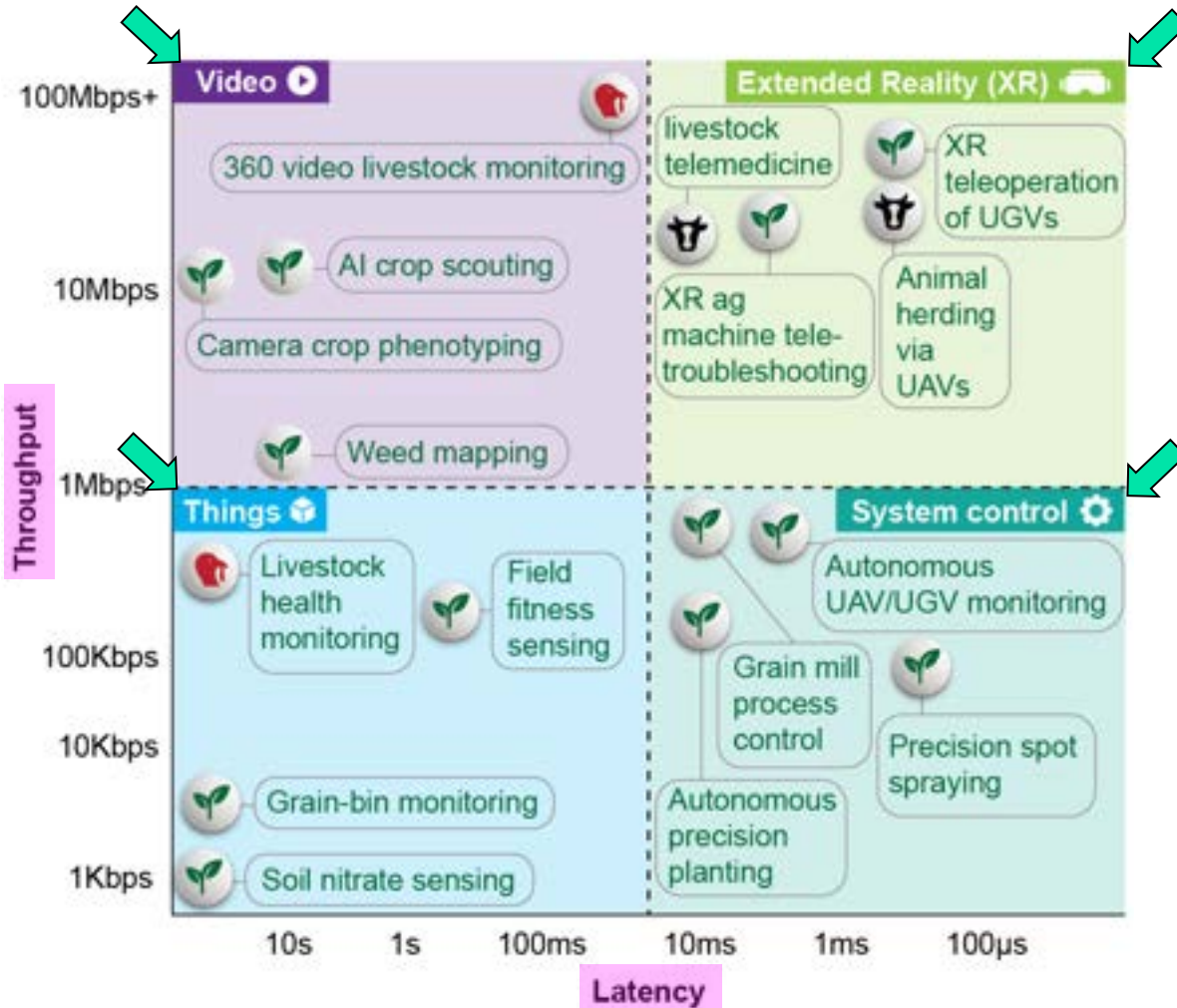
Connecting the Unconnected!

- Over 3 billion people worldwide
- Most agriculture farms
- 39% rural U.S.

- Charting new paradigm
 - Subsidy vs. rural-focused broadband innovation & capacity building
 - \$9B FCC Rural 5G Fund and more

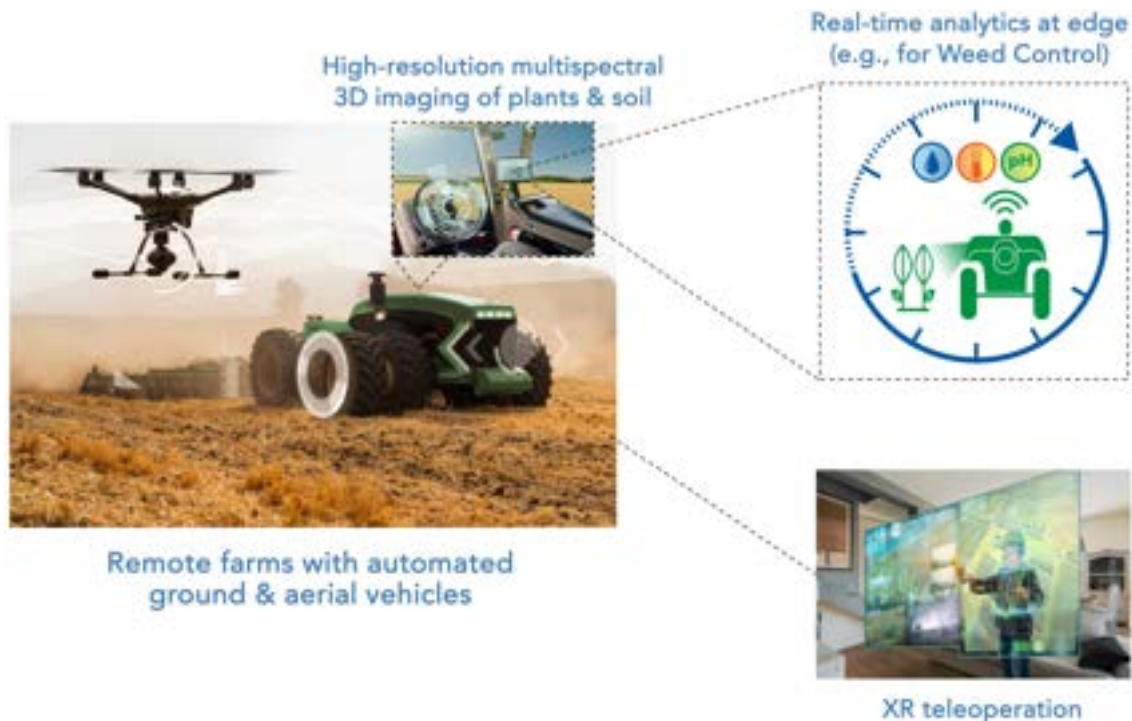
Rural Opportunities

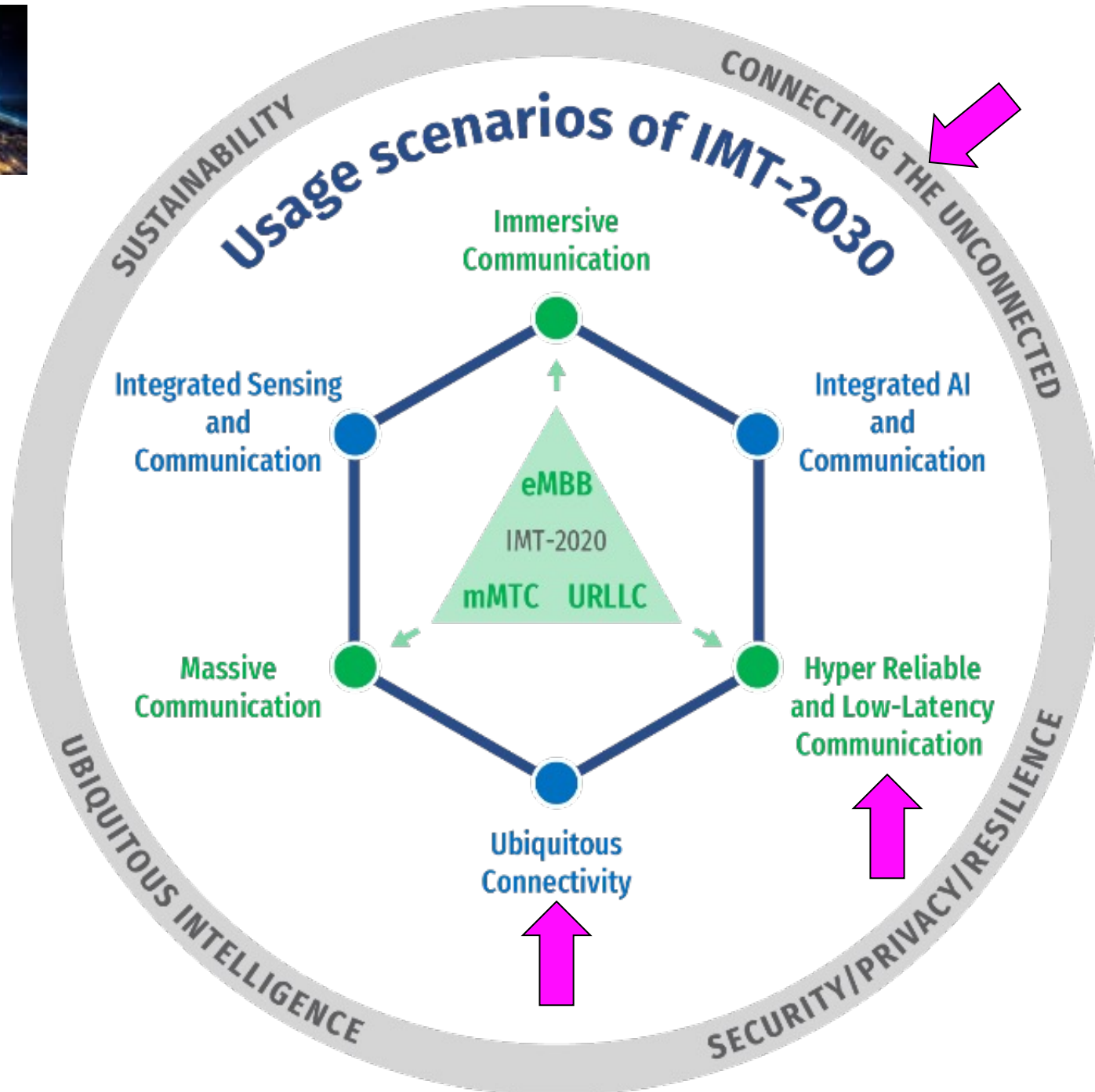
- **Rich, diverse** use cases



Rural Opportunities

- **Rich, diverse** use cases
- **Rural-first advantage** in application pilot







ARA: Wireless Living Lab for Smart and Connected Rural Communities



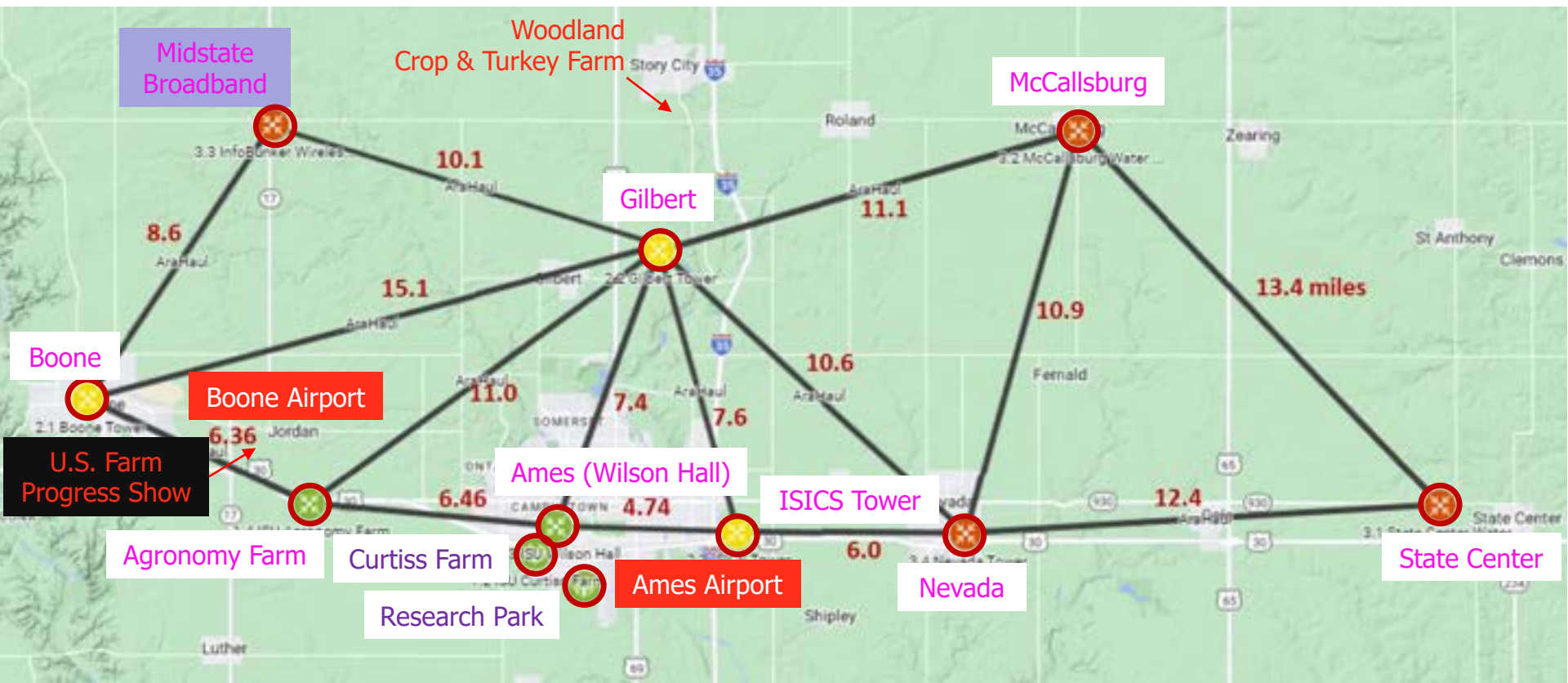
arawireless.org

- \$19M+ investment from NSF Platforms for Advanced Wireless Research (PAWR) program
- ARA: southern constellation of stars in astronomy; agriculture and rural Communities.
- The image of Ara (upper-right corner of the image above) shows the way rural wireless is expected to look like, that is, with disk-like wireless access networks connected by long-distance wireless backhuls.
- The light in the sky from the Ara stars also signifies the vision of “ARA as the light for rural wireless and broadband”.

ARA Design Principles

- Capturing real-world rural context
 - Deployment & operation
 - Spatial community distribution, community infrastructures
 - Applications: from communities to industries (precision agriculture etc)
 - Economics: factor of 10+ reduction in CapEx
 - Making rural broadband as affordable as urban broadband!
- Fostering wireless & applications co-evolution
 - Programmability
 - Performance
 - Robustness
 - Heterogeneity

ARA Deployment in Agriculture and Rural Settings



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

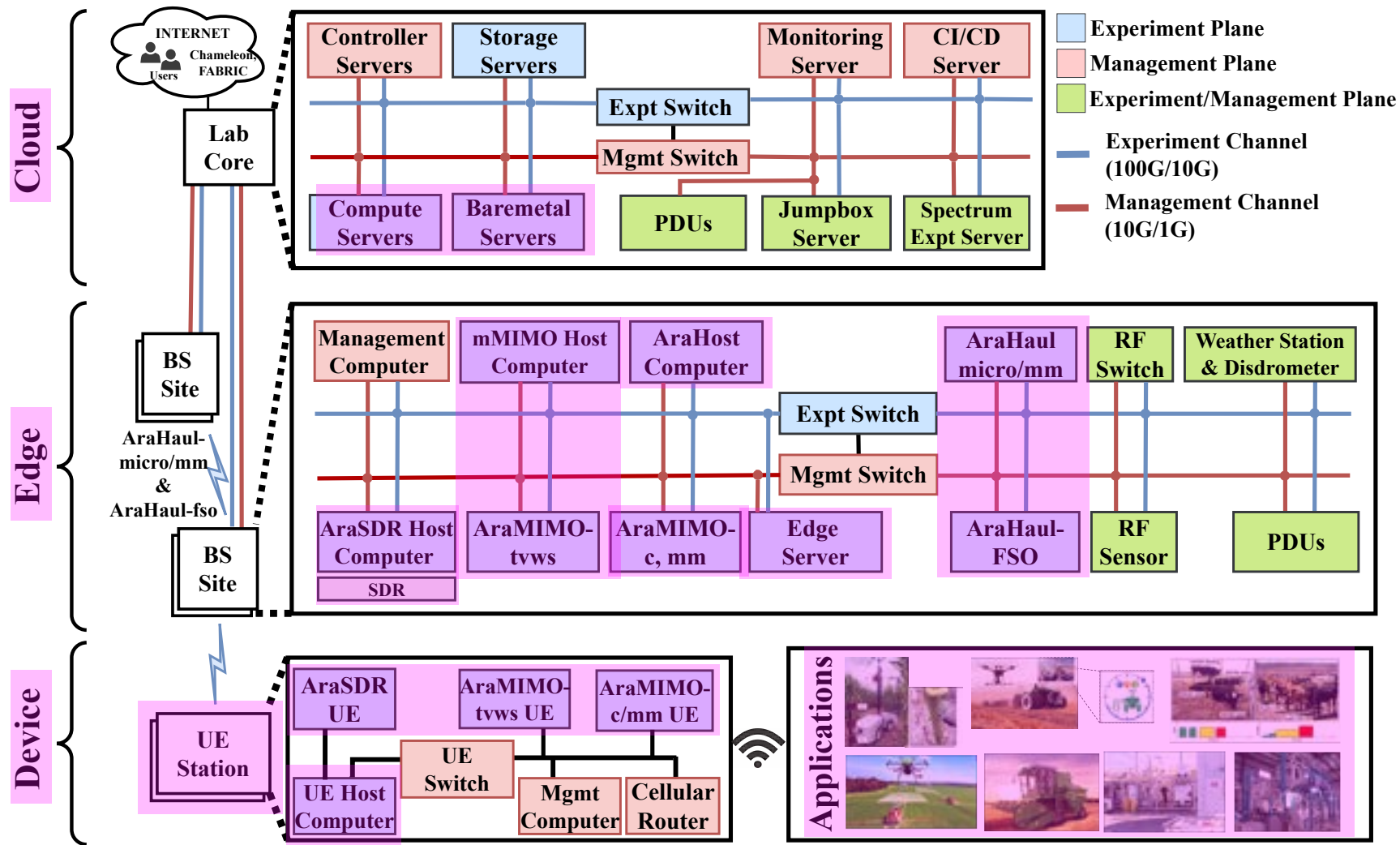
- Low-UHF mMIMO (Skylark)
 - mid-band (Ericsson, NI)
 - mmWave (Ericsson, NI, InterDigital)

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!

ARA System Architecture



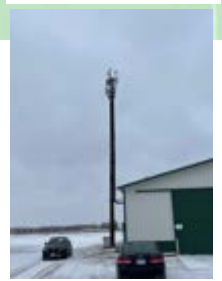
Phase 1 Base Station (BS) Sites



Agronomy Farm



Ames (Wilson Hall)

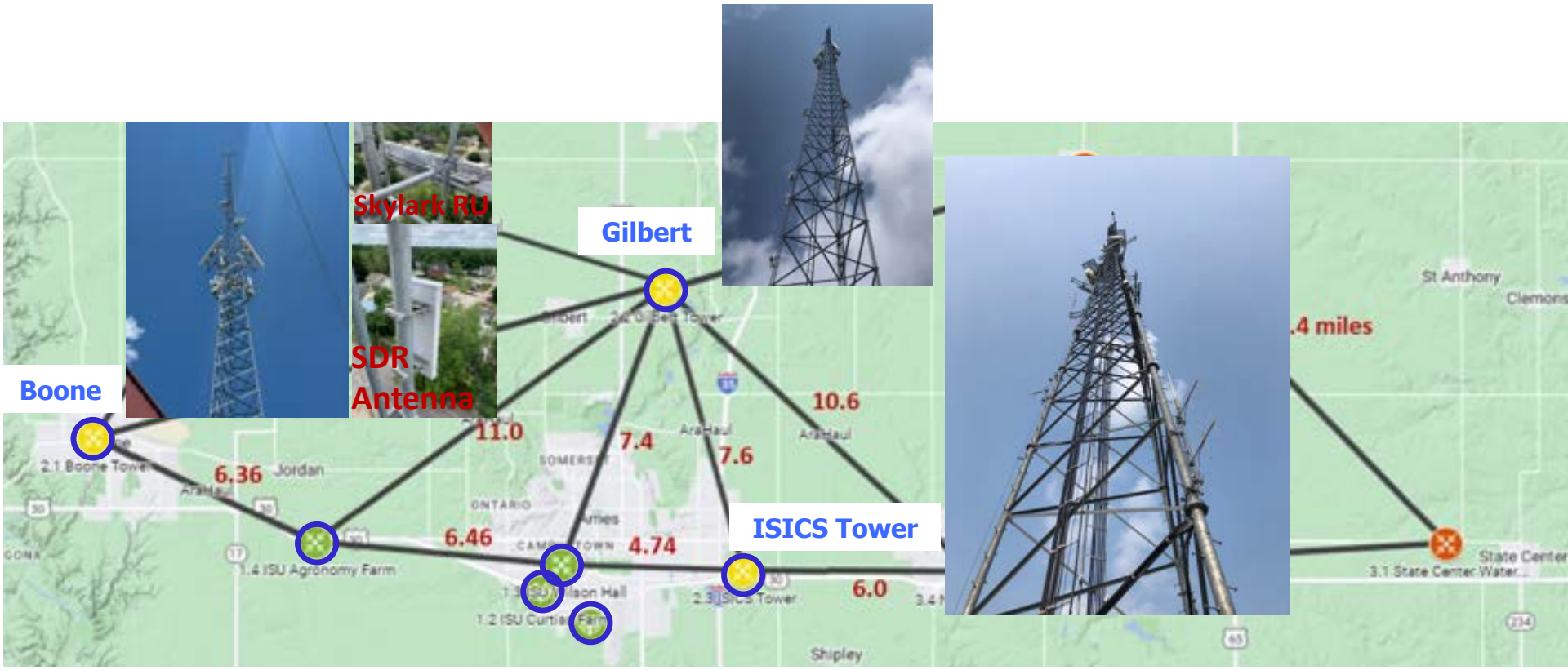


Curtiss Farm

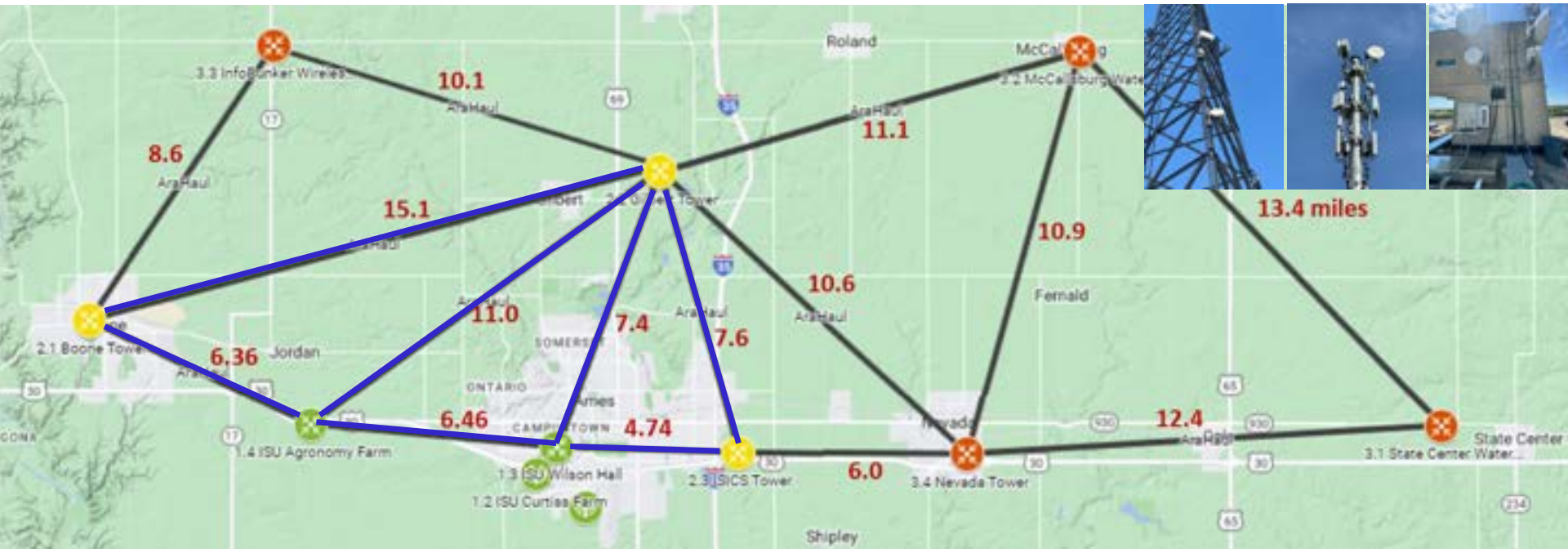


Research Park

Phase 2 BS Sites



Phase 1 & 2 AraHaul



LEO Satcom Terminal



OneWeb (Hughes)



Starlink

Phase 1 User Equipment (UE) Sites

ARA UE sites status
ARA Wireless

Phase 1 UE sites - completed (13)

- AgronomyFarm-UE-000 (LEBRC Barn)
- AgronomyFarm-UE-001 (Farm Field #1)
- AgronomyFarm-UE-010 (Farm Field #2)
- AgronomyFarm-UE-020 (Grain Bins)
- Ames-UE-000 (City of Ames SAM Water Tow...)
- Ames-UE-120 (CyRide Bus #1 - No. 418)
- CurtissFarm-UE-000 (Farm Field)
- CurtissFarm-UE-001 (Kent Burns Barn)
- DairyFarm-UE-000 (Barn)
- DigitalAg-UE-000 (Tractor)
- KitchenFarm-UE-000 (Barn)
- PhenoBot-UE-000 (PhenoBot #1)
- SheepFarm-UE-000 (Barn)

Phase 1 UE sites - to be installed (6)

- Ames-UE-100 (City of Ames Fire Commande...)
- BeefFarm-UE-000 (Beef Nutrition Barn)
- CurtissFarm-UE-002 (Maize Genetics Barn)
- PhenoBot-UE (x3)

Phase 1 UE sites - to be constructed (3)

- Ames-UE-121 (CyRide Bus #2)
- Community-UE-000 (Volunteer's Farm Locati...)
- MobileTraffic-UE-000 (Mobile Traffic Light)



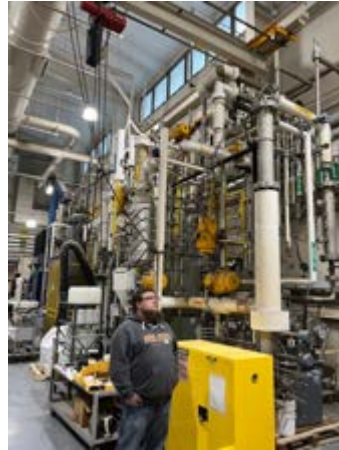
<https://www.google.com/maps/d/u/0/edit?mid=1b0U0G1U8wfEE4S4eTSHI3ZO1Vix1H4Q&usp=sharing>

Phase 2 UE Sites



ISU feed mill





ISU Bioprocessing Plant



Portable Traffic Light



Residential



AMIGA Robot

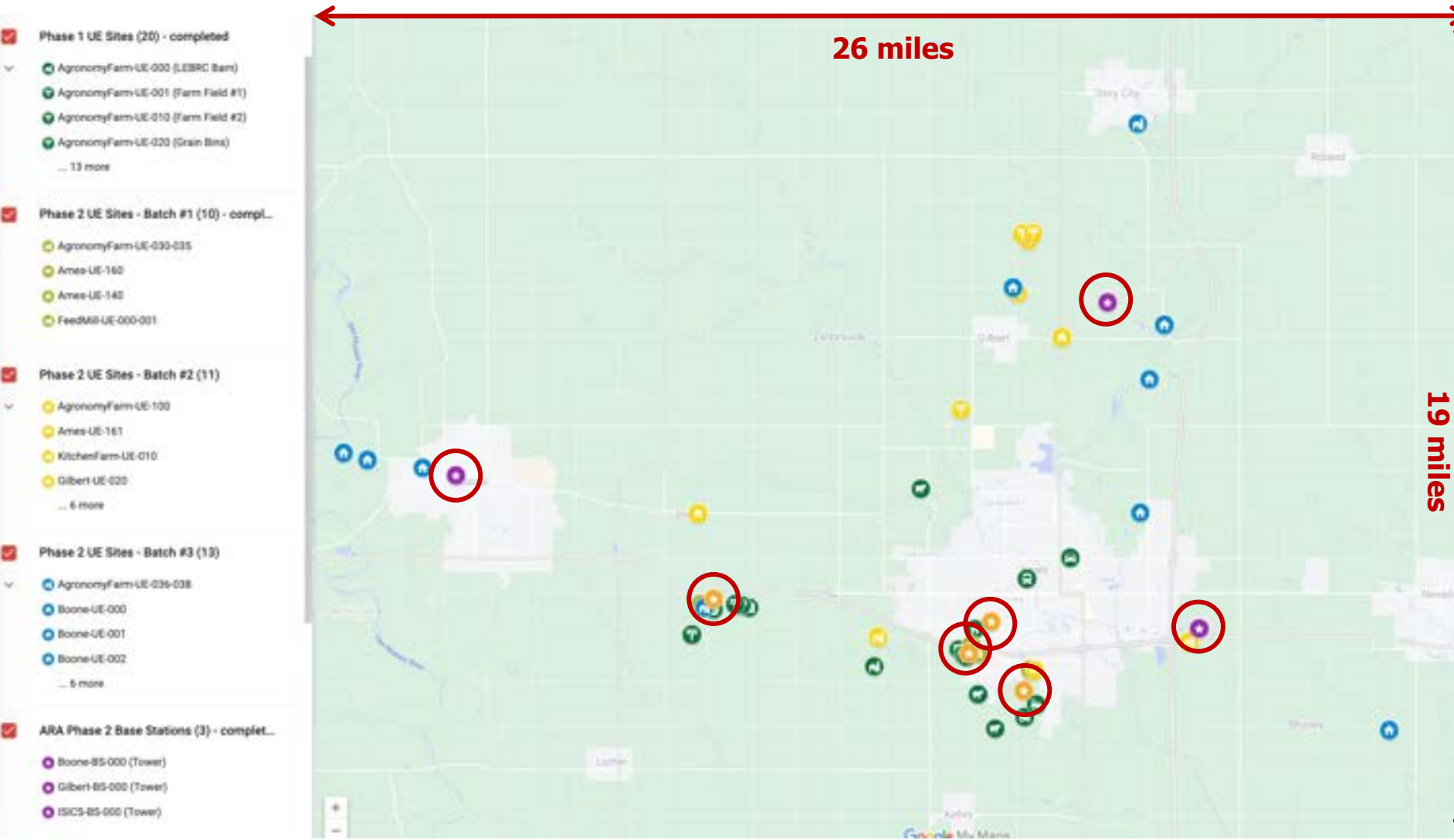
UAV with Camera

- UAV: [Aurelia X8 MAX](#)
 - Payload up to 11 kg (24 lb)
 - Flight time up to 50 minutes
 - Communication range up to 3 miles
 - GPS, GLONASS, Galileo, BeiDou, L2 Band (concurrently)
- Camera: [Gremsy Vio G1](#)



BS & UE Sites: Phases 1 & 2

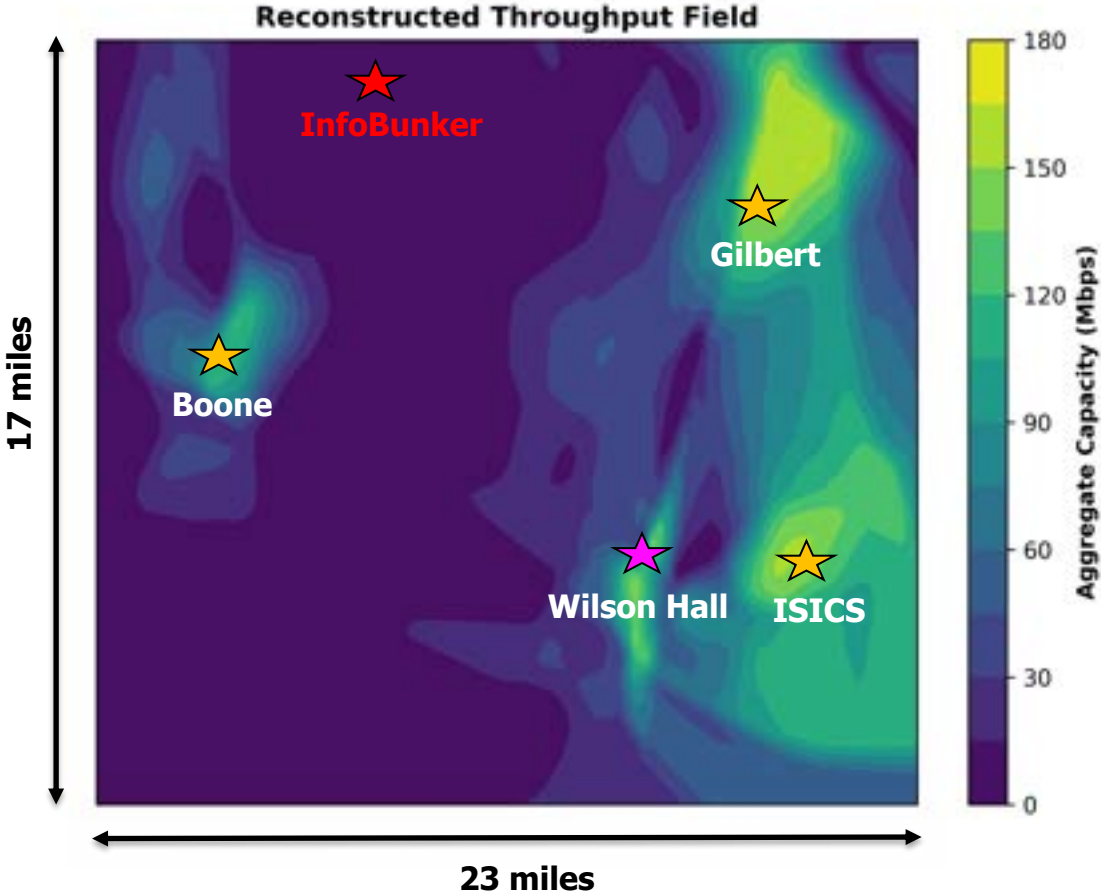
- 7 BSes deployed (circled in red)
- 50+ UEs in total: 35 UEs deployed (green), 15+ UEs to be deployed UEs (yellow and blue)



Preliminary Capacity/Coverage Measurement

- Up to 3+ Gbps wireless access throughput to agriculture farms
 - Best-connected farms today!
- Up to 10+ miles effective cell radius
 - Reducing rural broadband cost
- Close to 10+ Gbps wireless backhaul throughput across link of 6.3 miles
 - Fiber-like capacity without having to lay fibers everywhere

Skylark TVWS Coverage



~290 square miles

Ericsson 5G Capacity

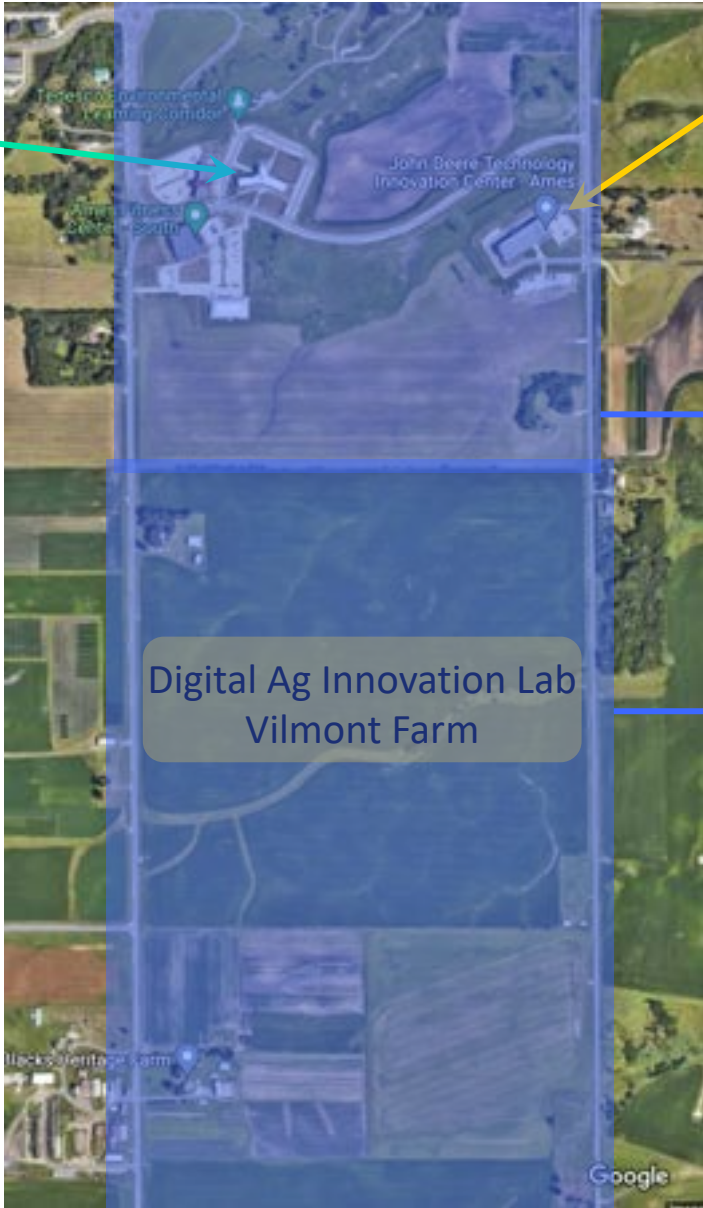
Research Park
Base Station

JD Innovation Center

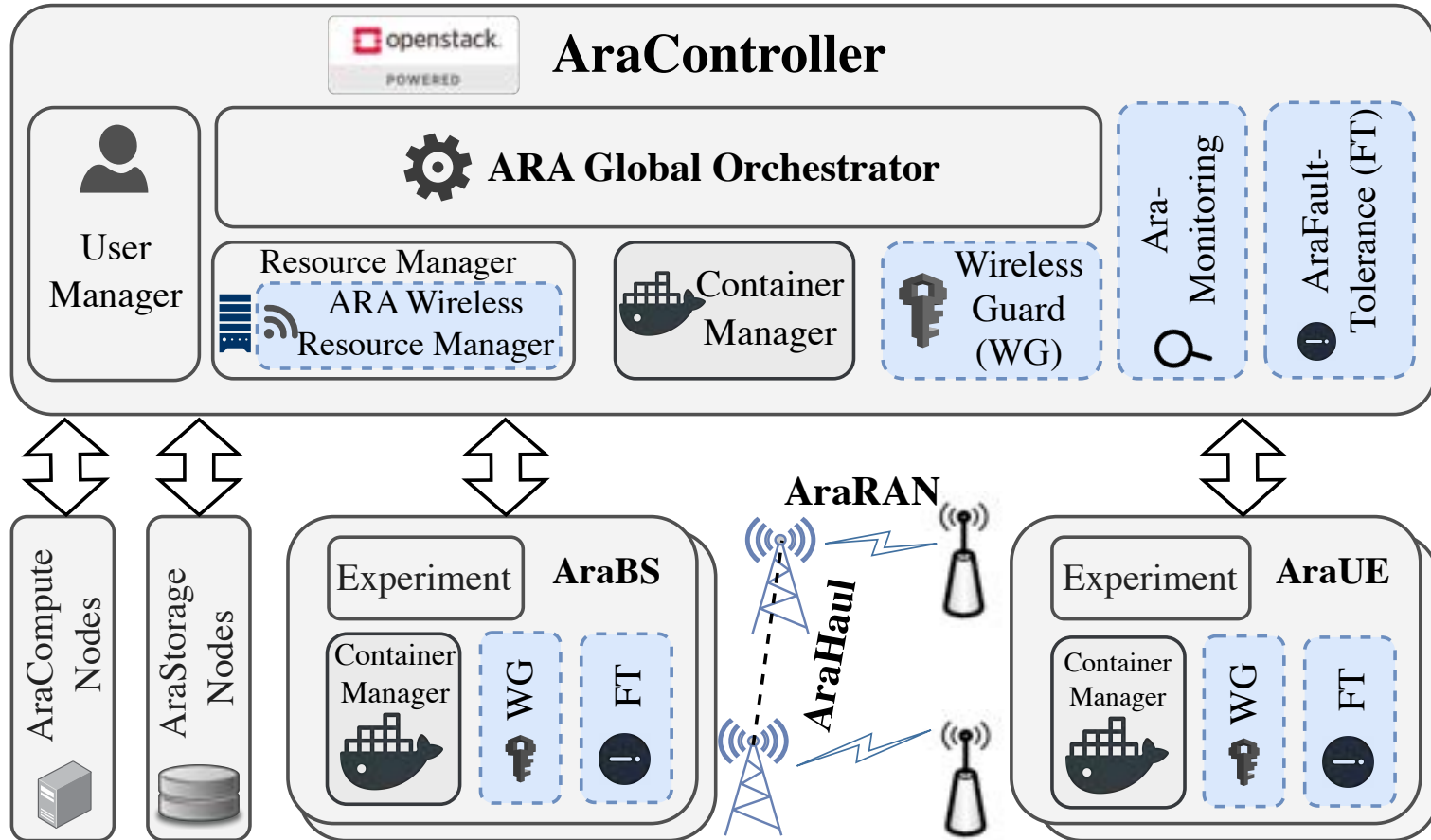
Ericsson AIR 5332 (28GHz) and
AIR 6419 (3.5GHz) aggregate
capacity up to **3Gbps**

Digital Ag Innovation Lab
Vilmont Farm

Ericsson AIR 6419 (3.5GHz)
capacity up to **600+Mbps**



AraSoft: From Infrastructure to Research Instrument



Wireless Research

- Rural channel and link measurement
 - *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
 - mMIMO
 - 5G, 6G, Open RAN
 - Spectrum sharing
- End-to-end real-time communications and computing

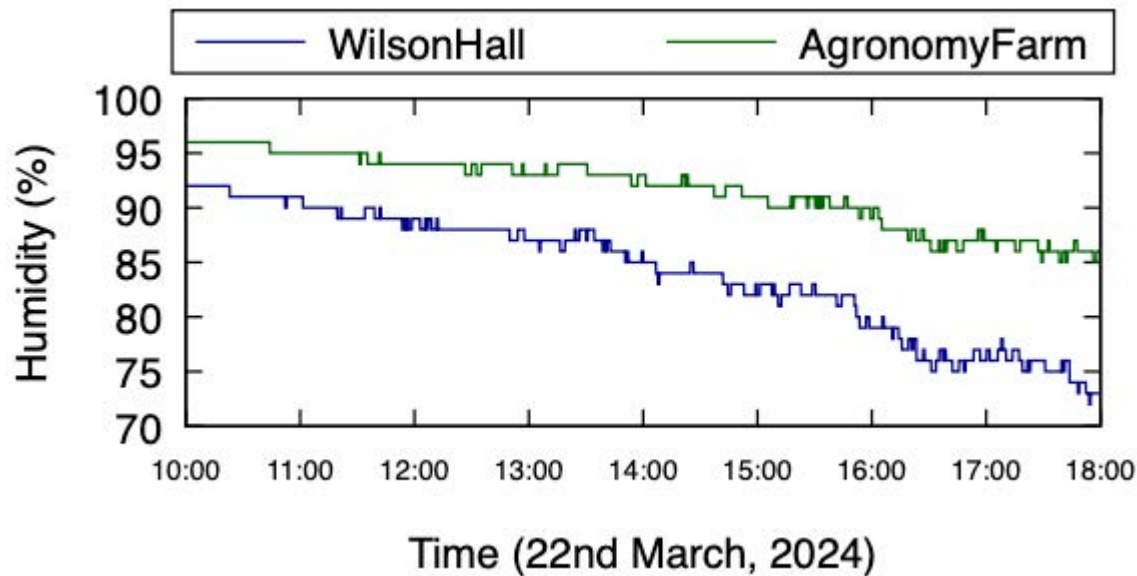
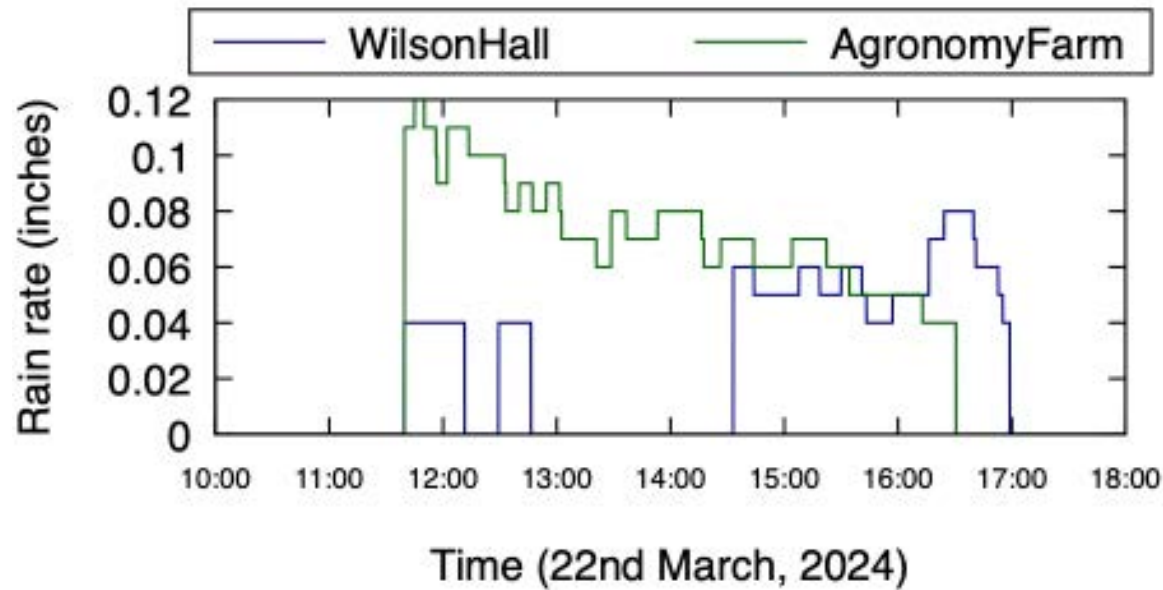
Weather, New Spectrum and Rural Wireless

- Weather as a key environmental factor impacting wireless channel behavior
 - Weather resiliency key to adoption of fixed wireless and wireless x-haul
- ARA weather & wireless measurement: *new spectrum & rural channels*
 - RAN: TVWS, mid band, mmWave band
 - Long-distance, high-capacity x-haul: microwave, mmWave, FSO (THz)
- From weather modeling & prediction to wireless modeling & predictive adaptation

Weather Data

- Precipitation type (rain, snow, hail etc)
 - Precipitation intensity
 - Drop-size distribution
 - Drop velocity
 - Visibility ...
- Wind speed and direction
 - Humidity
 - Temperature
 - Weather code (e.g., haze, drizzle, rain, snow) ...

Weather Spatial Diversity



Rain Impact: Long-Distance FSOC



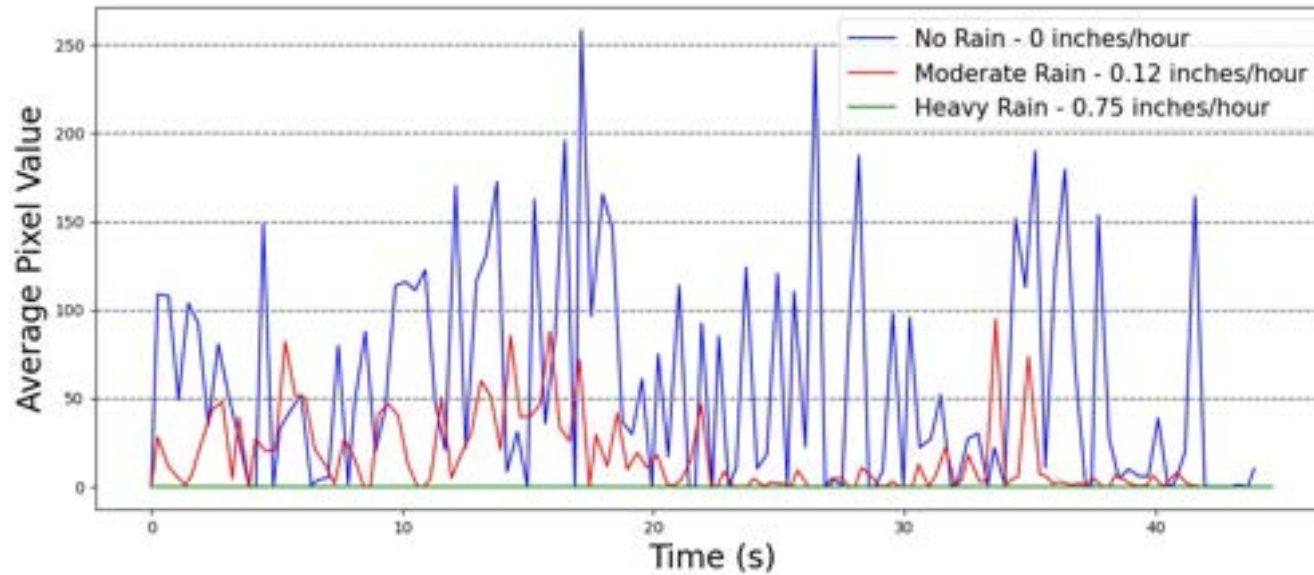
No Rain



Moderate Rain



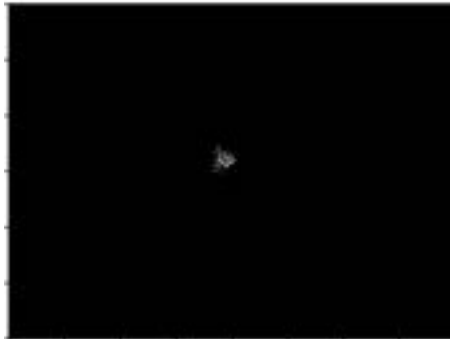
Heavy Rain



Impact of Rain Rate on FSOC: CMOS camera output



No Rainfall: Rain Rate 0 inches/hour



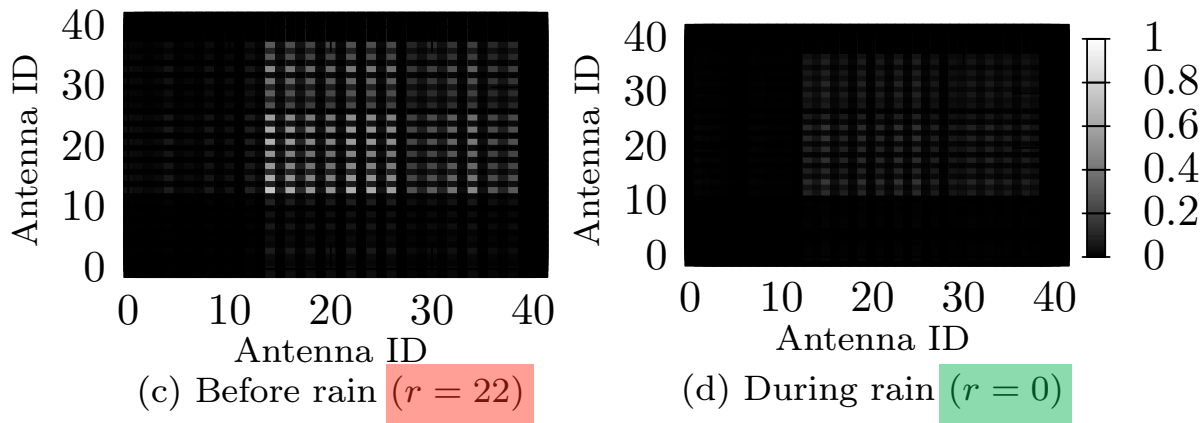
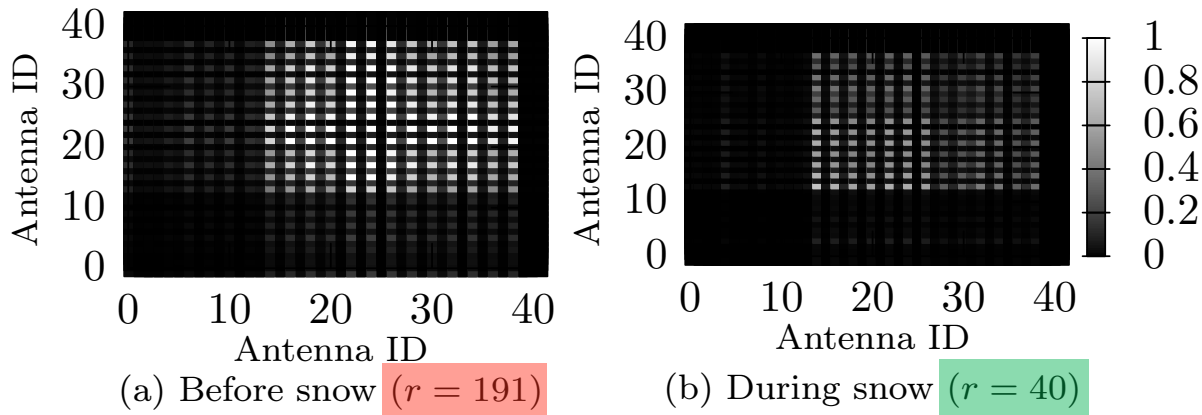
Moderate Rainfall: Rain Rate 0.12 inches/hour



Heavy Rainfall: Rain Rate 0.75 inches/hour

Skylark mMIMO: Snow & Rain Impact

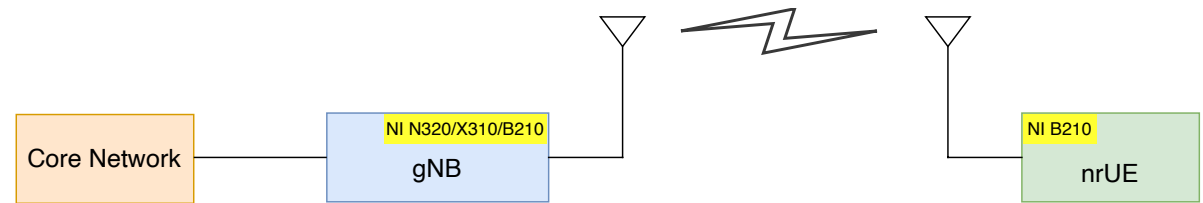
r : # of channel pairs with corr. coefficient greater than 0.5



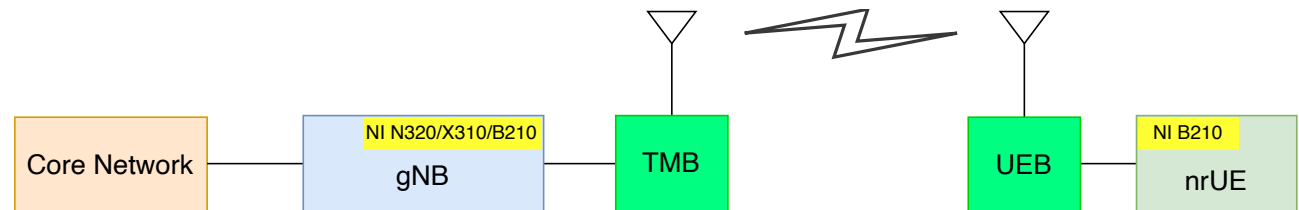
Open-Source 5G and Open RAN



Sandbox



In-Field



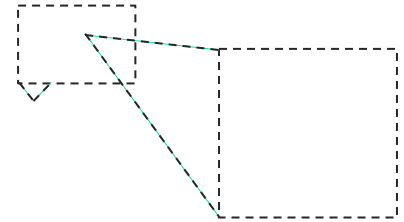
OpenAirInterface, srsRAN, SD-CORE,
SD-RAN, OSC RIC, FlexRIC

**End-to-end, in-field & whole-stack 5G programmability
from UE to gNB and core!**

Applications Research

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

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



Demos at 2023 ARA Public Launch

- Real-time liquid wireless networking demo
 - [Real-Time Liquid Wireless Networking for Data-Intensive Applications \[video\]](#)
- Agriculture
 - [Data Throughput and Connectivity for AI Infused Ag Machinery Systems \[video\]](#)
 - [ARA-Enabled Teleoperation of Automated PhenoBots \[video\]](#)
 - [Livestock Monitoring via Telepresence and Video Streaming](#)

Demos at AraFest'24

- Wireless

- [Integrated Wireless Access, X-Haul, and LEO Satellite Communications for Digital Agriculture \[slides\]](#)
- [End-to-End, Whole-Stack Open-Source 5G Experimentation in ARA \[slides\]](#)

- Agriculture

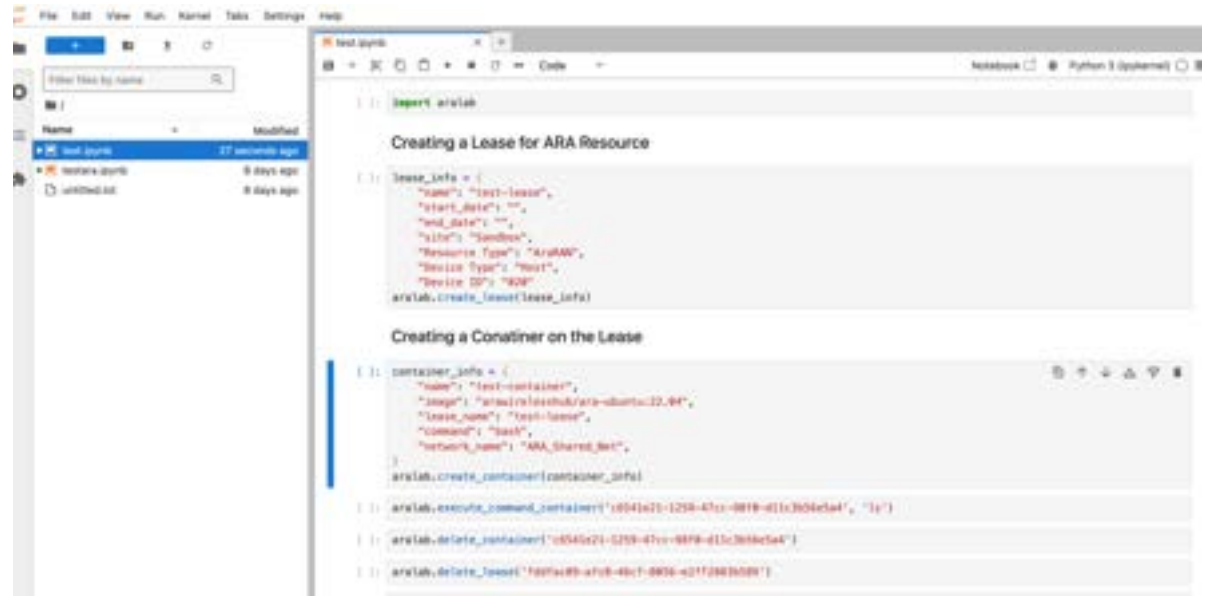
- [ARA-Enabled AI for Precision Agriculture \[slides\]](#)

Experiment Reproducibility & Community Building

- ARA tooling support
 - *Profile*: experiment spec in YAML files
 - *Jupyter Notebook*: experiment spec as Python programs

```
heat_template_version: '2015-04-30'
resources:
  lease_0:
    type: OS::Blazar::Lease
    properties:
      start_date: ''
      end_date: ''
      name: Demo_Lease
      reservations:
        - resource_properties:
            - Site: DataCenter
              Resource_Type: ComputeNode
              Device_Type: Compute
              Device_ID: '000'
  container_0:
    type: OS::Zun::Container
    depends_on:
      - lease_0
    properties:
      command: bash
      image: arawirelesslab/ara-ubuntu:22.04
      name: Demo_Container
      hints:
        host_name: DataCenter-Compute-000
      networks:
        - network: ARA_Shared_Net
```

Experiment Profile



The screenshot shows a Jupyter Notebook interface with a file browser on the left and a code editor on the right. The code editor contains the following Python code:

```
import aratah

Creating a Lease for ARA Resource

lease_info = {
    "name": "test-lease",
    "start_date": "",
    "end_date": "",
    "site": "SandBox",
    "Resource_Type": "ARA4W",
    "Device_Type": "Host",
    "Device_ID": "000"
}
aratah.create_lease(lease_info)

Creating a Container on the Lease

container_info = {
    "name": "test-container",
    "image": "arawirelesslab/ara-ubuntu:22.04",
    "lease_name": "test-lease",
    "command": "bash",
    "network_name": "ARA_Shared_Net",
}
aratah.create_container(container_info)

aratah.execute_command(container_id="054621-5259-47cc-9819-d1c3b96e54f", "ls")

aratah.delete_container("054621-5259-47cc-9819-d1c3b96e54f")

aratah.delete_lease("1001c0b-af08-49c1-8936-e0112803001")
```

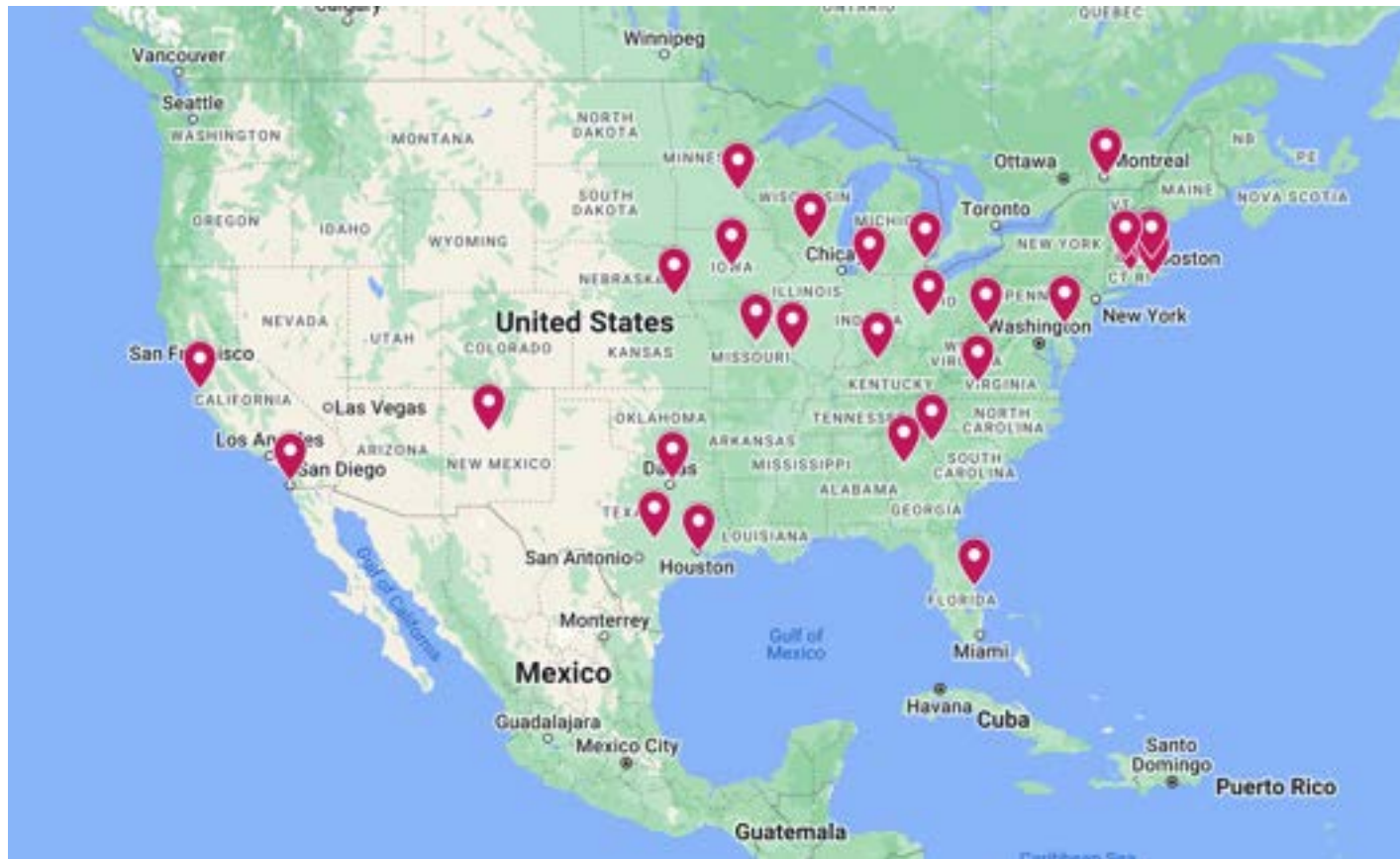
Jupyter Notebook

ARA User Community

Usage Metric	Count
Number of Organizations (e.g., universities, companies)	48
Number of Teams (ARA Projects)	95
Number of Individual ARA Users	319



ARA User Distribution



International Universities: 8

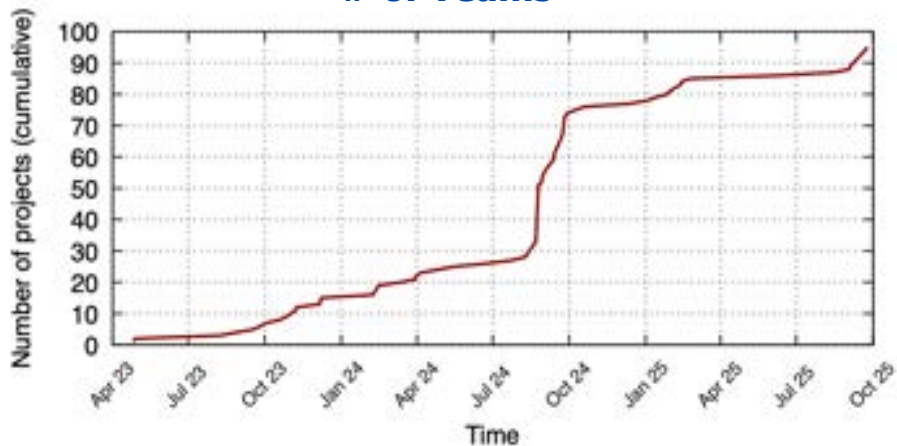
Canada, Brazil

Austria, France, Italy, Sweden

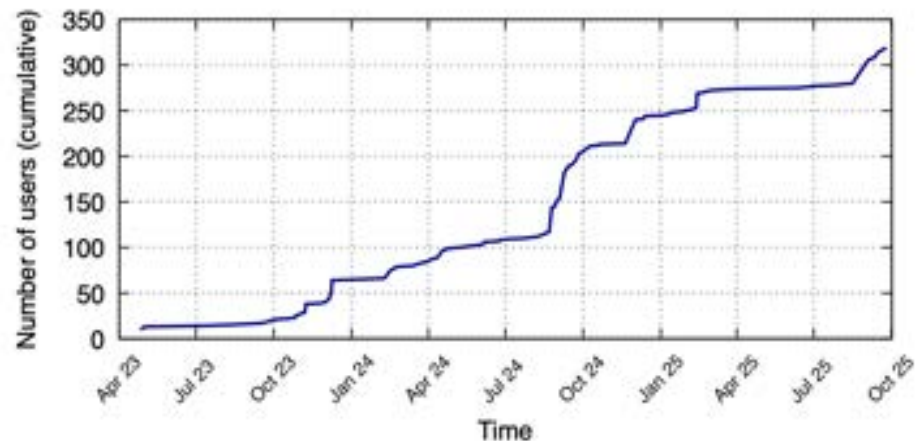
Taiwan, Thailand

ARA Usage Statistics

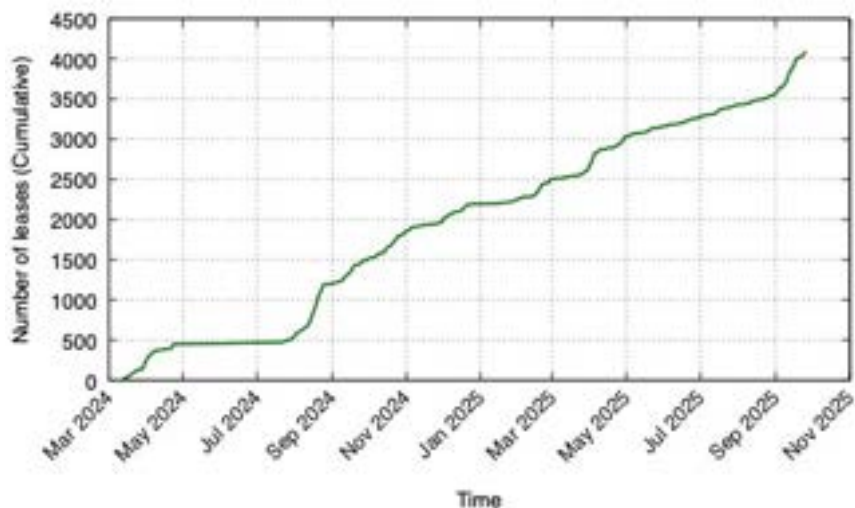
of Teams



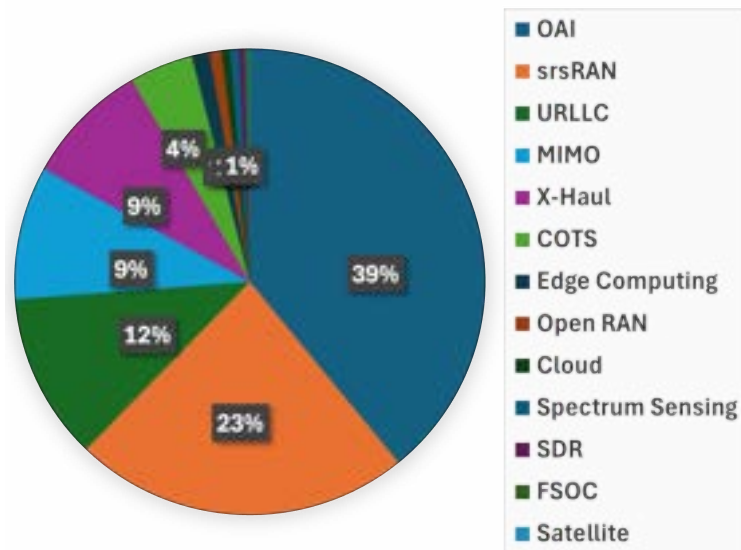
of Users



of Experiments



Experiment Distribution



2024 ARA User Workshop & Arathon, August 24 - 25



2025 ARA User Workshop & Arathon, Sept. 27-28



2024 Farm Progress Show, August 27-29

farmprogressshow.com



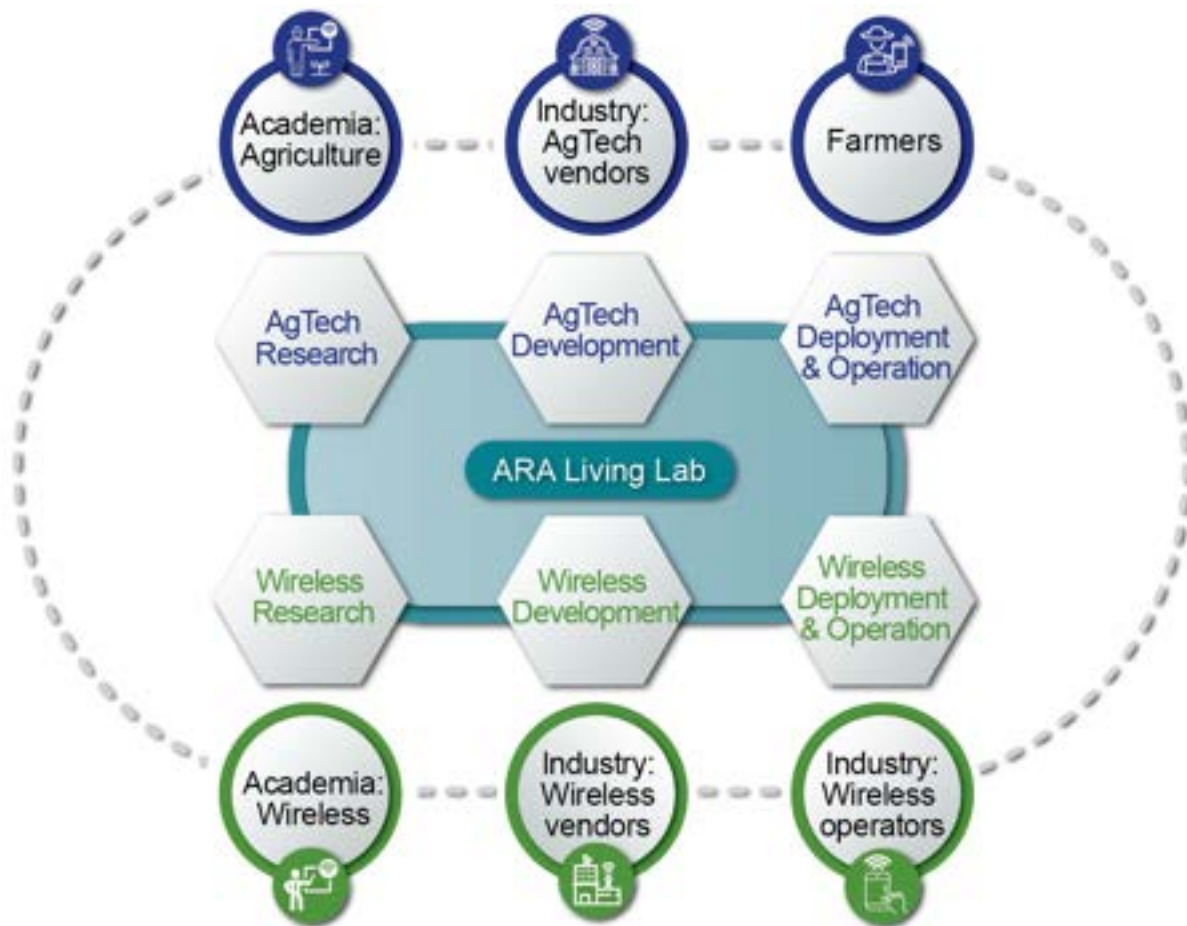
Farm Progress Show



150,000+ visitors
30+ countries
45+ U.S. states

2026 Farm Progress Show, Sept. 1-3





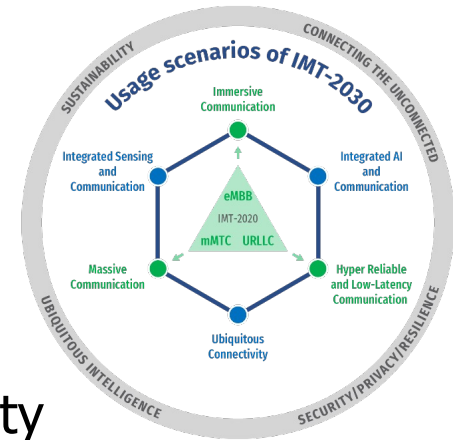
Major Initiatives with ARA-Enabled Ecosystem Collaboration

- [ARA-OTIC](#): O-RAN Open Testing and Integration Center
- [ACCoRD](#): O-RAN testing & evaluation with wireless industry (\$42M)
- [ArMORED](#): energy-efficient massive MIMO O-RU (\$10M)
- [ICICLE](#) AI Institute on AI cyberinfrastructure (\$20M)
- John Deere, Collins Aerospace etc



wici.iastate.edu/projects
[icicle.ai](https://www.icicle.ai)

Summary



- Connecting the unconnected: challenge & opportunity
- Living lab challenges
 - Research & innovation platforms
 - Openness vs. performance & robustness
 - Continuous evolution of software & hardware
 - Community building
 - From individual experiments to integrated solutions
 - Wireless and application co-evolution & ecosystem alignment