Demo: A Novel 3D Environment-Aware Digital Twin Online Channel Modeling Platform

Shiyu Xiao[1], Hanbin Zhang[1], Mingchuan Yao[1], Chenhao Cui[1], Junling Li[1,2*],
Chen Huang[2,1], and Cheng-Xiang Wang[1,2*]
[1]National Mobile Communications Research Laboratory, School of Information of Science and Engineering,
Southeast University, Nanjing 210096, China
[2]Purple Mountain Laboratories, Nanjing 211111, China
[*]Corresponding Authors: Junling Li, Cheng-Xiang Wang
Email: {s.y.xiao, hb_zhang, mc_yao, 213212498, junlingli, chxwang}@seu.edu.cn, huangchen@pmlabs.com.cn

***Abstract*—The digital twin (DT) is a real-time representation that maps physical systems to the virtual world, facilitating the sensing and analysis of physical data for prediction and decision-making. Our work proposes a three-dimensional environment-aware digital twin online channel modeling platform (3D-EADTOCMP), comprising the virtualization, perception, and processing modules. The virtualization module reconstructs the real world, including 3D shapes, materials, and locations. The perception module enables real-time sensing of dynamic 3D environments, including the detection of object types and their motions. Subsequently, the processing module updates channel characteristics based on environmental variations. In conclusion, the 3D-EADTOCMP offers a low-cost, low-complexity, and high-precision method for acquiring 3D channel characteristics in real time, significantly optimizing 6G networks.**

***Index Terms*—Digital twin, 6G online channel modeling, environment-aware, perception.**

I. Introduction

The sixth generation (6G) wireless communication networks are envisioned to achieve "global coverage, all spectra, full applications, all senses, all digital, and strong security" [1]. Traditionally, the pilot-training method has been employed to obtain real-time channel state information (CSI), which incurs significant overhead. However, 6G wireless communication networks are designed to accommodate denser user nodes and network infrastructure, requiring larger dimensional channels to support the use of larger antenna arrays, wider bandwidths, and higher user mobility in the environment. This increased complexity exacerbates the difficulty of obtaining real-time CSI using the pilot-training method [2]. Consequently, a low-cost, low-complexity, and high-precision method to acquire channel characteristics is needed.

To address this challenge, we introduce a three-dimensional (3D) environment-aware digital twin (DT) online channel modeling platform (3D-EADTOCMP). This platform leverages extensive offline data, including material properties and spatial positions of static objects, as well as pre-measured channel data, to accurately reconstruct the channel. It can perceive 3D spatial changes of dynamic objects in real time, update the channel map information accordingly, and ultimately present the 3D visualization results to the user.

II. System Overviews

The development of 3D-EADTOCMP involves pre-constructing static scenes and their channel characteristics, with real-time updates for dynamic objects and channel adjustments. This approach effectively reduces the pilot overhead, offering three key benefits:

- **3D digital twin online channel modeling**: 3D-EADTOCMP uses reconstructed 3D environments and ray-tracing (RT) for precise channel simulation and electromagnetic properties analysis.
- **Interactive user interface (UI)**: 3D-EADTOCMP offers a user-friendly design for customizing positions of transmitters (Tx), receivers (Rx), and channel characteristics, and visualizing interactions between channel characteristics and the environment, enhancing understanding of environmental impacts on communication quality.
- **Comprehensive channel characteristics**: 3D-EADTOCMP provides extensive channel characteristics including large/small-scale fading, statistical properties across all six domains, capacity calculation, and model details, ensuring deep insights into channel performance under varied conditions.

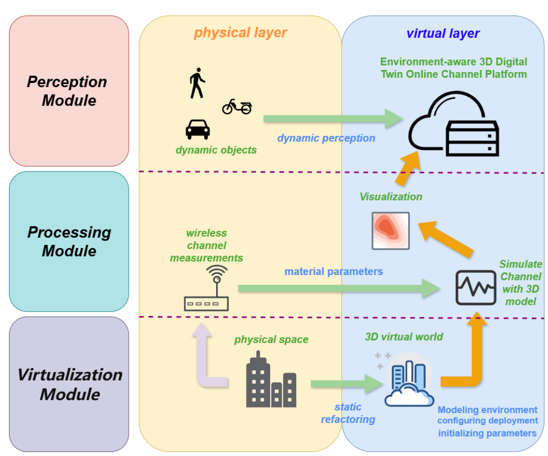

Fig. 1. System overviews.

III. Design procedure of Digital Twin Online Channel Models

A. Environment Reconstruction for Static Scenes

1) Image Acquisition and Building Reconstruction: The project initiates with drone-captured 3D imagery, featuring significant overlap for terrain reconstruction. Blender reconstructs buildings to scale, applying textures from aerial views for realism, aligning the 3D scene's electromagnetic properties with reality.

2) CSI Generation: Blender's output, endowed with electromagnetic attributes, integrates into Wireless Insite for accurate simulation with RT, which generates precise CSI, calibrated against empirical data for enhanced predictive accuracy.

3) Channel Characteristics Visualization: Channel characteristics are graphically represented through heat maps within the visualization module. This interface supports customization options for heat map aesthetics, Tx location depiction, and choice of channel characteristics for visualization, thereby enriching the analytical capabilities and understanding of channel characteristics.

4) Integrated 3D-EADTOCMP Development: Unity consolidates static models and channel characteristics with an interactive UI, enabling intuitive exploration and analysis of 3D environments and channel characteristics.

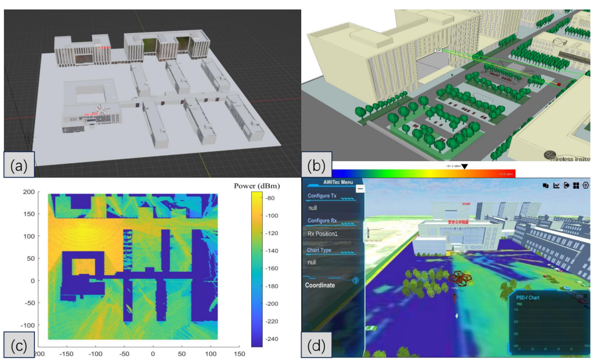

Fig. 2. Illustration of static scene reconstruction.

B. Environment Perception for Updating Dynamic Scenes

1) Environment Perception: Video stream bifurcates for parallel processing: you-only-look-once (YOLO) [3] network detects object class and 2D coordinates in one stream, while a depth camera program provides depth in another.

2) Synchronization within 3D-EADTOCMP: Post-synchronization of timestamps, the transmission of 3D coordinate data, inclusive of depth metrics and object classifications, to the Unity platform enables the faithful instantiation of virtual objects at their correct spatial positions.

3) Case Study: Demonstrating outdoor dynamic object sensing and update, Fig. 3 depicts the test site and the sensor setup. The workflow includes manual sensor position input for initialization, object detection, and bounding in the environment, depth conversion, calculation of object world coordinates, and display of object position and current power azimuth spectrum (PAS) information, In this case, the pedestrian acts as the dynamic object and the Rx, as illustrated in Fig. 4.

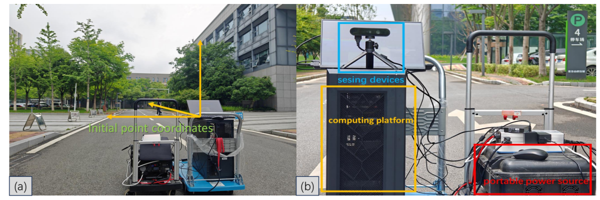

Fig. 3. Test site demonstration.

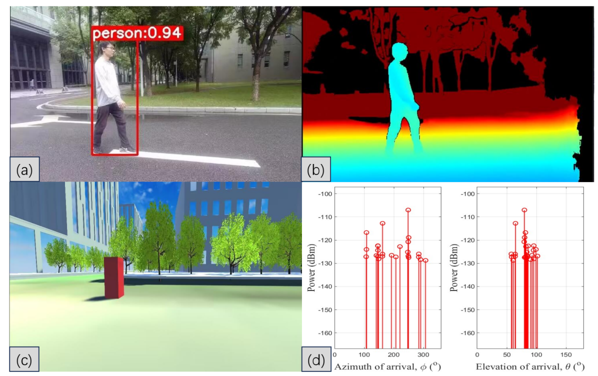

Fig. 4. Real-time channel characteristics demonstration.

IV. Conclusions

In this paper, we have proposed a framework for 3D-EADTOCMP, providing a comprehensive study of real-time channel characteristics. Static scenes permit visualization of channel characteristics at various points given a fixed Tx. The platform identifies moving object types and 3D coordinates, updating channel characteristics accordingly. Future enhancements will enable real-time channel characteristics updates for the whole network, based on scatter positions and velocities. We hope that the 3D-EADTOCMP will improve the efficiency, adaptability, and performance of future networks.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (NSFC) under Grants 62301151 and the Fundamental Research Funds for the Central Universities under Grant 2242022k60006.

References

[1] C.-X. Wang, X. You, X. Gao, et al., "On the road to 6G: Visions, requirements, key technologies and testbeds," *IEEE Commun. Surveys Tuts.*, vol. 25, no. 2, pp. 905–974, 2nd Quart. 2023.

[2] Y. Zeng and X. Xu, "Toward environment-aware 6G communications via channel knowledge map," *IEEE Wireless Commun.*, vol. 28, no. 3, pp. 84–91, June 2021.

[3] J. Redmon, S. Divvala, R. Girshick and A. Farhadi, "You only look once: unified, real-time object detection," *IEEE Conf. Comput. Vis. Pattern Recognit.*, pp. 779–788, Las Vegas, NV, USA, 2016.