Federal Register Notice: 89 FR 51554, Federal Register :: Networking and Information Technology Research and Development Request for Information on Digital Twins Research and Development, June 18, 2024.

Request for Information on the National Digital Twins R&D Strategic Plan

Salvatore D'Oro
Michele Polese
Pedram Johari
Tommaso Melodia
The Institute for the Wireless Internet of Things (WIoT) at Northeastern University

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Before the

Networking and Information Technology Research and Development (NITRD)

National Coordination Office (NCO), National Science Foundation

Alexandria, VA 22314

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COMMENTS OF THE INSTITUTE FOR THE WIRELESS INTERNET OF THINGS AT NORTHEASTERN UNIVERSITY

The Institute for the Wireless Internet of Things (WIoT) at Northeastern University respectfully files these comments on the NITRD Request for Information (RFI) on digital twins research and development. WIoT commends NITRD for seeking comments on this topic. This document aims to provide comments on a specific subset of matters raised by the RFI, as outlined below.

Regulatory:

Regulatory Science Challenges associated with the use of Digital Twins

Digital twins can significantly enhance spectrum management by providing spectrum regulators like the FCC with detailed insights into the dynamic needs of modern wireless communication. By simulating various scenarios and use cases, digital twins can help regulators evaluate, revisit and update existing spectrum regulations. For example, they can aid in extending spectrum coexistence principles beyond the Citizens Broadband Radio Service (CBRS) and Industrial, Scientific, and Medical (ISM) bands. With most spectrum allocated exclusively but rarely utilized, digital twins can model and optimize spectrum sharing, making better use of this valuable resource. They can be instrumental in reassessing exclusion zones, refining tiered spectrum access policies, and improving the deployment of cognitive radios, which can dynamically adapt to real-time spectrum availability and conditions. These insights can drive more efficient and flexible spectrum management practices, ensuring that regulatory frameworks keep pace with technological advancements and evolving usage patterns.

Furthermore, digital twins can also support the Federal Aviation Administration (FAA) in enhancing regulations for beyond line of sight (BLOS) UAVs and drone operations. By creating accurate virtual environments that replicate real-world conditions, digital twins can simulate UAV and drone activities in various scenarios, helping to identify potential risks and optimize safety protocols. This capability allows the FAA to evaluate and refine regulations related to BLOS operations, ensuring that they are robust and adaptable to emerging drone technologies and applications. For instance, digital twins can be used to test and validate new flight paths, assess the impact of UAVs on existing air traffic, and develop advanced collision avoidance systems. By leveraging digital twins, the FAA can create a more responsive and effective regulatory framework that supports the safe and efficient integration of UAVs into the national airspace, fostering innovation while maintaining high safety standards.

Ecosystem:

Establish a National Digital Twin R&D Ecosystem: Possible focus areas: smart and connected communities

The development of intelligent connectivity with robust and reliable algorithmic components and seamless multi-vendor integration requires addressing several challenges at the architectural, algorithmic, and system-level design. In this context, digital twins for smart and connected communities can serve as a safe digital playground to address the following challenges:

- **Need for Datasets.** To develop robust and scalable Artificial Intelligence (AI) and Machine Learning (ML) solutions, which generalize well across a variety of real-world deployment scenarios, it is necessary to leverage rich datasets of Radio Access Network (RAN) telemetry, data, and performance indicators [1]. While network operators are in a unique position to collect such datasets, it is often impractical or impossible to use them for research and development due to privacy and security concerns. Wireless testbeds represent a feasible path to overcome this limitation [2–6]. However, they are often limited to the Radio Frequency (RF) characteristics and topology of their deployment area.

- **End-to-end AI and ML Testing.** Once trained, AI/ML-based control solutions need to be validated and tested in controlled environments to avoid disruption in production networks. At the same time, the testing conditions need to be realistic to obtain meaningful results that consider, for instance, the user load, traffic patterns, and RF characteristics of real-world deployments the models will be used to control.

- **Continuous Software Validation.** While softwarization introduces flexibility and programmability of the stack, it also comes with concerns around software quality, reliability, security, and performance [7]. Therefore, integrating, validating, testing, and profiling software for wireless in a continuous fashion is key to the Open RAN vision. Additionally, this validation needs to consider various compute platforms and hardware acceleration solutions for physical layer processing.

- **Automated Integration and Testing of Disaggregated Components.** Disaggregation comes with a more robust supply chain, but also a need for the validation of interoperability across vendors and devices. This is a labor-intensive and often manual process that calls for the development of automated techniques [8].

- **Bidirectional Interaction Between the Virtual and Physical Media.** Incorporating Digital Twins (DTs) into wireless communication can enhance predictive maintenance, resource allocation, and troubleshooting, thus bolstering network reliability. To unleash these capabilities, it is essential for DTs to integrate real-time data when mirroring their real-world counterparts. This enables precise monitoring, planning and optimization of a pre-deployed wireless networks, which requires bidirectional and near real-time links between real-world deployment and their DT replicas. Lightweight publish-subscribe, machine to machine network protocols such as MQTT can be utilized to enable such bidirectional data transfer between the twin media [9].

To this end, a digital twin infrastructure that complements real-world wireless testbeds can play a unique role in addressing these challenges and advancing smart and connected communities. To this end, we have been developing digital twin capabilities in the Colosseum network emulator—the world's largest wireless network emulator with hardware in the loop [10]—thanks to support from the O-RAN ALLIANCE, the NTIA Innovation Fund, OUSD R&E, and NSF. A the Open RAN digital twin, Colosseum can be leveraged to address these challenges and to develop end-to-end, fully integrated, and reliable solutions for Open RAN, as shown in Figure 1, from [11]. Through its channel and traffic emulation capabilities, Colosseum can replicate countless real-world scenarios representative of real-world cellular deployments, and generate datasets that can be used to train AI/ML models robust to network changes [12]. A combination of generic compute nodes, Software-defined Radios (SDRs), and the possibility of integrating Commercial Off-the-Shelf (COTS) devices, allows for the digital replica of Open RAN and 5G-and-beyond protocol stacks [13, 14], which we manage through automation and Continuous Integration (CI) and Continuous Deployment (CD) pipelines [15]. This enables repeatable experiments, where different network configurations and protocol stacks can be tested against the same

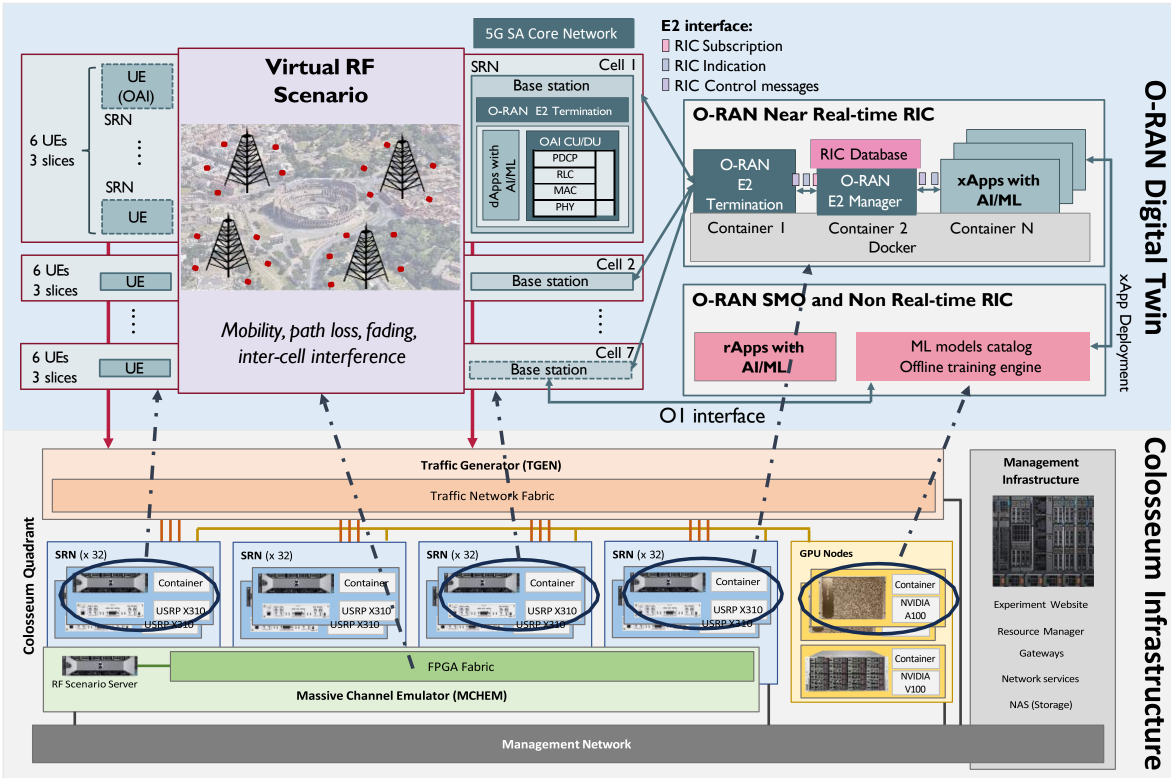

Figure 1: Open RAN twinning capabilities in Colosseum.

channel and traffic conditions, as well as a safe playground for testing of AI/ML solutions. The CI/CD and automation also enable continuous validation, as the same software can be tested over time for regression in a realistic environment, and against various other stacks for integration.

We argue that to further the development of smart and connected communities it is fundamental to coalesce resources across government, industry, and academia to advance the capabilities of digital twin solutions such as Colosseum, toward 6G and next-generation wireless systems.

/s/ Salvatore D'Oro
Research Associate Professor
Institute for the Wireless Internet of Things
Northeastern University

/s/ Michele Polese
Research Assistant Professor
Institute for the Wireless Internet of Things
Northeastern University

/s/ Pedram Johari

Principal Research Scientist
Institute for the Wireless Internet of Things
Northeastern University

/s/ Tommaso Melodia

William Lincoln Smith Professor
Institute for the Wireless Internet of Things
Northeastern University

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