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Demo Abstract: UnionLabs: AWS-based Remote Access and Sharing of NextG and IoT Testbeds

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***Abstract*—Over-the-air (OTA) validation is an important step before deploying new techniques in real world for NextG (5G, 6G and beyond) and wireless Internet of Things (IoT). However, most existing NextG and IoT testbeds are limited in scenario diversity, availability of computing and hardware resources, as well the flexibility to access and operate the resources. To alleviate these limitations, in this work we introduce *UnionLabs*, an AWS-based unified platform for remote access and sharing of OTA testbeds for NextG and IoT. We will demonstrate UnionLabs by i) federating six heterogeneous wireless testbeds deployed at University at Buffalo and the University of Utah, spanning ground, underwater and underground domains; ii) scheduling and conducting real-time OTA experiments over these testbeds, and iii) engaging with public repositories for user-generated code and datasets. Through UnionLabs, we aim to create a grassroots campaign to democratize access to wireless research testbeds with heterogeneous hardware resources and network environments.**

***Index Terms*—Over-the-air (OTA) experiments, NextG, IoT, Testbed Sharing, Amazon Web Services (AWS).**

I. Introduction

In this demo we introduce a new scalable testbed federation platform, referred to as *UnionLabs*, aiming to accelerate experimental wireless communication and networking research by providing a unified access point to distributed diverse NextG and IoT testbeds. We demonstrate through real-time experiments the integration of heterogeneous NextG and IoT testbeds located in Buffalo, NY, and Salt Lake City, UT, USA.

Significant efforts have been made by the community to accelerate experimental wireless research. A notable example is the NSF Platforms for Advanced Wireless Research (PAWR), including POWDER, COSMOS, AERPAW, ARA, and Colosseum [1]. Based on the lessons learned through these efforts, there are still several major challenges towards creating a mature, scalable and sustainable ecosystem for the wireless community. First, most existing testbeds are deployed at fixed pre-selected sites, and this makes it hard to test the effects of those site- and testbed-dependent factors, such as multipath channels, local interference and hardware nonlinearities, on the generalizability of new, particularly data-driven, signaling processing, communication and networking techniques [2]. Second, it can be both time and monetary costly for individual researchers to construct their own over-the-air (OTA) testbeds. Particularly, due to the instable global semiconductor supply chain, the price of software radio and computing devices has gone up significantly in the past several years. For example, the cost of a small-scale Open Radio Access Network (O-RAN) testbed with USRP X310 software radios for eNodeB and USRP B210 for UE may easily exceed $50,000 USD.

To address these challenges, we launched the initiative of *UnionLabs* in 2022, aiming to create a grassroots campaign to democratize access to wireless research testbeds with heterogeneous hardware resources and network environments. UnionLabs is designed to provide a unified remote and real-time access to a set of diverse NextG and IoT testbeds, hence removing the barriers to OTA experimentation for validation of new communication techniques and algorithms.

II. UnionLabs Framework Design

As outlined in Fig. 1, the UnionLabs framework is comprised of three core components, i.e., *User Plane*, *Testbed Plane*, and *Federation Plane*. In the *User Plane*, users are divided into three categories: i) Testbed Users, which represent all individuals using the platform to conduct experiments; ii) Testbed Owners, which are institutional representatives who own and manage a testbed; and iii) Administrators, which define testbed namespaces, solve operational issues, and manage public repositories. The *Testbed Plane* includes all

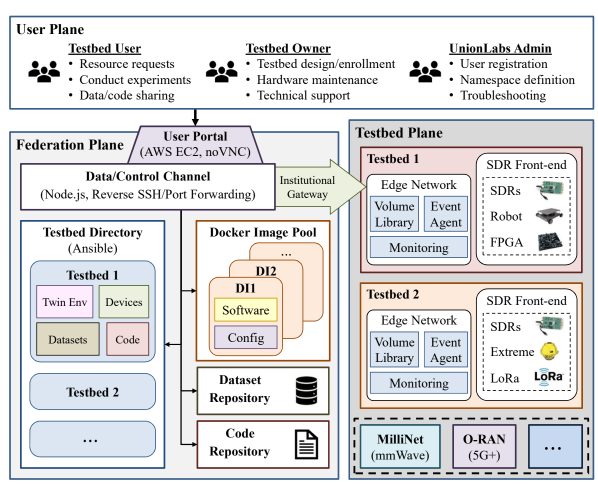

Fig. 1: Overview of UnionLabs architecture.

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TABLE I: Configuration summary of federated testbeds.

Testbed	Supported Experiments	Edge Cloud	Software Radio	Frequency	Bandwidth
NeXT (UB)	Ad Hoc in-air networking	Dell PowerEdge R340	USRP N210 w/ CBX	1.2-6 GHz	10 MHz
UWCT (UB)	Underwater communications	Dell Latitude 5491	USRP N210 w/ LFTX/LFRX	0-30 MHz	300 kHz
UGCT (UB)	Underground communications	Dell Latitude 5491	USRP N210 w/ LFTX/LFRX	0-30 MHz	300 kHz
MilliNet (UB)	Beamforming, RADAR	Dell Latitude 5491	M-Cube, USRP B210	60 GHz	2.16 GHz
O-RAN (UB)	Network slicing, xAPP design	Dell Precision 7920	USRP X310 w/ CBX, USRP B210	1.2-6 GHz	40 MHz
IoT (UoU)	Long-range IoT	Grafana & InfluxDB	Adafruit RFM95W LoRa	868, 915 MHz	125, 500 kHz

the federated testbeds, including all hardware and software resources provided by testbed owners, as well as edge networks to provide remote access to each testbed through institutional gateways. Finally, the *Federation Plane* is developed and deployed based on Amazon Web Services (AWS) [3] for management of all user data, public repositories, and activity between users and testbeds.

In the Federation Plane, the *user portal* interface is deployed as a monolith Node.js application, which enables access to the requested testbeds via noVNC client in a Docker container hosted on AWS EC2. The *code and dataset repositories* standardize both testbed-specific and cross-compatible file sharing among testbed users and owners. The *testbed directory* hosts library of Ansible Playbooks for each testbed node, which defines the Docker volume, Docker image, and other files needed for automated node instantiation. After experimental resource reservation, the Federation Plane starts the Docker service on each node, deploys containers using the selected Playbooks, and starts a TightVNC server for user access.

III. Demonstration

We will demonstrate the scalability and flexibility of UnionLabs in testbed federation, remote experiments, and code/dataset publication.

Scalable Testbed Federation. We showcase the scalability of UnionLabs by integrating six heterogeneous NextG and IoT testbeds. These are i) *UB NeXT*, a software-defined testbed for integrated RF network simulation, experimentation and optimization [4]; ii) *Underground Communication Testbed (UGCT)*, which supports HF-band software-defined experiments using magnetic induction (MI) transceivers; iii) *Underwater Communication Testbed (UWCT)*, which supports underwater communication experiments using acoustic transceivers; iv) *MilliNet*, a software-defined testbed based on M-Cube [5], supporting wireless communications and RADAR sensing experiments in the mmWave frequency band (60 GHz for MilliNet); v) *O-RAN testbed*, enabling network slicing, X-APP development and data-driven optimization for NextG networks; and vi) *IoT testbed*, supporting data collection and communication experiments using LoRa-based wireless sensor network. The first five testbeds are deployed at University at Buffalo and the last one is deployed at the University at Utah. Figure 2 provides a snapshot of the federated testbeds, and Table I summarizes the configurations of these testbeds.

Flexible Remote Experiments. We will show the flexibility of UnionLabs through several walkthrough experiments. To reserve testbed resources, a request will be submitted via the AWS user portal. Once authenticated, one can specify a testbed and the number of nodes to use, and select start time and experiment duration using a centralized control panel. At

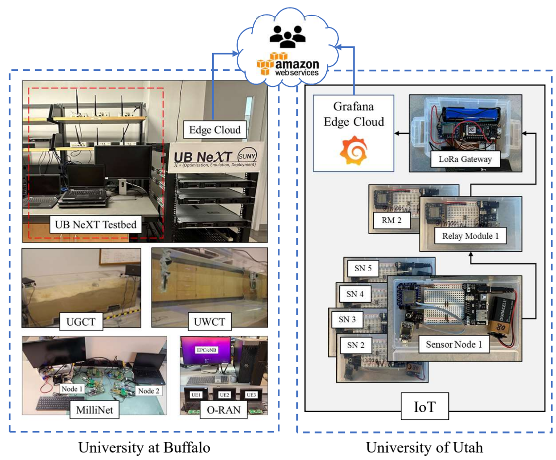

Fig. 2: Federated testbeds (from top left): UB NeXT, UGCT, UWCT, MilliNet, O-RAN, and IoT Testbed.

the reservation start time, pre-configured Docker containers are started on the reserved nodes, and connect TightVNC servers to the User Portal noVNC client via reverse SSH proxy with port forwarding. Once connected, experiments will have real-time control over each node and their associated Docker volume. The walkthrough experiments include joint power and routing optimization in ad hoc networks over UB NeXT testbed, xAPP configuration over O-RAN testbed, channel estimation over UWCT, moisture sensing over UGCT, link quality analysis over MiliNet, and distributed data collection over the IoT testbed. Through these experiments, we will show that *UnionLabs allows users to access and operate heterogeneous NextG and IoT testbeds remotely, with enhanced flexibility while requiring zero configurations of the user-side computers.*

Automated Code/Dataset Loading and Publication. To prevent the tedious manual download/upload tasks, experimenters are allowed to load files from the code and dataset repositories on testbed containers in an automated manner during experiments. Similarly, after experiments, one can save the modified files or collected data to the Docker volume, or publish them to the public cloud for community sharing.

References

[1] https://advancedwireless.org/.

[2] M. McManus, Z. Guan, N. Mastronarde, and S. Zou, "On the Source-to-Target Gap of Robust Double Deep Q Learning in Digital Twin Enabled Wireless Networks," in *Proc. of SPIE Big Data IV: Learning, Analytics, and Applications*, Orlando, Florida, United States, April 2022.

[3] https://aws.amazon.com/.

[4] J. Hu, M. McManus, S. K. Moorthy, Y. Cui, Z. Guan, N. Mastronarde, E. S. Bentley, and M. Medley, "NeXT: A Software-Defined Testbed with Integrated Optimization, Simulation and Experiment," in *Proc. of IEEE Future Networks World Forum (FNWF)*, Montreal, Canada, October 2022.

[5] R. Zhao, T. Woodford, T. Wei, K. Qian, and X. Zhang, "M-Cube: A Millimeter-Wave Massive MIMO Software Radio," in *Proc. of ACM MobiCom*, London, United Kingdom, September 2020.