Author Name: Frank Obegi

DECLARATION OF ORIGINALITY

I confirm that the project dissertation I am submitting is entirely my work. Any material used from other sources has been identified, properly acknowledged, and referenced. In submitting this final version of my report to the JISC anti-plagiarism software resource, I confirm that my work does not contravene the university regulations on plagiarism as described in the Student Handbook. In so doing, I also acknowledge that I may be held to account for any particular instances of uncited work detected by the JISC anti-plagiarism software or as may be found by the project examiner or project organiser. I also understand that if an allegation of plagiarism is upheld via an Academic Misconduct Hearing, I may forfeit any credit for this module, or a more severe penalty may be agreed upon.

MSc Dissertation Title: MSc Project Title: Wireless AI: AI-enabled joint communication, sensing, and localisation (110\_5267)

Author Signature Date: 04/05/2022

WORDCOUNT

Number of Pages:

Number of Words:

Abstract

Millimeter-wave (mm-wave) technology quickly establishes itself as the de facto enabler for next-generation high-speed communications. Consider the capabilities of applications such as Wi-Fi/routers for sensing when designing a unified mm-wave system for integrated communication and robust sensing. The millimetre-wave (mm-wave) spectrum is a carrier frequency band utilised in 5G cellular and local area networks that range from 30 to 300 GHz. As a result, mm-wave systems are suited for indoor networks when installing infrastructure at a sufficiently high density is cost-effective. Furthermore, beamforming can assist focus radio energy to enhance the link budget by employing antenna arrays and their components. However, because mm waves range from 10 mm to 1 mm, they are more susceptible to air loss, absorption, reflection, and attenuation.

The study would go deeper into the empirical and theoretical elements for joint sensing and communication in future millimetre-wave systems. It will use programming languages such as Python and machinery approaches to Joint Sensing and Communication to test signal performance, localisation, and the usefulness of employing machine learning simulation in an indoor context. The study would also investigate the potential of using machine learning to detect changes in the environment and move accordingly, which could avert many accidents by warning, such as when a person is about to walk into a closed-door or is about to fall off a staircase. Today, millimetre-wave systems in urban settings are not yet commercially available. A possible strategy for adopting such a technology would be testing and proving its commercial viability on-site with low-cost hardware and open-source software. The study would see how this new technology could provide benefits such as faster response times, greater accuracy and reduced costs.

Introduction

Machine Learning for Joint Sensing and Communication in Future Millimetre-wave IEEE802 WLAN is this research topic. Millimetre waves are a "sensing opportunity" [1]. In addition, the millimetre wave is an essential technology for the next-generation Wi-Fi system [2], which uses Wi-Fi devices as the enabler for detecting items in the present, identifying people, and recognising gestures. Receiving several packets might also detect changes in a wireless connection over time. Signal processing and machine learning/artificial intelligence are commonly employed to examine the channel's temporal fluctuations, such as in a multi-static radar with numerous mm-wave WLAN devices.

With a high fidelity channel, antenna model, and system-level protocol, the NIST Quasi-Deterministic Framework (Q-D) analyses 802.11ay end-to-end performance. There's also the possibility of extending Q-D to support 801.11by. Further in the project, Nist Q-D Channel Realisation Software, Nist 802.11ay Phy, Ns-3 802.11ad/ay with Q-D channel, Codebook Generator, and the Nist Q-D interpreter are the software used. The measurements are then sent into a Nist Q-D channel, As-3 803.11ad/ay and to the Nist interpreter. The Quasi-Deterministic Framework (Q-D) is a deterministic electromagnetic wave description that may be used to simulate a variety of astronomical phenomena. Therefore, recognising the target and taking into account its reflections is critical. The project aims to create a complicated item with reflections from a macro or more significant object. The human body is an example of a macro item that employs 17 distributed joint centres and necessitates the usage of a scattered mechanism technique.

The project employed a frequency of 60GHz and a channel realisation of 1ms using the Dataset provided. Wireless LAN sensing with two channels, four transmitters, and four receivers with a random number of targets (from 1-8) and 128 channel realisation. The ML would be given a dataset to analyse, output, and assess to see whether the results matched the expectations (number of targets, target sector).

The project's significance is the capacity to detect "Waldo" in a static environment geometry. It would also aid in precisely detecting movements in restricted places. Next-generation deployments are challenging, complex, crowded, with many interactions and combinatorial action space. As a result of the distribution of transmission power over the spectrum, throughput would be increased. Channel bonding for neighbouring devices is also significant. The main benefit is the large available bandwidth in millimetre waves. Two main research bridges have been done in the last 10 to 15 years: communication and sensing. The main idea is to reuse Wi-Fi devices and turn them into motion sensors.

Objectives

The purpose is to use Python as the programming language to execute the code or Dataset provided and obtain a result that fits the ground truth. As a result, the source code for each milestone would be examined for efficacy before being made available for review. Python was studied and put to use. A prepared machine learning dataset from the ITU IEEE 802.11 challenge will be used as an input to the project to:

⦁ Check for signal fluctuation in a localised context by detecting motion using a provided dataset.

⦁ To check for signal fluctuation in a localised context, detect motion using a specified dataset.

⦁ Get the result of the ML in a 3D matrix (Ns, Na, Nc)

⦁ Compare the code against other types of coding to see how effective it is.

Achievements

The technical and theoretical understanding of the requirement and understanding is achieved. Thus, finding several targets moving throughout the room and which sector. Across the Dataset, the number of targets, velocity of each target, and trajectory are to be randomised. The file also includes noisy IEEE 802.11ay channel estimate fields. The Dataset is appropriate for developing and testing machine learning or deep learning methods.

On the other hand, other difficulties were discovered when working on the supplied Dataset. For instance, the Dataset was too large to download. Moreover, the remote file link was not working and could not be reached.

Overview of the interim report

The 6G system will be based on the 5G core network and will be able to support a wide range of services, including mobile broadband, machine-to-machine communication, and the Internet of Things. 5G is expected to enable a comprehensive range of services, such as mobile broadband, Machine-to-Machine (M2M), Internet of Things (IoT), and Virtual Reality (VR). In addition, 6G will be an intelligent wireless system that will enable high-accuracy localisation, high-resolution sensing services, and ubiquitous communication. Deep Neural Networks (DNNs) are a type of Artificial Neural Network (ANN) based on the human brain's biological neural networks.

BACKGROUND THEORY AND LITERATURE REVIEW

Beyond 5G (B5G) systems are designed to satisfy increasingly strict criteria, such as enabling combined communications, sensing, location, and computing services while maintaining ultra-high throughput and dependability for real-time communications. These needs can't be fully met with current technologies due to their limited capacity to handle various use cases. As a result, developing new and creative technologies with minimal cost, complexity, and energy consumption is critical [1]. Due to their high system throughput and data rate, MIMO systems and their variations are the most potential 5G wireless communication systems technology. However, the difficulty of leveraging the multiple-antenna and computational complexity is the most significant hurdles in MIMO communication. The recent success of RL and DL brings unique and powerful techniques for resolving problems in MIMO communication systems [2].

6G will be an intelligent wireless system that will enable high-accuracy localisation, high-resolution sensing services, and ubiquitous communication. Localisation, sensing, and communication must all cohabit in the envisioned 6G systems, sharing the same time-frequency-spatial resources. However, there are numerous unanswered concerns about how a 6G ecosystem with convergent communication, location, and sensing will appear. 6G will be an intelligent wireless system that will enable high-accuracy localisation, high-resolution sensing services, and ubiquitous communication. Localisation, sensing, and communication must all cohabit in the envisioned 6G systems, sharing the same time-frequency-spatial resources. However, there are many unsolved questions regarding how a 6G environment with converged communication, location, and sensing [3].

The use of a new radio frequency (RF) spectrum at high-frequency ranges (e.g., the Terahertz bands) or the use of beamspace processing techniques that reflect the growth of beamforming techniques in the 3D space domain are encouraged by technology for 6G environment-aware communication systems. Because of their ability to change the electromagnetic environment, large, intelligent surfaces (LIS) in either active or reflecting mode have previously been identified as a robust paradigm. By reducing handover failures and facilitating autonomous navigation and localisation-based apps, LISs can improve services for high-mobility consumers [4]. Radars provide a high-resolution range, angular location, and speed measurements. Thanks to powerful AI algorithms, the ability to identify and classify (human) movement and behaviour is now possible. Academic experts will present state-of-the-art in radar sensing technologies. Industry speakers will focus on the opportunities and problems these radars present for their applications [3].

With its capacity to create better models from massive amounts of data, deep learning has transformed numerous academic fields. Deep Neural Networks are a new generation of Artificial Neural Networks (ANNs) that are used in this technology (DNNs). The assumption is that a DNN's performance is often superior to that of a traditional ANN at the cost of longer training times, which may be lowered by employing sophisticated hardware (e.g., GPU) and unique methodologies (e.g., Transfer Learning). A DNN's design is critical to its success.

Convolutional Neural Networks (CNNs) are ANNs with a lot more layers and nodes than regular ANNs. They are frequently used to categorise images. In comparison to other classification techniques, CNN requires less preprocessing. Instead, CNNs utilise relevant filters to capture the image's temporal and spatial relationships. Similarly, ZFNet, ResNet, GoogleNet, VG-GNet, AlexNet, and LeNet are the most prevalent CNN designs.

Another notable DL architecture is the RNN. Unlike a CNN, where the layers are connected in sequential order, an RNN has specific nodes whose output is relayed back to the input of a primary node. As a result, the network is capable of remembering certain time-related information. In a configuration known as LSTM [6], recurrent neural networks (RNNs) are used extensively for time-series analysis and prediction.

Deep learning approaches have been used in mmWave and Ma-MIMO systems for some intriguing and essential applications. This system uses iterative signal recovery methods, and DL approaches to create an understood denoising-based approximation message-passing network. Compared to prior approaches with poor phase shifter resolution, the suggested work claims to offer a superior spectrum efficiency.

RL approaches, particularly the DL method, have shown to be valuable tools for improving the accuracy of channel estimate and improving the performance of Ma-MIMO in a variety of applications, including virtual reality, 5G systems, the Internet of Things, and autonomous driving." Wireless systems must be designed to deliver ultra-low latency, vast numbers of connections, and ultra-high data rates for these applications.

One of the probable possibilities to satisfy these needs is MIMO systems, particularly large-scale MIMO. The direction-of-arrival and channel estimation for Ma-MIMO systems utilising RL algorithms are studied. To achieve end-to-end performance and execute an online-offline learning process. While only a direction-of-arrival estimate using DL was examined, this is an efficient technique for learning wireless channel statistics and spatial structures in the angle domain. In ultra Ma-MIMO systems, a DL approach is employed for channel estimation. By estimating efficiency and accuracy, the approach may handle the concerns of high processing complexity and calculation time.

In, a DL-enabled channel estimation approach is presented to improve the performance of the Ma-MIMO system. The method utilised improves the recovery quality and the Ma-MIMO system's trade-off between complexity and compression ratio. A technique based on the CSI network combined with the gated recurrent unit and dropout approach scheme was used to reduce overfitting during the learning phase. The introduction of gated recurrent unit layers, on the other hand, might increase complexity owing to the projected increase in run time. The channel estimate approaches in TDD Ma-MIMO systems utilising DL in pilot contamination. Claiming that they outperform least-squares and covariance estimation methods in terms of channel normalised mean square error for imperfect and perfect temporal synchronisation.

Beamforming enhancements in mmWave systems are possible, and considerable path loss may be avoided by employing several antennas. However, digital precoders are difficult to construct with many antennas because of hardware limits, and analogue precoders have performance limitations. Therefore, hybrid precoding is critical in mmWave MIMO systems since it reduces cost and complexity while ensuring a reasonable total rate. For hybrid precoding, optimisation techniques have been utilised in the literature. On the other hand, these systems are dependent on the channel data quality and achieve sub-optimal performance while also adding complexity. As a result, it examined a few options for using DL-based hybrid precoding.

When the BS has a uniform planar array, and the classic fingerprint type is substituted with the "angle-delay channel power matrix," indoor localisation based on DL and CSI for 128 channel realisation is explored. This approach is advantageous because it incorporates angles, which have power in horizontal and vertical axes. The code created dynamic localisation structures in time-varying settings and proved the suggested architecture's performance in an indoor scenario.

Summary

"The Wireless Artificial Intelligence Location DetectiOn challenge tackles one most promising applications of current 5G and future 6G wireless systems" [7]. Beyond 5G (B5G) systems are built to meet ever-stricter requirements, such as combining communications, sensing, location, and computation services. 6G will be an intelligent wireless system that will allow high-accuracy localisation, high-resolution sensing services, and ubiquitous communication. Deep Neural Networks are a new generation of Artificial Neural Networks (ANNs) that are used in this technology.

TECHNICAL CHAPTER

RESULTS

CONCLUSION

Reference

Bibliography

[1]“Artificial Intelligence Enabled Internet of UAVs Communications | IEEE Communications Society," Aug. 31, 2022. https://www.comsoc.org/publications/magazines/ieee-wireless-communications/cfp/artificial-intelligence-enabled-internet (accessed May 04, 2022).

[2]“IEEE International Symposium on Personal, Indoor and Mobile Radio Communications." https://pimrc2021.ieee-pimrc.org/integrated-communication-localization-and-sensing-in-6g-era/ (accessed May 04, 2022).

[3]“Flanders Make," Nov. 17, 2021. https://www.flandersmake.be/en/events/sensing-understanding-smart-radars-technology-innovations-and-applications (accessed May 04, 2022).

[4]“VTC2022-Spring." https://events.vtsociety.org/vtc2022-spring/conference-sessions/call-for-workshops/w12-localization-and-sensing-with-intelligent-surfaces-for-6g-networks/ (accessed May 04, 2022).

[5]“PubMed Central (PMC)," Jan. 01, 2022. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8749942/ (accessed May 04, 2022).

[6]J. Brownlee, "Machine Learning Mastery," May 11, 2017. https://machinelearningmastery.com/memory-in-a-long-short-term-memory-network/ (accessed May 04, 2022).

[7]“ITU.” https://challenge.aiforgood.itu.int/match/matchitem/38 (accessed May 15, 2022).