School of Electrical, Electronic and Mechanical Engineering

Design of Coverage Digital Twin for wireless 5G/6G Networks

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I. Introduction

- ❖ **Indoor Network Coverage Optimization:** Considers complex layouts, material properties, and losses from reflection, refraction, and diffraction
- ❖ **Digital Twin:** Virtual replica of a physical system, enabling fusion of real-time and synthetic data and predictive capabilities to show extended coverage beyond the available
- ❖ **Propagation Modelling:** Simulating how signals travel through environments to determine factors like signal strength, interference, path loss, etc.
- ❖ **Deep Learning:** Predicting the signal characteristics such as signal strength, path loss, beyond the available

II. Objectives

- ❖ **Data Fusion:** Integrate **real-time and synthetic data** using ray-tracing and 3GPP models.
- ❖ **Virtual Environment:** Create **2D/3D coverage models** with optimal access points and simulate signal characteristics
- ❖ **Predictive Modeling:** Use deep neural networks to **predict path loss and signal strength** based on environmental factors
- ❖ **Validation:** Validate the model with **coverage and SINR plots** and evaluate accuracy using **MAE and MSE metrics**

III. Background

3 GPP Model:

- ❖ Stands for 3rd Generation Partnership Project

InH - Office	Line-of-sight		$PL_{InH-LOS} = 32.4 + 20\log_{10}(d_{3D}) + 20\log_{10}(f_c)$	$1m \le d_{3D} \le 150m$
	Non-line-of-sight		$PL_{InH-NLOS} = \max(PL_{InH-LOS}, 17.3 + 38.3\log_{10}(d_{3D}) + 24.9\log_{10}(f_c))$	$1m \le d_{3D} \le 150m$
InF	Line-of-sight		$PL_{InF-LOS} = 31.84 + 21.5\log_{10}(d_{3D}) + 19\log_{10}(f_c) + 4$	$1m \le d_{3D} \le 600m$
	Non-line-of-sight	Street Level	• $PL_{InF-NLOS} = \max(PL_{InF-LOS}, PL_{InF-NLOS})$ • $PL_{InF-NLOS} = 33 + 25.5\log_{10}(d_{3D}) + 20\log_{10}(f_c) + 5.7$	$1m \le d_{3D} \le 600m$
		Dense-Urban	• $PL_{InF-NLOS} = \max(PL_{InF-LOS}, PL_{InF-NLOS})$ • $PL_{InF-NLOS} = 18.6 + 35.7\log_{10}(d_{3D}) + 20\log_{10}(f_c) + 7.2$	$1m \le d_{3D} \le 600m$
		Sub-Urban	• $PL_{InF-NLOS} = \max(PL_{InF-LOS}, PL_{InF-NLOS})$ • $PL_{InF-NLOS} = 32.4 + 23.0\log_{10}(d_{3D}) + 20\log_{10}(f_c) + 5.9$	$1m \le d_{3D} \le 600m$
		Dense – Sub-Urban	• $PL_{InF-NLOS} = \max(PL_{InF-LOS}, PL_{InF-NLOS})$ • $PL_{InF-NLOS} = 33.63 + 21.9\log_{10}(d_{3D}) + 20\log_{10}(f_c) + 4.0$	$1m \le d_{3D} \le 600m$

Figure 1: 3GPP Path Loss model equations for different kinds of indoor environments [2]

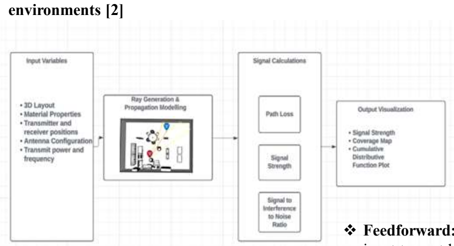

Figure 2: Ray-Tracing on MATLAB

- ❖ Specified for frequencies ranging from **0.5GHz to 100GHz**

Models for an indoor environment:

- ❖ **InH - Office:** High Density, open floor plan
- ❖ **InF – Indoor Factory:** Lower density, large metallic objects and Machinery

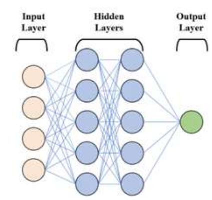

Figure 3: Fully connected feedforward neural network with input layer, two hidden layers and one output layer [3]

- ❖ **Feedforward:** Data flows in one direction without loops serving as input to next layer
- ❖ **Fully Connected:** Every neuron connected to every other neuron; each layer connected fully to next
- ❖ **Result:** Using RMSProp as optimizer and determine MSE and MAE losses for prediction of Path Loss & signal strength

IV. System Architecture

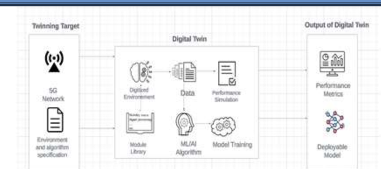

Figure 4: Main functionalities of a Digital Twin[1]

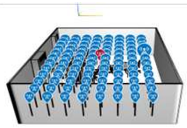

Figure 5: Simulation to determine the optimal transmitter location in a single room environment

- ❖ **Twinning Target:** 5G system with measured data serving real-world input
- ❖ **Digital Twin:** Fusing real and synthetic data to create a virtual coverage map with performance metrics, enabling AI/ML-driven extended coverage predictions
- ❖ **Output of Digital Twin:** Performance metrics generation and a deployable model, used to enhance the real-world 5G network

V. Results and Analysis

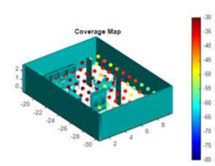

Figure 8: Coverage Map with optimal access point location for a single room environment

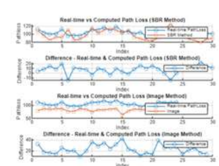

Figure 7: Difference between real-time and synthetic data with SBR and Image Method

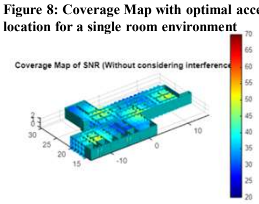

Figure 8: Coverage Map with optimal access point location without considering interference

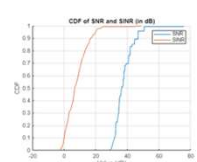

Figure 9: CDF plot of SNR and SINR for coverage map with and without considering interference

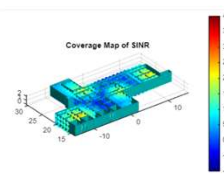

Figure 10: Coverage Map with optimal access point location and considering interference

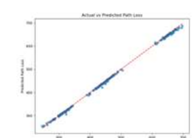

Figure 11: Actual vs. Predicted path loss using Deep Neural Networks

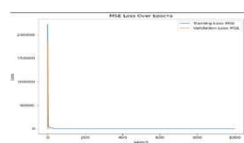

Figure 12: Mean Squared Error Loss in FNN network

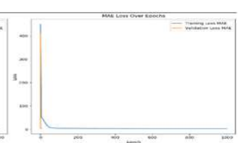

Figure 13: Mean absolute error Loss in FNN network

VI. Conclusion

- ❖ We present a coverage digital twin that integrates ray-tracing, 3GPP models, and deep learning for optimized transmitter placement and accurate signal strength prediction
- ❖ The comparison of real-time and ray-traced synthetic data in a 1-room environment showed a minimal difference of less than 15 dB, validating the reliability of the synthetic data for coverage modeling.
- ❖ Coverage maps in a single floor environment, using the 3GPP model, assessed signal coverage and optimized transmitter placement across varying channel widths
- ❖ Signal characteristics such as signal strength, interference and SNR and SINR values are plotted and analyzed
- ❖ Deep learning model accurately predicted path loss based on material properties, achieving a 1% Mean-squared error and 2.52 Mean Absolute Error

VII. References

1) Li, P., Aijaz, A., Farnham, T., Gufran, S., & Chintalapati, S. (2023). A Digital Twin of the 5G Radio Access Network for Anomaly Detection Functionality. In 2023 IEEE 31st International Conference on Network Protocols (ICNP) (pp. 1-2). IEEE.
2) 3rd Generation Partnership Project (3GPP). Study on channel model for frequencies from 0.5 to 100 GHz (3GPP TR 38.901 version 16.1.0 Release 16). 3GPP, 2020. Web.
3) H. Liu, Y. Jin, X. Song, and Z. Pei, "Rate of penetration prediction method for ultra-deep wells based on LSTM--FNN," Applied Sciences, vol. 12, no. 15, p. 7731, 2022

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