Deep Learning m-MIMO Channel Reconstruction Techniques

SYSC5807F Project Proposal

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Abstract

I. Introduction

Telecommunication systems demand constant innovation, the requirements grow exponentially with each generation of wireless technology. One of the ways 5^{th} Generation (5G) wireless systems respond to these growing requirements is through the use of massive Multi-Input Multi-Output (m-MIMO) antennas [1]. These m-MIMO systems have the potential to improve the channel bandwidth, coverage, and capacity through beamforming and spacial multiplexing. To take advantage of these perks the systems require accurate Channel State Information (CSI). However, the more antennas a system has, the larger the channel matrix, further complicating the channel sounding process. m-MIMO systems have increased amount of overhead when acquiring CSI, specifically in the down-link direction [2]. Channel reciprocity is a technique used to reduce the amount of feedback overhead in m-MIMO systems. Specific aspects of the channel are frequency independent, such as path delay and angle. These aspects can be measured in the uplink direction, instead of fed back from the UE. Additionally, m-MIMO channels typically have many more antennas then dominant paths, causing them to be sparse in the delay-angle space. Classical algorithms to calculate the delay and angle include Newtonized Orthogonal Matching Pursuit (NOMP) [3], Multiple Signal Identification Classification (MUSIC) [4] and Least Absolute Shrinkage and Selection Operator (LASSO) [5]. Researchers have also proposed using Machine Learning (ML) techniques to such as You Only Look Once (YOLO) to extract the path delays and angles from received pilots [6]. Improving channel estimation and reducing the overhead of CSI feedback is an active area of research for 5G systems that will be explored through this term project.

II. Problem Statement

The NOMP, MUSIC, and LASSO algorithms all have very promising results, however they are computationally complex. The calculation of CSI and channel estimation are done frequently due to constantly changing channel conditions. Channel estimation algorithms have a real-time constraint, the faster they are the more accurate the results and the longer they will be relevant. For this reason, path estimation is a problem that could be solved using a Machine Learning (ML) algorithm. Often trained models can solve a complex problem with a faster run time than traditional algorithms. The authors of [6] represent the sparse channel as an image and use a the YOLO algorithm to identify the dominant paths. With reasonably good SNR ratios, the delay-angle transform produces an image with very pronounced paths. It is possible that a more basic image recognition algorithm may outperform YOLO in run time without sacrificing the accuracy. Additionally, the authors require sparsity for their algorithm to function, it is possible that different ML algorithms may not require channel sparsity.

This project will be an analysis of m-MIMO path estimation techniques with a focus on run time and performance. This will require a m-MIMO simulator to create realistic channel data along with received and transmitted pilots. It will include an implementation of one or more classical algorithms such as NOMP, LASSO, or MUSIC, as well as the YOLO algorithm described in [6]. New ML and classical image processing algorithms will be compared with the state of the art under varying channel conditions. The results will be presented in a report assessing the which techniques are the most practical for path gain delay and angle estimation.

III. Work Plan

To accomplish our project objectives, the project is split into several phases, each generating a different deliverable and data for channel reconstruction technique comparison. To begin, a FDD m-MIMO system will be developed in MATLAB to enable the simulation of downlink and uplink channels between one, or several, UE and the m-MIMO Base Station (BS). Next, downlink channel reconstruction techniques, such as NOMP, MUSIC, and YOLO, will be implemented alongside the MATLAB simulation to extract the necessary data needed from channel reconstruction. After, the authors will introduce modifications to

YOLO's deep learning algorithm with the aim to improve the accuracy and spectrum efficiency of the algorithm. Finally, the channel estimation techniques for downlink channel reconstruction will be compared against several metrics.

The first step of the project will be to produce a simulator in MATLAB of a m-MIMO system with varying parameters. The m-MIMO simulation will be able to simulate a m-MIMO with a different number of antennas, sub-carriers, propagation paths to test the downlink channel reconstruction techniques in a variety of m-MIMO configurations. The Signal to Noise Ratio (SNR) will also be dynamic and randomly generated in the simulation to simulate environments with different noise levels and test the chosen techniques in varying environmental conditions. The m-MIMO will be connected to one simulated UE to generate and simulate the data exchanged between the UE and the m-MIMO BS across the downlink and uplink channels. If time permits it, then more than one UE will be introduced to study the effect of multiple users communicating with the m-MIMO BS with regards to the ability of the channel reconstruction techniques to extract the downlink channels while multiple users are sharing the spectrum. The simulation will produce the CSI, for exact channel details, and uplink pilots received at the m-MIMO BS. The CSI will be used to construct the actual channel details for later comparison and the details of the pilots will be used by the channel reconstruction techniques to extract the estimated channel.

The channel reconstruction techniques defined in [6] will be implemented in MATLAB, or another programming language, to estimate the downlink channel from the m-MIMO to the UE and select the optimal propagation paths. The deeping learning technique, YOLO, defined in [6] will require a large amount of labelled data to train its machine learning model and is the main algorithm of interest. The CSI and uplink information generated in the simulator can be used to produce the labelled channel images for training of the YOLO algorithm. The training parameters used by the authors of [6] are defined in the text. Similar parameters will be used when training our deep learning algorithm, but to avoid common pitfalls of training, such as over or under fitting, we will also introduce Cross Validation, Regularization, and several performance metrics to monitor the training of the deep learning algorithm.

Following the implementation of the channel reconstruction techniques, the authors will investigate and introduce a few novel approaches and modifications to the original YOLO algorithm to improve its performance, accuracy, and efficiency. Different machine learning techniques can be explored and reviewed to determine whether using another algorithm would be beneficial. Other image analysis techniques that extract the bright propagation paths of the YOLO images without deep learning will also be investigated to avoid training and produce a more simple algorithm thereby reducing computation time.

Once the channel reconstruction techniques have been implemented and trained, they shall be deployed against the varying parameters and noise coniditions of the m-MIMO simulator for a direct comparison. The comparison of the channels will include statistical error functions, such as the Mean Squared Error (MSE), comparing the exact downlink channels to the estimated channels predicted by the reconstruction techniques. The techniques running times will also be compared along with the spectrum efficiency of each technique in a variety of conditions.

IV. Expected Final Outcome

The proposed project will produce several deliverables which will contribute to the research and techniques of m-MIMO downlink channel reconstruction. A configurable MATLAB m-MIMO simulator will be created and made available on Github to enable future research and channel reconstruction technique analysis. Building off of the work presented in [6], the YOLO CSI and images generated by the project's MATLAB simulator could be used to train other machine learning models to improve or enhance the current deep learning channel reconstruction techniques for m-MIMO systems. As discussed in the sections above, the authors plan to make their own modifications to the YOLO deep learning algorithm to estimate the channels with higher precision and investigate other simple image analysis techniques to reduce the computation time of channel estimation. Finally, a comprehensive paper detailing and comparing the modern downlink channel reconstruction techniques will be presented in a final report to discuss our findings. Several comparative metrics will be used in the assessment of the different techniques outputting the error and accuracy of each across different conditions to provide evidence for selecting a particular technique.

References

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