Institut für Mathematik
Fakultät II – Mathematik und Naturwissenschaften
Technische Universität Berlin

Internship Report

Santos Michelena
0473179
Scientific Computing, MSc.

Dr. Renato Cavalcante
Fraunhofer Heinrich Hertz Institute

March 2023

Contents

1 The Company **3**
1.1 What is Fraunhofer HHI? 3
1.2 My Role at The Institute 3

2 Description of my Activities and Results **4**
2.1 The Research Project 4
2.2 Literature Review 4
2.3 Working With NS3 5

3 Summary and Outlook **5**

1 The Company

1.1 What is Fraunhofer HHI?

The Fraunhofer Heinrich Hertz Institute (HHI) is a research center here in Berlin that focuses on developing cutting-edge technologies in the fields of communications, multimedia, and security. It is part of the Fraunhofer Society, Europe's largest applied research organization, which operates more than 70 research institutions throughout Germany.
The HHI was founded in 1928 and has since then become a leading research institute in the development of technologies for telecommunications. Today, the institute's research areas include 5G and future communication networks such as 6G technologies, immersive media technologies such as virtual and augmented reality, artificial intelligence and machine learning, and secure communication and identity management.
The HHI collaborates with industrial partners, government agencies, and research institutions both nationally and internationally, and provides a wide range of services, including consulting, training, and technology transfer to industry partners.
In addition to its historical focus on telecommunications, the Fraunhofer Heinrich Hertz Institute (HHI) has expanded its research activities to encompass a diverse range of fields. The institute is currently organized into the following departments:

- Photonic Networks and Systems: develops solutions for the next generation of optical communication networks, including high-speed transceivers, network planning and optimization tools, and optical switching technologies.
- Photonic Components: focuses on the design, simulation, and fabrication of advanced photonic components such as lasers, modulators, detectors, and integrated photonic circuits.
- Fiber Optical Network Systems: works on the development of fiber optic communication systems, including new transmission technologies, network architectures, and optical sensing applications.
- Video Communication and Applications: develops technologies for video coding, processing, and transmission, as well as applications for immersive media such as virtual and augmented reality.
- Vision and Imaging Technologies: conducts research in computer vision, image processing, and machine learning, with a focus on applications in areas such as autonomous driving, healthcare, and security.
- Artificial Intelligence: develops machine learning algorithms and applications for a variety of domains, including computer vision, natural language processing, and predictive analytics.
- Wireless Networks and Communications: works on the development of 5G and beyond-5G wireless communication technologies, including novel network architectures, wireless access technologies, and spectrum management solutions.

Overall, the HHI's research activities are aimed at developing innovative solutions for some of the most pressing challenges facing society, including the need for faster and more efficient communication networks, improved healthcare and safety, and the transition to a more sustainable future.

1.2 My Role at The Institute

I developed my internship as a student research assistant at the signal and information processing group within the wireless networks and communications department. This group specializes in the application of mathematical techniques, such as signal processing, information theory, numerical analysis, and machine learning, to address advanced challenges in telecommunications.

Figure 1: The institute's building in Einsteinufer

2 Description of my Activities and Results

2.1 The Research Project

As a member of the ORAN alliance (as mentioned in [Polese et al., 2022]), Fraunhofer HHI collaborates on joint research projects aimed at furthering alliance goals. The ORAN alliance proposes a network architecture in which 'xApps' work on top of the network to improve its performance. These xApps are software applications designed to perform specific optimization or machine learning tasks, such as resource allocation or interference mitigation.
However, the use of multiple xApps raise the question of whether one xApp can interfere with another, leading to conflicts that may harm overall network performance. The research project I participated in during my internship had the goal of modeling, detecting, and ultimately predicting these conflicts. Through this project, we aimed to contribute to the development of conflict detection and optimization algorithms that reduce the inherent risk of conflicts.

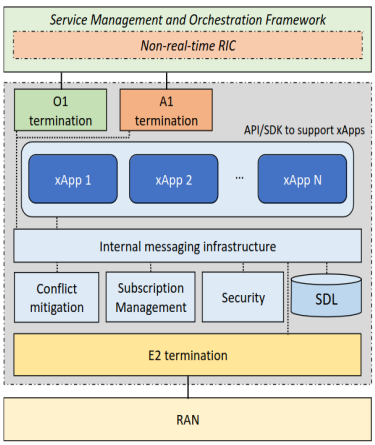

Figure 2: The near real time ORAN network architecture

2.2 Literature Review

For my first task, I conducted a literature review to explore various methodologies for modeling and detecting conflicts. The review had two objectives: first, to evaluate the suitability of different methods, and second, to provide an overview of available tools.
The methodologies I examined included:

Multiobjective Optimization

Multiobjective optimization aims to optimize multiple variables simultaneously. There are several approaches to this, as outlined in [Bjornson et al., 2014].

Conformal Prediction and Quantile Regression

Conformal prediction and quantile regression are methods for identifying prediction sets of a random variable (see [Romano et al., 2019]). We explored whether these techniques could be applied to conflict detection by identifying conflicts as anomalies.

Causal Inference

Causal inference involves identifying a causality graph for random variables. This methodology enables rigorous statements of causation, rather than relying solely on correlation. Causal inference achieves this by performing an intervention in one of the system's variables and then examining the joint distribution of the remaining variables. We referred to [Peters et al., 2017] for this part of the review.

Although all of the methods we reviewed were applicable to our problem, we chose to begin with causal inference a we have access to the ns3 network simulator (See `https://www.nsnam.org/`), which allowed us to perform interventions on simulation variables and create compelling scenarios.

2.3 Working With NS3

After completing most of our literature review, I was assigned the task of learning to use the ns3 network simulator to build simulations that would generate data for training causal inference models.
Ns3 is a c++ library for discrete event network simulation. To build a simulation, you need to write a c++ script using different objects and commands defined by ns3. However, the basic ns3 does not support the implementation of xApps. Therefore, I had to use a tool called "ns3 ai," an extension of ns3 that enables the writing of Python scripts that interact with the same memory as the ns3 script in simulation time. This feature allows for the implementation and deployment of machine learning models using popular Python frameworks such as PyTorch.
I have thus been working on writing simulations in this ns4-ai + ns3 framework, most of my work has been towards making simulations with causal inference style interventions possible.

3 Summary and Outlook

During my internship at Fraunhofer HHI, I gained a wealth of knowledge in the areas of wireless communication networks, signal processing, machine learning, literature review, and team collaboration. I had the opportunity to experience the entire research process from conception to development and learned how to work effectively in a group setting.
I was fortunate to work with an incredibly talented and supportive team that fostered a workplace culture of creativity and innovation. This experience made me feel right at home and has motivated me to pursue a career in science.
As a result of my internship, I am currently writing my thesis within my research group and in collaboration with the mathematics department at TU Berlin. Although my thesis topic is unrelated to my internship project, the skills and experience gained during my time at Fraunhofer have been invaluable in developing my current project.
Overall, my time at Fraunhofer was exceptional, and I am grateful for the opportunity to have worked with such a talented and supportive team. I am confident that the skills and experience gained during my internship will continue to benefit me as I pursue a career in science.

References

[Bjornson et al., 2014] Bjornson, E., Jorswieck, E. A., Debbah, M., and Ottersten, B. (2014). Multiobjective signal processing optimization: The way to balance conflicting metrics in 5g systems. *IEEE Signal Processing Magazine*, 31(6):14–23.

[Peters et al., 2017] Peters, J., Janzing, D., and Schölkopf, B. (2017). *Elements of Causal Inference: Foundations and Learning Algorithms.* MIT Press, Cambridge, MA, USA.

[Polese et al., 2022] Polese, M., Bonati, L., D'Oro, S., Basagni, S., and Melodia, T. (2022). Understanding o-ran: Architecture, interfaces, algorithms, security, and research challenges.

[Romano et al., 2019] Romano, Y., Patterson, E., and Candès, E. J. (2019). Conformalized quantile regression.