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Creating a Digital Twin for Cellular Networks

Undergraduate Thesis

Submitted in partial fulfillment of the requirements of

BITS F421T Thesis

By

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Declaration of Authorship

I, Pulak Mehrotra (ID: 2021AATS0017P), declare that this Undergraduate Thesis titled, 'Creating a Digital Twin for Cellular Networks' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Certificate

This is to certify that the thesis entitled, "*Creating a Digital Twin for Cellular Networks*" and submitted by Pulak Mehrotra ID No. 2021AATS0017P in partial fulfillment of the requirements of BITS F421T Thesis embodies the work done by him under my supervision.

Supervisor	*Co-Supervisor*
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University of California, San Diego	BITS Pilani
Date:	Date:

"Keep your eyes on the stars, and your feet on the ground."

Theodore Roosevelt

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Abstract

Bachelor of Engineering (Hons.)

Creating a Digital Twin for Cellular Networks

by Pulak MEHROTRA

Multimedia applications are witnessing a surge in popularity and constant evolution, often surpassing the advancements in network infrastructure. For application developers, comprehending the performance of these applications on cellular networks poses a significant challenge. Although the concept of digital twins in communication and network systems research is not new, the pursuit of identifying an effective, easy-to-deploy twin or framework for efficient app testing on radio networks remain critical. Our research endeavors to harness the potential of open-source software and hardware to evaluate a comprehensive and lightweight framework for rapid application testing on radio networks during the development phase. We hope to address two fundamental questions: (i) What defines a good digital twin? Has any study compared real-world performance with its virtual counterpart? (ii) Can we benchmark application performance on the twin using real-world channel traces and derive insights into potential RAN parameter functions for specific applications?

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Abbreviations

BOM	**B**ill **O**f **M**aterials
PCB	**P**rinted **C**ircuit **B**oard
NoC	**N**etwork **on** **C**hip
SoC	**S**ystem **on** **C**hip
VC NUM	**V**irtual **C**hannel **NUM**ber
VC SIZE	**V**irtual **C**hannel **SIZE**
RC	**R**oute **C**omputer
CB	**C**ircular **B**uffer
IR	**I**njection **R**ate

Dedicated to my parents, for their endless support.

Chapter 1

Introduction

In this chapter, the main motivation to do this study is presented.

The drivers of the next generation of cellular wireless networks are likely to be demanding applications, such as large-scale autonomy, extended reality, and sensing and control via IoT, all of which critically depend on wireless access to edge compute that hosts their intelligence. These applications desire strict guarantees on network performance in terms of throughput, latency, or jitter, as well as the ability for the network to adapt to their needs quickly. Jointly developing such applications and their complementary network algorithms over commercial radio access networks (RAN), or large-scale testing frameworks such as Colosseum [1] or Powder [2], is challenging due to the high costs and extended duration of doing so. Rather, the common practice today is to test in simple, simulated environments during development, with final evaluation on a real-world radio network.

However, this approach involves a tradeoff between capturing the intricacies of the cellular network that can have a dramatic influence on application performance and the ease of utilizing the testing environment during the application development cycle.

A lightweight digital twin of a real-world cellular network would be a valuable resource for application developers, as it would permit continuous refinement and evaluation of both application-level and network-level algorithms. But what level of artifacts, control or metrics at the RAN-level would attain the ideal trade-off between capabilities, accuracy, and simplicity? Our thesis, upon which this work is based, is that

Chapter 2

Background And Related Work

2.1 Background

In this section, we provide a brief overview of the key concepts and technologies that are relevant to fully understanding the work presented in this thesis.

2.1.1 Wireless Multipath Model

2.1.2 Coherence Time

2.1.3 Orthogonal Frequency Division Multiplexing (OFDM)

Chapter 3

Channel Representation

3.1 Problem Formulation

3.2 Metrics-In-Use

Chapter 4

System Framework

4.1 Key Considerations

4.2 System Architecture

The 5G network platfrom: We build on top of one of the existing and widely used open-source cellular network stacks, Open Air Interface [2], to emulate the 5G network and base station to provide connectivity. This means that we utilize well-established platforms that have already been tested and proven effective in real-world applications.

Chapter 5

Conclusion

The objective of this study was to take the initial step towards understanding how to construct a real-world cellular digital twin, or a *"full twin"*. Our efforts can be characterized into two main parts: **the wireless efforts**, which involved understanding the most significant contributions of the wireless channel's multipath and how it changes over time, and **the systems efforts**, which focused on building the digital twin on top of a pre-existing, open-source RAN stack.The PHY-level hypotheses were tested using Sionna [1], a ray-traced wireless channel simulator. Additionally, a framework to input these channel taps was developed on top of the 5G version of Open Air Interface [2].

By the end of this study, we developed a comprehensive channel pipeline to transform a real-world, temporally varying wireless channel into a format that can be used as input for our newly built OAI framework. The channel pipeline was tested across more than 100 different transmission scenarios and was found to generalize across various modulation schemes, LoS/NLoS conditions, and different coding rates. Future work on this study involves testing the channel pipeline on a real-world setup and further refining the system framework to include more advanced features like MIMO and sub-nanosecond channel updations and MIMO. We also aim to conduct end-to-end application benchmarks on the digital twin to assess the impact of the wireless channel on the application layer.