Demo: ARA PAWR Wireless Living Lab for Smart and Connected Rural Communities

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***Abstract*—ARA is an at-scale Platform for Advanced Wireless Research (PAWR), specifically tailored to the unique community, application, and economic context of rural regions. It features the first-of-its-kind real-world implementation of long-distance, high-capacity wireless backhaul and access systems spanning over 30 km in diameter. Leveraging both software-defined radios and programmable Commercial Off-The-Shelf (COTS) systems, ARA orchestrates the wireless resources alongside the networking and compute resources for enabling end-to-end experiments involving user equipment, base stations, edge computing, and cloud infrastructure. Such an integration facilitates the co-evolution of rural-focused wireless innovation and applications, while helping to advance the frontiers of advanced Next-G wireless systems such as Open RAN. As of summer 2024, ARA is publicly accessible with 7 base stations (BSes) and over 30 user equipment (UEs). In this demo, we share advanced wireless research experiments enabled by ARA, involving MU-MIMO in TV White Space (TVWS) bands, long-range mmWave and microwave backhaul communications, and open-source 5G NR protocol stacks such as srsRAN and OpenAirInterface (OAI).**

***Index Terms*—ARA, Rural Wireless, xHaul, NextG, Precision Agriculture**

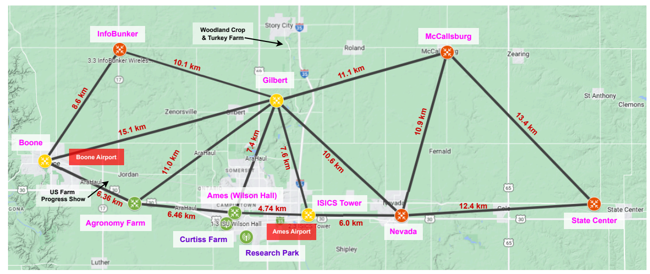

Fig. 1: ARA deployment in central Iowa, U.S.A.

TABLE I: Heterogeneous, High-Capacity Wireless Access and X-Haul Platforms in ARA

	Platform	Frequency	Bandwidth	Capacity	Range
AraRAN	AraMIMO-TVWS	460–776 MHz	upto 40 MHz	100+ Mbps	8.5+ km
	AraMIMO-C	3.45–3.55 GHz	100 MHz	650+ Mbps	8.5+ km
	AraMIMO-mm	27.5–27.9 GHz	4 × 100 MHz	1.3+ Gbps	500+ m
	AraSDR	3.4–3.6 GHz	200 MHz	100+ Mbps	1.2+ km
AraHaul	AraHaul-micro	10.6–11.5 GHz	100 MHz	1 Gbps	20+ km
	AraHaul-mm	71–86 GHz	2 GHz	10 Gbps	15+ km
	AraOptical	191.7–194.8 THz	80 GHz	160 Gbps	10+ km

I. ARA Overview

Addressing the challenge of limited broadband access in rural areas necessitates innovative advancements in rural-focused broadband technologies [1]. To this end, we design and implement ARA [2] wireless living lab as one of the NSF Platforms for Advanced Wireless Research (PAWR) aimed at rural broadband and applications. ARA is uniquely designed to accommodate the distinctive community dynamics, application requirements, economic considerations, and operational challenges inherent in rural wireless systems. ARA marks a significant milestone with its implementation of cutting-edge wireless access and backhaul platforms in real-world agricultural and rural environments.

Fig. 1 shows the ARA deployment in central Iowa, U.S.A. ARA has completed its Phase-1 and Phase-2 deployments including 7×BSes, with the AraHaul mesh connecting the sites, as well as 30+ UEs, with 20 more UEs to be deployed by the end of 2024. The fixed UEs are deployed in crop and livestock farms and city facilities, while the mobile UEs are installed on ag-vehicles, city buses, and vehicles of pubic safety services. The BS marked in green, i.e., Wilson Hall, Curtiss Farm, Research Park, and Agronomy Farm, were deployed as part of ARA Phase-1 by summer 2023 while the ones marked in yellow, i.e., Boone, Gilbert, and ISICS public safety tower, are deployed as part of Phase-2 by summer 2024. Each BS supports heterogeneous access network platforms, i.e., *AraRAN*. In addition, except Research Park and Curtiss farm, the BSes form a long-distance, high-capacity wireless mesh xhaul, i.e., *AraHaul*. Both *AraRAN* and *AraHaul* span the City of Ames, where Iowa State University (ISU) resides, and surrounding agriculture farms and rural towns.

TABLE I shows the AraRAN components including both Software-Defined Radios (SDRs) and Commercial Off-The-Shelf (COTS) platforms that operate at frequencies ranging from low-UHF to mmWave bands. AraHaul consists of long-distance, high-capacity free-space optical, mmWave, and microwave wireless backhaul links. Fig. 2 shows the 4×Phase-1 BSes deployed outdoors, while Fig. 3 shows the UEs deployed in field such as crop farms, phenobots, and city water facilities. With first-of-its-kind deployment of advanced wireless and computing platforms in real-world agriculture and rural settings and through effective resource management and experiment orchestration, ARA enables unique research ex-

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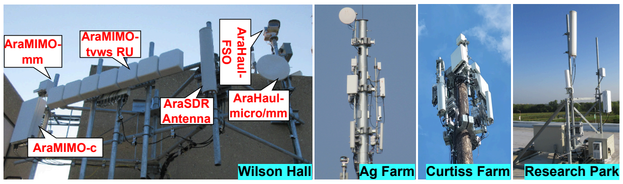

Fig. 2: ARA Field BS deployment

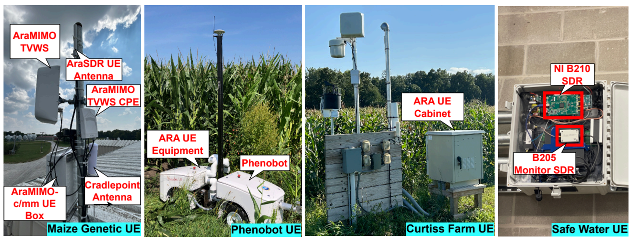

Fig. 3: ARA Field UE deployment

periments ranging from modeling, architectures, technologies, services, and applications of rural wireless systems, as shown in TABLE II.

TABLE II: ARA Enabled Research

Areas	Exemplars
Modeling	◦ Real-world rural wireless channel characterization ◦ Real-world characterization of physical dynamics and mobility of agriculture UAVs and UGVs
Network Architecture	◦ O-RAN architecture for real-time cyber-physical systems of agriculture vehicles and robots ◦ Multi-modal, long-distance, and high-throughput wireless x-haul networking ◦ Integrated rural wireless access and x-haul networking ◦ Integrated wireless networking and edge computing
Technology & Service	◦ Ultra-reliable, low-latency communications (URLLC) ◦ Massive MIMO, beam-forming, and beam tracking ◦ Dynamic spectrum sharing ◦ Open-source NextG for rural green networking
Application	◦ 360° video streaming for agriculture education ◦ Real-time video streaming and analytics for agriculture automation and livestock health monitoring ◦ XR-based teleoperation of agriculture UAVs

To enable reproducible scientific experiments in advanced wireless and applications, we develop the ARA control framework, called *AraSoft*, providing with a web interface for the users to execute their experiments. *AraSoft* is derived from the popular open-source cloud frameworks such as OpenStack and ChameleonCloud [3] with extensions for managing wireless infrastructure resources along with compute and wired networking resources.

II. Demo

ARA infrastructure is made accessible to the broad communities for performing cutting-edge research and reproducible experiments [4]. ARA enables container-based resource provisioning for experimenters. Fig. 4 depicts the ARA experiment workflow, where on login, the user reserves the required resources and launches Docker containers (with access to wireless resources) to execute the experiments. After experiment completion, the container is deleted and resources are released.

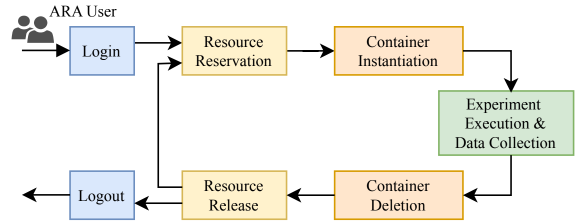

Fig. 4: ARA experiment workflow

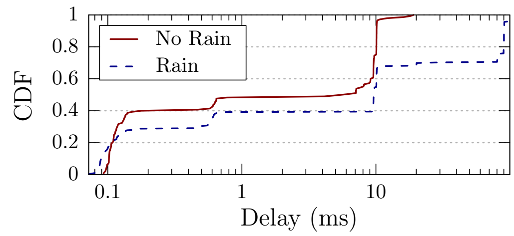

Fig. 5: Impact of rain on packet delays in 5G network

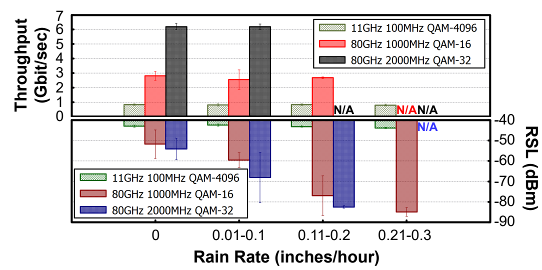

Fig. 6: Impact of rain rate on 11 GHz and 80 GHz xHaul links

A. Demo Experiments

We present two representative demo experiments to showcase the ARA-enabled research: 1) Demonstrating the fine-grained measurement of packet delays in the field-deployed OpenAirInterface (OAI) 5G network stack leveraging the fully-programmable SDRs under different weather conditions. Fig. 5 shows the cumulative distribution function (CDF) of the delays of 100 packets, measured with *LatSeq* OAI5G. For a target delay bound of 10 ms, it can be seen that only 70% of packets meet the delay bound with rain falling at an average rate of 2.06 inches per hour; 2) Demonstrating the impact of weather on multi-modal, long-distance, and high-capacity mmWave and microwave wireless backhaul links. Fig. 6 shows that the mmWave link at 80 GHz is more impacted by increasing rain rates as compared to microwave link at 11 GHz, which maintains stable received signal level and throughput values under changing weather conditions.

In addition, we demonstrate example experiments on COTS TVWS, microwave, and mmWave platforms to help the conference audience understand the unique experiments enabled by ARA and the insights derived from them.

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