SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
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ADAPTIVE BEAMFORMING ALGORITHM FOR SMART ANTENNA SYSTEM IN MOBILE NETWORK

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of B.Sc. (Honors) in Electronics Engineering (TELECOM)

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Dedicated To Those Who Believe In Us

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ABSTRACT

As the growing demand for wireless communications is constantly increasing, the need for better coverage, improved capacity, and higher transmission quality rises. One of the promising technologies is the use of smart antenna system. Smart antennas combine the antenna array with signal processing capability to optimize automatically the beam pattern in response to the received signal through beamforming.

The purpose of this thesis work is to investigates Adaptive beamforming algorithms for optimum weight computation. Afterward, developing and possibly implementing an adaptive beamforming algorithm in the mobile communication environment to enhance service quality and capacity.

The strategy used to achieve the major aim was an in-depth investigation of Two adaptive algorithms, the Least Mean Square (LMS) and the Sample Matrix Inversion (SMI). The Simulation results provided showed that the beam steering ability and nullifying capability was satisfactory for those algorithm, and (LMS) algorithm had slow convergence rate beside simplicity, (SMI) on the other-hand had fast convergence rate but suffering from computational complexity. So a Matrix-Inversion Least Mean Square (MI-LMS) adaptive algorithm was proposed and developed, which combines (SMI) and (LMS) to improve the convergence speed. Simulation results revealed that the MI-LMS algorithm provides remarkable improvements in terms of interference suppression and convergence rate over LMS and SMI. Furthermore, The effects of varying the array parameters have been analyzed and investigated. Finally, a simulation scenario was presented for verifying the Spatial Division Multiple Access (SDMA) concept.

المستخلص

بما أن الطلب على الاتصالات اللاسلكية يتزايد باستمرار، فعليه تتطلب الحاجة إلى تغطية أفضل، وتحسين للسعة، و ارتفاع أعلى لجودة الإرسال، وبالتالي زيادة كفاءة استخدام الطيف الراديوي. واحدة من التقنيات الواعدة هي استخدام نظام الهوائي الذكي. الهوائيات الذكية تجمع بين مجموعة هوائيات مع إمكانية معالجة الإشارات تلقائيا لتحسين نمط الاشعاع، وذلك بالاستجابة على الاشارة الواردة من المستخدم من خلال تكوين الشعاع التكيفي.

الغرض من هذه الدراسة هو عمل تحقيق مفصل عن أداء خوارزميات تكوين الشعاع التكيفي لحساب الوزن الأمثل، و لتطوير و تنفيذ خوارزمية تكوين الشعاع التكيفي في بيئة الاتصالات المتنقلة لتحسين جودة الخدمة والسعة.

الاستراتيجية المستخدمة لتحقيق الهدف الرئيسي من الدراسة هو تحقيق عميق لاثنين من خوارزميات تكوين الشعاع التكيفي ، هما لست مين سكوار(LMS) و سامبل ماتريكس إنفرجن (SMI). حيث أظهرت نتائج المحاكاة أن القدرة على توجيه الاشعاع والقدرة على قمع المتدخلين مرضية لتلك الخوارزميات، وكانت خوارزمية لست مين سكوار (LMS) بطيئة في حساب الوزن الأمثل لكنها بسيطة حسابيا، و سامبل ماتريكس إنفرجن (SMI) مقارنة معها كانت سريعة و لكنها معقدة حسابيا. على أساس ذلك تم اقتراح خوارزمية ماتريكس إنفرجن- لست مين سكوار (MI-LMS) وتطويرها. ماتريكس إنفرجن- لست مين سكوار (MI-LMS) تجمع بين خوارزميات سامبل ماتريكس إنفرجن (SMI) و لست مين سكوار(LMS) لتحسين سرعة حساب الوزن الأمثل. خوارزمية الاشعاع التكيفي على أساس النهج الجديد تتميز ببساطة LMS وسرعة SMI. كشفت نتائج المحاكاة أن الخوارزمية (MI-LMS) تقدم تحسينات ملحوظة من حيث قمع التدخل ومعدل سرعة حساب الوزن الأمثل. بعد ذلك، الآثار الناتجة عن تفاوت قيم الهوائي من حيث عدد عناصره والمسافة بين كل عنصر و عنصر تم تحليلها والتحقيق فيها. تم عرض سيناريو محاكاة لحالة اثنين من المستخدمين للتحقق من مفهوم تعدد الوصول عن طريق تقسيم الاماكن بينهم (SDMA).

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LIST OF SYMBOLS & ABBREVIATIONS

AF	-	Array Factor
d	-	Inter-element spacing
e	-	Error signal
K	-	Block Length
N	-	Number of Array Elements
R	-	Array Correlation Matrix
r	-	Array Correlation vector
x	-	Received Signal
w	-	Weight
y	-	Array Output
α	-	Array Steering Vector
μ	-	Step Size
θ	-	Angle
BS	-	Base Station
DOA	-	Direction of arrival
LMS	-	Least Mean Square
LOS	-	Line Of Sight
MI-LMS	-	Matrix Inversion- Least Mean Square
MS	-	Mobile Station
MMSE	-	Minimum Mean-Squared Error
MSIR	-	Maximum Signal-to-Interference Ratio
SMI	-	Sample Matrix Inversion
SDMA	-	Space Division Multiple Access
SOI	-	Signal Of Interest
SNOI	-	Signal Not Of Interest
RLS	-	Recursive Least Square

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CHAPTER

1

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Background:

Wireless communication has come a long way since the invention of the wireless concept by Marconi in 1897 [1]. In recent years there has been an explosive growth in the number of wireless users, particularly in the area of mobile communication. In future wireless mobile systems will be more sophisticated and more widespread. This growth has triggered an enormous demand not only for capacity but also better coverage and higher quality of service. Consequently, fulfilling this growing demand motivates the need for new technologies to improve capacity and spectrum utilization, therefore the optimization of the whole system performance.

Several new technologies have been explored and deployed in this regard to make effective use of the limited resources. One way to improve capacity is by using the concept of cellular technology, which involves dividing a large coverage zone into small hexagonal cells [3]. Each cell is allocated a set of frequency channels that are different from those allocated to the neighboring cells. However the same set of frequencies can be reused by another cell as long as they are separated well enough not to cause interference. Since each of these cells reuses the frequency spectrum, a significant increase in capacity can be achieved. However, increasing the number of cells to accommodate growing subscriber needs is neither an economical nor an effective option. Within the cells in a cellular network a further increase in capacity is achieved by efficiently sharing the frequency channels using multiple access techniques.

So far these technologies have brought about tremendous increase in wireless network capacity to meet the increasing demand for wireless services. However personal wireless communications is getting more and more popular and is continuing to grow at an exponential rate. Therefore new technologies are required in the area of mobile communications to accommodate future capacity needs. Space division multiple access (SDMA) has emerged as a key technology and holds a lot of promises for the future of mobile communication [2]. SDMA exploits the spatial domain of the mobile radio channel to bring about increase in network capacity in the existing wireless systems. Unlike wireless systems in the past, which used fixed antenna systems, SDMA based systems uses smart antennas which consist of a set of radiating elements arranged in the form of an array [5]. The signals from these elements are combined to form a movable or switchable beam pattern that follows the desired user. In a Smart antenna system the arrays by themselves are not smart, it's the digital signal processing (DSP) that makes them smart, which is have two objectives: direction of arrival estimation (DOA) and Beamforming [6]. The process of combining the signals and then focusing the radiation in a particular direction is often referred to as digital beamforming [4],[5],[7],[8]. Smart antenna systems specially adaptive arrays are dynamically able to adapt to the changing traffic requirements, and they are usually employed at the base station, radiates narrow beams to serve different users. As long as the users are well separated spatially the same frequency can be reused, even if the users are in the same cell. This additional intra-cell channel reuse based on spatial separation is the key in achieving an increase in the capacity of the system and this is the basic philosophy behind SDMA.

Most advanced approach based on smart antenna technique, known as *adaptive Beamforming* uses antenna arrays backed by strong signal processing capability to automatically change the beam pattern in accordance with the changing signal environment. It's not only directs maximum radiation in the direction of the desired mobile user but also introduces nulls at interfering directions while tracking the desired mobile user at the same time. The adaptation is achieved by multiplying the incoming signal with complex weights and then summing them together to obtain the desired radiation pattern. These weights are computed adaptively to adapt to the changes in the signal environment. The complex weight computation based on different criteria is incorporated in the signal processor in the form of software algorithms [6].

Adaptive algorithms form the heart of the array-processing network. Several algorithms have been developed based on different criteria to compute the complex weights. They have their own disadvantages and advantages as far as complexity, convergence speed and other aspects are concerned. There is still a lot of room for improvement in this regard to improve the performance of the whole adaptive system by improving present algorithms.

1.2 Problem Statement:

The purpose of almost, all beamforming algorithms are to form multiple beams towards desired users while nulling to the interferers at the same time, through the adjustment of the beamformer's weight vectors. Although smart antenna system has numerous advantageous compared to traditional Beamforming arrays, it has limitations on the performance characteristics like computational complexity, speed of convergence, beam steering ability, nullifying capability and side lobe level. However does the adaptive algorithms perform well and functioning properly in steering the mean beam toward the desired users and tracking them, also rejecting the interferers at the same time and do the spatial filtering? And how that could improve the capacity and performance of the whole system? After that kind of investigation the outcomes of depolying and utilizing smart antenna systems and their adaptive algorithms in the area of mobile communications will be clearly stated.

1.3 Proposed Solutions:

The ultimate solutions to the weight computation for smart antenna systems is based on investigating and intensively studying Adaptive Beamforming algorithms such as: Least mean square (LMS), Recursive least square (RLS), ,Constant modulus algorithm (CMA) and Sample matrix inversion (SMI), through extensive analysis, simulation, and experimentation, to provide substantial performance improvements. Speed of convergence, beam steering ability, nullifying capability and other performance measurements criterion must be analyzed for those algorithms and suggestions are made that which one is the best according to an application.

1.4 Thesis Aims and Objectives:

The aim of this thesis work is to understand different smart antenna approaches, most importantly have a thorough understanding of a fully adaptive beamforming approach based on smart antennas. The focus and the main objective of this project will be an investigation of various adaptive beamforming algorithms that are used to compute the complex weights. The investigation includes a detailed study of algorithms like the Least Mean Square (LMS) algorithm, and recommend the best algorithm and parameter based on different criterion. And also developing and proposing, a possible implementation of an adaptive beamforming algorithm. Therefore, to utilize it in the area of mobile communications to provide the solutions to the various system problems that are limits the system capacity and performance.

1.5 Methodology:

The methods to be employed to achieve the objectives of the project are:

- **Literature Review**: includes reading books, articles, simulation tools and other resources related to the topic, for helping us to understand the nature of the problem that need to be solved and its importance, also reviewing the important aspects related to the topic.
- **System Modeling:** involves the structure of the system to be simulated along with the formulation of adaptive beamforming algorithm that is used in this project (such as mathematical and physical modeling). Also defining the appropriate procedures to be deployed for implementing the adaptive algorithm, and organizing it in a flow chart to facilitate the simulation step.
- **Simulation:** involves implementing and simulating the modeled communication system using the adaptive beamforming algorithm and preparing it by MATLAB coding.
- **Analysis of the Results:** the results obtained from the simulation are analyzed and compared based on performance analysis

criteria's. Therefore the research finding can be clearly stated, thus based on it the conclusion is derived.

1.6 Thesis Outlines:

The remainder of the thesis is organized as follows: The first chapter has already provided an introduction and background on mobile network development with justifying the need for smart antenna specially adaptive array antenna in the current cellular network, therefore the problem statement and objectives of the thesis followed by the proposed methodology was presented. Chapter 2 will provide a brief discussion of fundamental of mobile network and it deals with general antenna theory along with antenna arrays as to provide a basic understanding of antenna arrays, which is the main component of the smart antenna structure. Chapter 3 presents a brief overview of smart antenna systems including the different types of smart antenna systems and adaptive beamforming algorithms. Similarly, Chapter 4 introduce adaptive Beamforming algorithms used in this thesis, it's implementation (such as mathematical and physical modeling) and simulation results obtained using MATLAB. Finally, Chapter 5 concludes the thesis and summarizes the results of the work, and the scope for future researches in the area of adaptive beamforming algorithms for mobile communication are also suggested.