OPTIMIZATION OF CHANNEL ESTIMATION FOR MIMO-OFDM NETWORKS

BY

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ABSTRACT

The 5th generation of cellular communication is a highly competitive market that promises some distinct features compared to the legacy LTE (long-term evolution) era. Some of these exclusive features include enhanced mobile broadband (eMBB), massive machine type communications (mMTC), and ultra-reliable low latency communication (URLLC) traffic (1 ms one-way latency, 99.999% reliability). Enabling these cutting-edge technologies requires a very smooth processing of user data and transmitted signals. Channel estimation and acquisition of channel state data is one of the important points in this regard because they can eventually enable signal transmission and subsequent processing. However, most of the estimators in research nowadays suffer from high complexity due to either too many constraints or conditions for unique solutions. This is already a significant problem in the communication industry because of its high dependency on resource allocation and system overhead. This research focuses on the enhancement of the legacy channel estimation processes to fit the 5G cellular standards. The industry standard Least Squares (LS) estimator was used as the basis for the optimized estimation. A dual residual function was enabled instead of a single one to make the estimator adaptive. Results show that making the weight function adaptive reduces the error at the receiver and provides a sharper response curve. A comprehensive study was carried out against the trending compressed sensing (CS) based semi-blind estimators as a second objective. And finally, the optimized algorithm was characterized on MIMO-OFDM systems to show its performance improvements in the cases of large arrays. These objectives were carried out through simulation, and results were constructively discussed based on the earlier points. Results were compared with parameters SNR, SER, PER, and BER. Some potentials regarding the channel estimation in MIMO-OFDM were left as pick-up points for future research interests.

ملخص البحث

يعتبر الجيل الخامس من الاتصالات الخلوية سوقًا تنافسيًا للغاية ، نظرًا لما يقدمه من بعض مقارنة بعصر LTE (التطور طويل الأمد) القديم.تتضمن بعض هذه الميزات الحصرية لشبكات الجيل الخامس النطاق العريض المتنقل المحسّن (eMBB) ، والاتصالات الضخمة من نوع الماكينة (mMTC) ، وحركة مرور اتصالات منخفضة زمن الانتقال فائقة الموثوقية (URLLC) (زمن انتقال أحادي الاتجاه يبلغ 1 مللي ثانية ، وموثوق(99.999٪).يتطلب تمكين هذه التقنيات المتطورة معالجة سلسة لبيانات المستخدم والإشارات المرسلة. يعد تقدير القناة والحصول على بيانات حالة القناة أحد النقاط المهمة في هذا الصدد. لأنه يمكن في النهاية تمكين إرسال الإشارة والمعالجة اللاحقة. ومع ذلك ، يعاني معظم في البحث في الوقت الحاضر من درجة عالية من التعقيد إما بسبب قيود أو شروط كثيرة جدًا للحلول الفريدة في صناعة الاتصالات بسبب اعتمادها على تخصيص الموارد وإدخال النظام. يركز هذا البحث على تعزيز عمليات تقدير القنوات القديمة لتلائم المعايير الخلوية لشبكات الجيل الخامس. تم إعطاء الأولوية لمنطقتين مختلفتين في هذه الدراسة ، أولاً ، تم تحسين المربعات الصغرى (LS) والحد الأدنى لمتوسط الخطأ التربيعي (MMSE) لإشارات 5G. تم تمكين وظيفة متبقية مزدوجة بدلاً من وظيفة واحدة لجعل المقدر متكيفًا. تظهر النتائج أن جعل وظيفة الوزن قابلة للتكيف يقلل من الخطأ في المستقبل ويوفر منحنى استجابة أكثر حدة. كهدف ثان ، تم إجراء دراسة شاملة لاستكشاف المقدرات شبه العمياء القائمة على الاستشعار المضغوط (CS). وأخيرًا ، تم تمييز الخوارزمية المحسّنة على أنظمة MIMO-OFDM لإظهار تحسينات الأداء في حالات المصفوفات الكبيرة. تم تنفيذ كل هذه الأهداف من خلال المحاكاة وتمت مناقشة النتائج بشكل بناء بناءً على النقاط المذكورة أعلاه. تمت مقارنة النتائج مع المعلمات SNR و SER و PER و BER. تركت بعض التوجيهات المتعلقة بتقدير القناة في MIMO-OFDM كنقاط التقاط للبحث في المستقبل.

AishA

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APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

BS	Base station
CE	Channel estimation
CP	Cyclic prefix
CSI	Channel state information
FBMC	Filter bank multi-carrier
F-OFDM	Filtered orthogonal frequency division multiplexing
IFFT	Inverse fast Fourier transform
FFT	Fast Fourier transform
MIMO	Multiple input, multiple outputs
MMSE	Minimum mean square error
MSE	Mean square error
OFDM	Orthogonal frequency division multiplexing
LMMSE	Linear minimum mean square error
LOS	Line of sight
LS	Least squares
UE	User equipment

LIST OF SYMBOLS

η	White noise
H	Channel impulse
β	Path loss
U	Uniform distribution
γ	Signal to noise ratio

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The 5th generation of the mobile system era promises a lot of enabling technologies that are supposed to take the legacy LTE standards to a whole new level. Some of the few groundbreaking properties of this cellular system include Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (mMTC) and Ultra-Reliable Low Latency Communication (URLLC, <1ms) (Shafi et al., 2017). To enable these cutting-edge features, the next-generation cellular system will adopt a few new technologies and amendments (Beltran, Ray, & Gutiérrez, 2016). One of the most critically acclaimed ones is the millimetre wave (mmWave) Massive MIMO system, which lies in the vast range of 30Ghz-300Ghz (Rappaport et al., 2017). This technology's key features include elevated user throughput and enhanced spectral and energy efficiencies. Not to mention the increase in the capacity of mobile networks through the joint capabilities of the ultra available bandwidth in the mmWave frequency bands and high gains using new techniques as spatial multiplexing obtained via massive antenna arrays (Rappaport et al., 2017).

Although the potentials of what could be gained in the mmWave range are promising, the difficulties in building and sustaining such an infrastructure are also very demanding (Xiao et al., 2017). Nevertheless, much research has already been conducted, and even more proposals regarding the solutions are starting to arise. One of the major considerations among these is the Ultra-Dense Network or UDN (Kamel, Hamouda, & Youssef, 2016). It refers to the ultra-dense deployment of the small-scale BS within the coverage of bigger cell BSs. The cell types are classified as metro, micro, pico or femtocell in a decreasing manner.

The Massive MIMO is another major part of this new generation of cellular communication schemes. It is characterized by increasing the number of antennas for transmission and reception several times (Buzzi et al., 2016). Clearly, this intends to achieve the already discovered benefits of the MIMO on a large scale. Using spatial multiplexing can enhance the capacity of the current cellular infrastructure (D. Liu et al., 2016). The large number of available degrees of freedom through numerous antennas can improve spectral efficiency. With the help of hybrid beamforming, further reduction in interference is possible (Ahmed Alkhateeb & Heath, 2016). It also helps reduce latency, one of the three major targets. The full benefit of Massive MIMO is only obtained when it's deployed in the aforementioned mmWave region. Because of the small size of the apertures, low power-consuming components and avoiding costly non-linear A/D converters, a cost-efficient infrastructure is possible (Hemadeh, Satyanarayana, El-Hajjar, & Hanzo, 2018). The maximum benefits for mmWave Massive MIMO are feasible, provided that different antenna pairs at the transmitter and the receiver undergo independent fading channel characteristics. For this, the antenna elements are spaced at $\leq 0.5\lambda$, which gets even smaller as we go deep in the mmWave region. Apparently, this allows for more antenna elements to be placed in close vicinity of each other. The feasibility of optimal performance is also heavily dependent on the availability of the CSI, which is the task of the channel estimation portion. Because the contribution of channel estimation is crucial for the receiver, this section is discussed separately at the end of this chapter.

However, small apertures mean low radiation power and, thus, high attenuation (Ghosh, Maeder, Baker, & Chandramouli, 2019). Therefore, mmWave systems must have antenna characteristics of high directivity, configurable, etc. But since this brings up the question of the economic viability, an alternative and even more promising aspect of the 5th generation cellular system comes into focus: the contribution of hybrid beamforming or precoding (Ahmed et al., 2018). But since that is another major area of the current research and also out of the scope of this work, we won't discuss it any further here.

Since the no of antennas at the BS increases exponentially at mmWave, the channel characteristics turn deterministic, and the channel orthogonality becomes asymptotic (Zhang, Ge, Li, Guizani, & Zhang, 2017). So, the no of UE that can be supported simultaneously decreases owing to fluctuating coverage area. The path-loss models for mmWave also show an increased degree of moderate path-loss, and the NLOS signals become more vulnerable to obstacles like solid bodies and buildings (i.e.

less penetration power) (Hong, Baek, & Ko, 2017). It is due to the smaller size of the wavelength compared to the obstacles. So the signals in this frequency range are more vulnerable to shadowing, diffraction, blockage etc.

Signal processing in mmWave is far more challenging than that of μWave. It's largely because of the increasingly random signal in this frequency range (Sun et al., 2016). Various models have been proposed assuming different criteria to characterize the signal behavior in mmWave effectively. Reportedly these models usually perform well to delineate a certain parameter while considering the behaviour of other parameters constant. However, since the performance parameters of signal in mmWave, like the attenuation is, random and heavily dependent (correlated) on other relevant parameters, it's far more challenging to characterize the behaviour of signals in this frequency range (Hemadeh et al., 2018; B. Wang et al., 2018).

The 3GPP has taken some new initiatives to alleviate this problem. For instance, starting from release 15, the available bandwidth is divided into two frequency ranges, namely FR1(<6Ghz) and FR2(23Ghz-53Ghz). For FR1, both TDD and FDD duplexing methods are being deployed, while in the higher frequency range FR2, only TDD is available for now. The subcarrier spacing in these ranges can be a power of two multiple of 15kHz or (2n×15kHz). Also, for the new release, the frame structure is renewed too. For instance, newer units like Bandwidth Parts(BWP) are being utilized further to facilitate the UE configuration to the BS.

The smallest physical resource is the resource element in the 5G New Radio (5G NR). Unlike the legacy LTE configuration, the Resource Blocks or RBs that carry these resource elements are evaluated in the frequency domain only. Precoding in mmWave is of even more importance than it was for LTE since the attenuation in mmWave is heavily dependent on beam steering and alignment (Sohrabi & Yu, 2017; Venugopal, Alkhateeb, Gonzalez Prelcic, & Heath, 2017). In addition, newer multiplexing techniques like Filtered-OFDM or F-OFDM are being considered, further dividing the band into subbands for more configurability. As it stands now, one of the major problems with the fifth generation of cellular networks will surely be the 'complexity'. It's clear from the already published numerous studies that the system overhead or complexity is increasing with leaps and bounds to make the new 5G era more configurable and user-friendly. So, the researchers also consider simplicity to balance the trade-off between features and resource allocation. It is one of the reasons for this study to optimize and, more importantly, to make the estimation of channel parameters more resource friendly and thus aid in less complex and more feature-friendly cellular communication.

1.2 PROBLEM DELINEATION

The channel estimation or the process of acquiring CSI (Channel State Information) is increasingly difficult in the 5G domain mainly due to the vast amount of instantaneous data to process and a pre-beamforming low SNR (Qin, Gui, Cheng, & Gong, 2018). But to reap most of the benefits from hybrid precoding, which is being well investigated at the moment, an efficient channel estimation (CE) algorithm is crucial. Without a substantially accurate knowledge of CSI, the accuracy of the precoding is very limited. Thus, these two aspects of signal processing are of great importance at the moment, and a lot of studies are focusing on a joint evaluation of hybrid precoding and estimation algorithms. Due to the numerous no of antennas and the large dimension of the channel matrix, the calculations required to determine the channel parameters are almost exponentially difficult. Owing to a high no of degrees of freedom, researchers are trying to exploit that the transmitted signal in mmWave is sparse in some domains. This lead to the idea of compressive/compressed sensing (CS) theories that involve representing the channel matrix in a domain in which most of its elements are sparse or zeros, thus reducing the number of calculations. Through this sparse representation, CS theories allow a signal to be sampled at a rate far lower than that required by the Nyquist criterion. But current CS algorithms present some complexity as most of these algorithms are NP times hard to compute. Even so, the CS methods are certainly one of the leading candidates for the CE process as it dramatically reduces the no of parameters to be estimated (Uwaechiaet al., 2019). Some of the recent research for the mmWave channel estimation assumes perfect CSI at the transmitter or CSI-Tx (Ahmed Alkhateeb et al., 2014; Dai et al., 2019; Uwaechia et al., 2019), which is itself, a potential topic for further exploration. On the other hand, some works took a more practical approach by assuming partial CSI knowledge at the transmitter (A. Alkhateeb et al., 2013). Another portion of the research on estimation in mmWave focused on determining the angle of arrival (AoA) and angle of departure (AoD) efficiently by presenting them as a sparse recovery problem and then proposing greedy or other types of algorithms to solve it.

So few of the significant problem regarding the estimation performance, such as complexity, applicability and the role of channel statistics, are still at large and requires further study for the 5th generation of mmWave cellular networks.-

1.3 RESEARCH OBJECTIVES

The intentions behind this work can be broadly put into three sections:

1. To Optimize the conventional training algorithms: As found in the literature, using static weights and a non-adaptive scheme reduces the efficiency of the legacy algorithms like LS. The first objective is to eliminate this problem by switching to a dual residual scheme.
2. To Adaptively estimate channel based on the Characterization of the new algorithms on MIMO-OFDM systems: This study is based on the MIMO-OFDM system; hence the results will reflect the effect of the proposed algorithm on a standard MIMO-OFDM system. The results are shown as criteria such as BER, SER, PER etc.
3. To evaluate Performance evaluation against trending CS-based methods: Compressed sensing-based methods are trending because of their efficiency. The last objective is to analyse the performance of the proposed algorithm against the benchmark CS one to show the superiority of the optimized LS method.

1.4 SCOPE OF THE RESEARCH

This research work is intended to be done with computer simulation software. We plan to utilize Matlab as the primary simulation platform. With the help of a communication toolbox to facilitate the new subchannel construction and thus run simulations according to the optimized algorithms. The simulations will be run in an x64-bit program, and the codes of the simulations can be found in the Appendix. Note that since the simulations involve multiple criteria evaluation, the simulation parameter may be changed from code to code. It is intended to present the simulation results in terms of bit error rate (BER), mean square error (MSE), symbol error rate (SER) and or throughput. This research doesn't involve any experimental data; thus, no apparatus or machine outside the computer software will be used.

1.5 ORGANIZATION OF THE THESIS

This thesis work is divided into six chapters. The first chapter is this one. The subsequent chapters are the literature review, methodology, paradigm, results & discussion and conclusion. Below is a short note on each of the containing chapters of this thesis-

Chapter 1: Contains the preface of the thesis and the organization of the rest of the chapters.

Chapter 2: Entails the studies used for this thesis work. It also discusses the features and limitations of this research and the research work(s) used for benchmarking this thesis.

Chapter 3: The methodology chapter briefly compares the techniques used for the research works stated in Chapter 2. Discusses their potential benefits and limitations and, based on these observations, derives the scheme(s) used to obtain the objectives of this research.

Chapter 4: Defines the setup of this thesis work, including method of obtaining results, simulation environment and method, type of statistical analysis used etc. Note that this thesis work is entirely simulation-based, but data outside the simulation environment may be added if necessary. The chapter includes the results obtained via simulation and compares them for benchmarking. It also demonstrates how the objectives are achieved and the amount of improvement done.

Chapter 5: The final chapter of this thesis deals with the conditions of the target objectives of this thesis. It also discusses the problems faced during the pursuit of the goals and also sheds light on the potential research objectives for the following

1.6 CHAPTER SUMMARY

The significance and contributions of this research have been demonstrated in this chapter. The existing problems and their potential solutions were also discussed. The intentions behind this study and possible outcomes were presented. Quick takeaways from the literature review have been proposed as a summary. The scope of the research has also been looked upon. At the end of the chapter, an outlook and total overview of the thesis have been summarized. Furthermore, what this study is about and limited to is also discussed.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Much work has been done through the years in signal processing for cellular networks (Zhang, Ge, Li, Guizani, & Zhang, 2017). Especially starting from the LTE era, the process of acquiring channel state information or CSI, known as channel estimation, has gained immense attention due to its ability to reduce the overhead to the system and increase the throughput. The CSI is usually estimated at the receiver and fed back to the transmitter unless otherwise specified. Although the CSI feedback system is also an integral part of the estimation procedure, most research regarding channel estimation doesn't explicitly provide any feedback algorithm since the amount of feedback is generally kept very small and tolerable for most OFDM systems. That being said, for the 5th generation cellular network, it's said that with an increased no of antennas (Massive MIMO), the feedback amount is expected to increase substantially. However, it's not a part of this study.

There are three types of conventional channel estimation procedures; Blind, Semi-blind & training/pilot based. Of these three, the semi-blind and especially the pilot-based channel estimations have gained popularity due to their flexibility and robustness against errors. Most widely researched pilot-based estimation techniques include the least square (LS) method, the Minimum Mean Squared Error(MMSE) method, and the Linear MMSE (LMMSE). There are, however, some other lesser-known modifications of these methods like Normalised Least Mean Square (NLMS) and Recursive Least Squares (RLS) (Masud & Kamal, 2010), Space Alternating Generalized Expectation-maximization (SAGE) (Ketonen, Juntti, Ylioinas, & Cavallaro, 2013), Iterative-Compensated MMSE (IC-MMSE) (Y. Liu & Sezginer, 2011) and so on. All these modified algorithms have in common that the researchers added weighted values, statistical info or similar criteria to make up for certain drawbacks in these proposed algorithms. For instance, adding further taps in the LS algorithm can decrease the estimation errors (Van de Beek et al., 1995), which led to numerous variations in these algorithms. This study intends to discover the appropriate approaches to these modifications that will suit the mmWave MMIMO OFDM systems. Despite being old, these algorithms are still large in practical cellular networks. They arguably can have the same amount of contribution to the 5th generation of cellular networks as any other new contenders like the compressed sensing (CS) algorithms. Which we shall focus on as another objective of this study.

The rest of this chapter is assembled as follows; First, a short history of pilot/training-based estimation is given, followed by the current trends in this domain and finally, the existing research gap. Next, a brief introduction to compressed sensing (CS) based theories is given along with current works in this manner. The CS section is kept short since optimising them in this study is not our concern; they'll be used to characterize the performance trade-off with overhead in contrast to the pilot-based estimations. The final section of this chapter will include a comparative demonstration of different trending algorithms, their limitations and possible amelioration. Finally, the chapter will be concluded with a brief summary.

2.2 PILOT-TRAINING-BASED CHANNEL ESTIMATION

As mentioned in the introduction, pilot-based channel estimation involves determining the channel impulse response in the frequency domain with the help of a set of predetermined symbols. The impulse response is selected from the knowledge of the received symbol matrix and the pilot symbols. There are three pilot structure types: block, comb, and lattice. Block type involves inserting the pilot symbols for all the subcarriers for a particular instant and then sending them periodically. So, this type of pilot training is helpful for slow-fading (frequency selective) channels.

On the other hand, comb-type pilots are useful for fast-fading channels since pilots are inserted following the time axis. In the lattice-type pilot, symbols are inserted in both time and frequency axes to ease interpolation. A generalized picture can be comprehended from Figure 2.1.

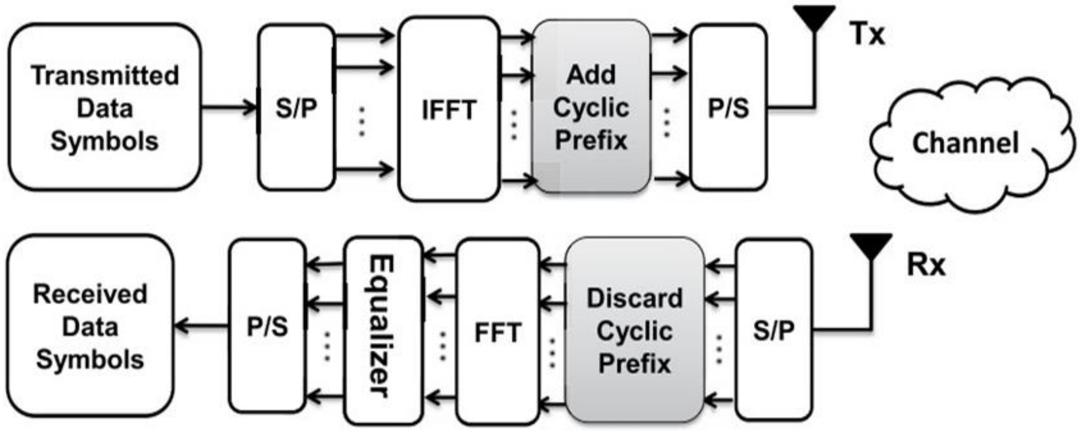

Figure 2.1 Organization of a general OFDM system (Hamamreh et al., 2018)

Pilot-based channel estimators are highly adjustable because of their simplicity. And any additional available info can be added to each iteration step to stretch the performance boundary further. In light of these features, the literature discussed in this chapter mainly focuses on pilot-based training. A short comparison of the differences in signal processing between microwave and millimetre waves is given in Table 2.1.

Table 2-1 Comparison between µWave and mmWave

Parameters	**µWave**	**mmWave**
Gain	Larger	About the order of two times smaller.
Path loss	Lower for a certain BS-UE distance.	Higher than µWave for a certain BS-UE distance.
Shadowing	Small and independent of blockage and NLOS propagation.	Larger than µWave and dependent on several random variables also affected by blockage and LOS/NLOS propagation.
Interference	They are affected by proximity, distance-dependent and result in background interference for increasing no of interferers.	High-attenuation by blockage and antenna gain patterns obscure in terms of distance and demonstrates