ADAPTIVE BEAMFORMING APPROACHES FOR SMART ANTENNA SYSTEMS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By

RAWAN MANSOUR

In Partial Fulfillment of the Requirements for The Degree of Master of Science in Electrical and Electronic Engineering

NICOSIA, 2016

RAWAN MANSOUR

ADAPTIVE BEAMFORMING APPROACHES FOR SMART ANTENNA SYSTEMS

NEU 2016

ADAPTIVE BEAMFORMING APPROCHES FOR SMART ANTENNA SYSTEMS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By

RAWAN MANSOUR

In Partial Fulfillment of the Requirements for The Degree of Master of Science in Electrical and Electronic Engineering

NICOSIA, 2016

Rawan MANSOUR: ADAPTIVE BEAMFORMING APPROACHES FOR SMART ANTENNA SYSTEMS

Approval of Director of Graduate School of Applied Sciences

Prof. Dr. İlkay SALİHOĞLU

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Electrical and Electronic Engineering

Examining Committee in Charge:

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Rawan Mansour

Signature:

Date:

ACKNOWLEDGMENTS

I would like to express my sincere appreciation and thanks to my supervisor, Dr. Refet Ramiz, for his guidance and support throughout my study and thesis preparation. His knowledge, advices and creative thinking were the source of inspiration throughout this work.

I would also like to express my gratitude to my mother, my father, brothers, and sisters for their support, patience, and feelings of love all over my life. Your constant love was the source of motivation for me to go on my way. The prayers of my mother and support of my father filled me with sense of pleasure and strengthened me always.

I would like to thank my beloved father Mohammed Mansour for his encouragements and continuous love. A special thank to my dearest brother Bassil Mansour with whom I passed most of my time abroad and who helped me always to reach my goals.

Last but never the least, I am thankful to my friends and colleagues in Near East University and abroad for their unlimited support, thank you all.

To my lovely family….

ABSTRACT

Smart antenna is considered as promising technology in wireless communication systems. It provides powerful solutions in the area of wireless networks. This system is capable of increasing the capacity, coverage, enhancing the control power and service quality, as well as reducing the co-channel interference and effects of multipath fading. Adaptive beam-forming is one of the main and most famous aspects in the development of smart antenna technologies. It uses different topologies and algorithms to identify the desired signals and separate the interference from a channel. Algorithms like Recursive Least Square (RLS), Constant Modulus Algorithm (CMA), and Least Mean Square algorithm (LMS) has proved their efficiency in adaptive beam-forming techniques. However, the increasing requirements in communication systems imply more focus on the implementation of the artificial intelligence in smart antennas.

Neural networks have witnessed fast development in the last three decades, ANNs has the ability to increase the efficiency and optimize the use of smart antennas in wireless communication systems. This work is sacrificed for the study and discussion of the smart antenna technology and the adaptive beam-forming approaches. It also provides an introduction to the implementation of back propagation neural networks in smart antenna as an adaptive beam-forming technique. Comparison and performance evaluation of these algorithms in terms of complexity, stability, convergence speed, amplitude response and tracking of desired signal will be present. The algorithms will be implemented in the MATLAB environment and results will be presented and discussed.

***Keywords*:** Smart antenna; adaptive antenna array; beam-forming algorithms; LMS; neural networks.

ÖZET

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AF:	Amplitude factor
ANN:	Artificial neural networks
AOA:	Angle of arrival
DOA:	Direction of arrival
LMS:	Least mean square
CMA:	Constant modulus algorithm
RLS:	Recursive least square
E:	Expectation
SAS:	Smart antenna system
ULA:	uniform linear array

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the field of communications, antenna is an electrical device which converts electric waves into electromagnetic waves or convert electromagnetic waves into electric waves.

The dramatic growth of wireless communication industry has resulted in searches for new technologies to overcome some problems associated with multipath such as fading, phase cancellation and delay spread in addition to problems associated with co-channel interferences.

Smart antennas are of the most important elements introduced into wireless communication systems nowadays. This is due to its special features and characteristics. However, The future implementation of techniques of smart antenna in wireless structures is likely to affect considerably the efficiency of spectrum employment, to minimize the price of new networks establishment, ameliorate the quality of service, and to simplify the inter-operation across different wireless network technologies. SAS are also able to eliminate or reduce the troubles caused by multi path propagation of waves. Recently, smart antennas have became very popular in different areas such as Cellular systems, wireless networks, radar systems, and electronic warfare (**EWF**) as a counter measure to electronic jamming and satellite systems.

The most important characteristics of smart antenna systems reside in their ability to maximize the gain of the antenna in the desired direction and attenuate the gain in interference directions. Therefore, smart antennas are able to reduce noise and interference that affect the desired signals, and thus increase the efficiency and performance of the wireless system. Smart antennas are using developed processing algorithms to ensure higher signal to noise ration upon reception of data, and due to the revolution in the use of communication systems, the need for more efficient, developed, and easy to implement algorithms is continuously increasing.

Artificial neural networks are very efficient and strong tools that have become popular in the recent decades. They are widely implemented in different scientific fields from control systems, power engineering, communication, financial sciences, banking, weather prediction and many other fields. ANNs have proved their extensive capability to offer high performance in solving different non linear problems that can't be solved easily by using traditional means.

This work will introduce the application of artificial neural networks in the function of smart antenna systems. The artificial neural networks will be implemented to optimize the performance of the system. Comparison between the most popular adaptive beamforming algorithms and ANNs algorithm for smart antenna will be carried out. Back propagation ANN algorithm will be implemented using MATLAB and its function to determine the weights of the antenna elements in order to minimize the errors in the received signal. Simulation result will be discussed and presented upon the end of this work.

1.2 Literature Review

The use of smart antenna is indispensable for the modern wireless communication systems. Researchers have started focusing on the smart antenna decades ago. Since then, different ideas, techniques, algorithms, and designs have been proposed and studied in literature. Smart antenna systems are developing and new ideas are being created with the sunrise of every new day. Zooghby, Christodoulou, & Georgiopoulos, (2000) has considered the problem of multiple source tracking using smart antenna relied on neural networks. The proposed system was implemented for terrestrial and satellite mobile communication systems. Radial basis function neural networks RBFNN algorithm was used to build a neural multiple sources tracking system. The neural network algorithm was used to perform detection and direction of arrival. The main advantage of this algorithm is that it needs no prior knowledge of the number of sources of signal; over more, it offers high accuracy and can locate sources that are greater than the number of elements of the antenna. The use of auto regressive (ARNN) and adaptive linear neural networks (ADALINE) to improve the performance of downlink beam forming was discussed in (Yigit, Kavak, & Ertunc, 2004). The work focused on the prediction of downlink weight vector using autoregressive modeling and ADALINE neural network functions. In (Sarevska, Milovanovic, & Stankovic, 2004), the neural network based smart antenna was also used for the solution of multiple source tracking problems. Two stages radial basis function neural network were used for signal detection and angle of arrival estimation. The proposed system has the advantage of high speed compared to normal neural algorithms.

Real time implementation of artificial neural networks for adaptive beam forming in a smart antenna was discussed in (Garcia, Ariet, & Rodriguez-Osorio, 2004). The implementation using DSP card of digital artificial neural network was presented. The paper has proven that the proposed system has accurately obtained the results compared to the LMS and RLS algorithms. ADALINE neural networks modeling for prediction of spatial signature to improve the performance of beam forming process was presented in (Kavak, Yigit, & Ertunc, 2005). In (Chang & Hu, 2012) and (Christodoulou, Tawk, Lane, & Erwin, 2012), the authors discussed the different reconfigurable components used in the antenna to modify its structure and function. They presented detailed analysis of the different classes of smart antenna systems such as adaptive arrays and multi-beam MIMO systems. They proved that the use of smart antennas instead of traditional antennas improves distinctly the performance of the communication systems. Different practical designs of smart antennas were discussed, presented and implemented in this work. A neural network approach to find the beam width of 15 elements dynamic phase array was discussed in (Rawat, Yadav, & Shrivastava, 2009). In this paper, three-layer neural network structure was implemented to compute the beam width in a smart antenna system.

Accuracy improvement in direction of arrival estimation in a smart antenna system using general artificial neural networks was proposed and discussed in (Pei, Han, Sheng, & Qiu, 2013). Switched beam smart antenna based on artificial neural networks structure was discussed and presented in (Orakwue, Ngah, Rahman, & Hashim, 2014). Feed forward back propagation artificial neural network was implemented in antenna beam switching. The proposed structure has shown its ability to switch different antennas of the base station depending on the actual location of the target.

Many different papers and publications have discussed the use of smart antenna and the algorithms used in its implementation. The use of artificial intelligence in smart antennas is getting more focus in literature due to its accuracy and high performance.

CHAPTER 2

ANTENNA AND ANTENNAS SYSTEMS

The foundation for all wireless communications is based upon comprehension of the transmission and reception of antennas as well as the electromagnetic waves radiation and propagation.

Antenna is the main and key element in the wireless communication systems as it is the responsible for the energy conversion from electrical to electromagnetic waves during the transmission phase; and from electromagnetic waves to electrical energy during the reception of signals.

Antenna is a metal object made often of copper, silver or aluminum; it converts electrical signals passing through them to electromagnetic signals and electromagnetic signals into electrical signals(Karmakar, 2011). With the continuous increase of communication needs and the need for more robust, accurate and efficient wireless data transmission systems; antennas have witnessed huge revolution in different aspects to be able to cover the requirements of users.

In this chapter, some of the basic parameters of the antenna will be presented. The different types of antennas in wireless communication system will be also presented and discussed. Finally, the design principles of the cellular systems will be discussed as well as the quest to develop service and capacity of wireless communication systems.

2.1 Antenna

Antenna is considered as an essential ingredient in all wireless systems and equipments that rely on radio waves, antenna can be defined as an electrical device that has ability to transform electrical energy into radio waves, or the inverse. The generated electromagnetic waves propagate through the space according the wave propagation principles transmitting data to another antenna system that receives and convert them into electrical waves (Karmakar, 2011). There for, antenna is the fundamental component in all transmitter and receiver devices that deal with electromagnetic waves. All antennas are constructed on the basis of wavelength of signals(Olenewa, 2013). Although they can pick up any available wave; but, the received signal will be weak due to the lack of compatibility with the antenna wavelength. Due to the multiplicity of wireless communications fields and the diversity of its applications, it was necessary to create different types of antennas to meet the needs of technology requirement and achieve satisfactory performance, based on this idea the used antenna in any system can be determined depending on several parameters that will be discussed in this chapter.

2.2 Antenna Parameters

In order to determine the quality of antenna with regard to transmission and reception capability, it must be taken into account many of the parameters that characterize an antenna such as: radiation pattern, radiation resistance, gain, polarization, and other factors that will be described in detail.

2.2.1 Radiation pattern

The term of radiation pattern in the antenna field can be expressed as the shape and direction of the beam of electromagnetic wave from antenna. It can be also defined as a graphical or mathematical representation of the radiation characteristic of antenna, and it is proven that all antennas can pick up the received signal only within the radiation area of other antennas. Figure 2.1 can be viewed as two-dimensional field pattern plot which describes two presentation methods, typical polar radiation plot and rectangular methods.

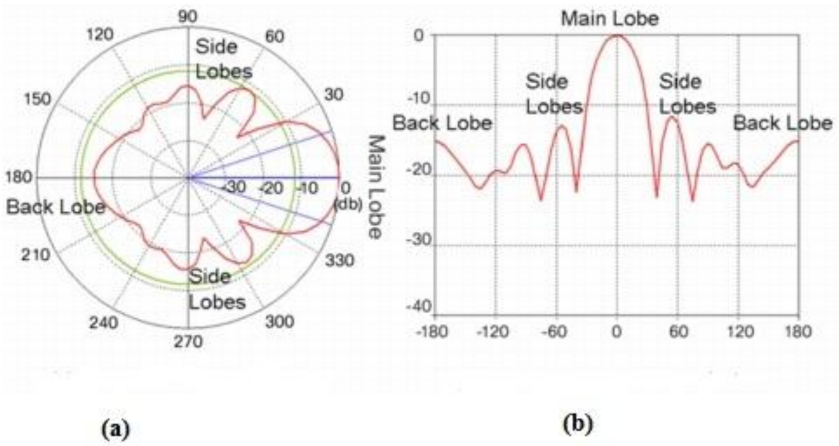


Figure 2.1: Two dimensional field pattern plot. a) Radiation pattern in polar coordinates. b) Radiation pattern in rectangular coordinates

In both methods the largest lobe which is called as “main lobe” expresses the radiation in the desired direction while the “side lobes” are that portion of the pattern which expresses propagation of waves in unwanted direction. Within the context of this topic it is important to mention to beamwidth of lobe which demonstrate the capability of antenna to distinguish between two different sources of radiation, (Khasim, Krishna, & Thati.).

2.2.2 Antenna gain

Among the many parameters that characterize antennas, this is the most effective expression of antenna performance characteristic, which is defined by the wireless communications terms as the ability of antenna to direct energy in particular direction, and it is an indication of the directivity of the directional Antenna feature, typically the measurement of antenna gain is measured in dB (Fonda & Zennaro, 2004). It is also observed that when the antenna has a high gain, it leads to narrower beamwidth, and that means fewer opportunities to receive interference. Oppositely, the antenna with the low-gain has the highest chances to receive interference due to the wide beam width.

2.2.3 Bandwidth

In the manufacturing stage of antennas, the broad band of antenna is determined. This characteristic indicates to the frequencies band that can be sent or received by antenna.

The bandwidth of an antenna usually described in two different way, the first method expresses the bandwidth of the antenna in absolute unit of frequency, while other method can describe this term with reference to the center of frequency band. This can be illustrated by the equation:

$$BW = 100 \times (FH - FL) / FC$$

Where:

FH is the highest frequency in the frequency band.

FL is the lowest frequency in the frequency band.

FC is the center frequency in the frequency band.

2.2.4 Polarization

This parameter is one of the fundamental characteristics of antenna; it refers to the direction of the radiated electric field of the electromagnetic wave, which is produced by antenna. Hence, antennas are categorized as "Linearly Polarized", "Circularly Polarized Antenna", and “elliptically polarized antenna”. If the magnetic and electric field perpendicular in respect to the plane wave and travelling in a signal direction, the electric field would be a Linear polarization, while if the field rotates in circle, this field would be said to be circularly polarized .However, if the electric field has two components that are perpendicular and out of phase but are not equal in magnitude, the E-field could be considered as elliptical polarized. Due to the reciprocity theorem, both transmitter and receiver antenna should be in the same polarity and thus there would be no loss of energy because of polarization mismatch. In another words, if the polarization of the transmitter is vertical while receiver antenna is horizontally polarized, the energy will not be transferred.(Boyle & Huang, 2008)

2.3 Antenna Classification

According to the antenna radiation, it can be classified into several types, including isotropic, omnidirectional and directional antenna .Whereas they can be categorized depending on their functions and operation to phased antenna array and adaptive antenna array.

2.3.1 Isotropic antenna

An isotropic radiator radiates the energy in all direction with equal intensity, Therefore, is considered as a theoretical ideal reference in electromagnetic waves laboratory in order to make comparisons with other types of antennas.

2.3.2 Omni directional antennas

This type of antenna is the most commonly used in wireless communication systems such as FM radio and radio broadcasting because it has the ability to receiving and radiating energy in all directions equally. Therefore; it can be said that it is non-directional antenna, and this is evident in the radiation pattern shown in figure 2.2. Despite the ability to broadcast the signal in 360 coverage directional, this feature leads to many bad consequences for wireless communication systems. The most prominent problems that are facing this type of antenna is inability to reject interference because it can’t send information to users directionally. Wherefore, it does not achieve the expected benefit in increasing Capacity and SIR for signal. (Fung, 2011)In addition , the most types of omni-directional antennas Can be considered as low gain antennas because they radiate the wave indirectly manner and it affects the quality of service .Thus the use of this type of antennas imposes a lot of restrictions on wireless communications systems, especially in the field of capacity, service quality, Powered Control ,coverage and frequency reuse. This behavior in non-directed broadcasts scatters signals and reduces the percentage of energy that reaches the desired user. Therefore, the designers solving this problem by increasing the power level of antenna broadcast, but this has made the situation worse because of the high chance of interference with co-channels in neighboring cells that operate in same set of frequencies(Antenna Basic Concepts).

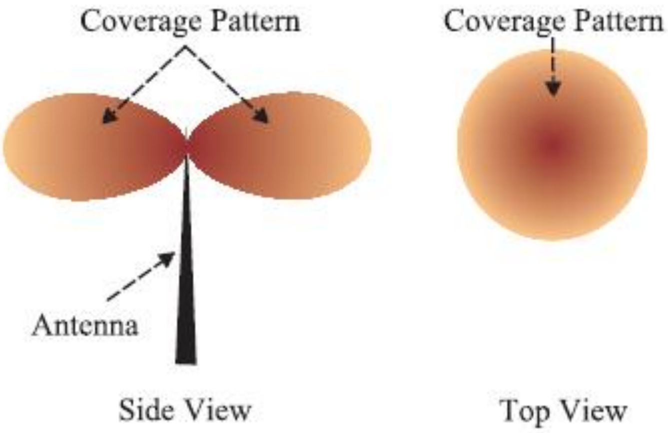


Figure 2.2: Coverage pattern for omni-directional antenna

2.3.3 Directional Antennas

With the development of communication it was necessary to find a solution leading to raise the antenna efficiency without polluting the environment with interferences ,this is what led to the adoption of directed antenna which can be defined as a device capable of transmitter and receiver the power in a particular directions by directing a narrow beamwidth of signal toward the target, this behavior raises the antenna performance by increasing the gain and makes it capable of reducing the proportion of receiving interference .

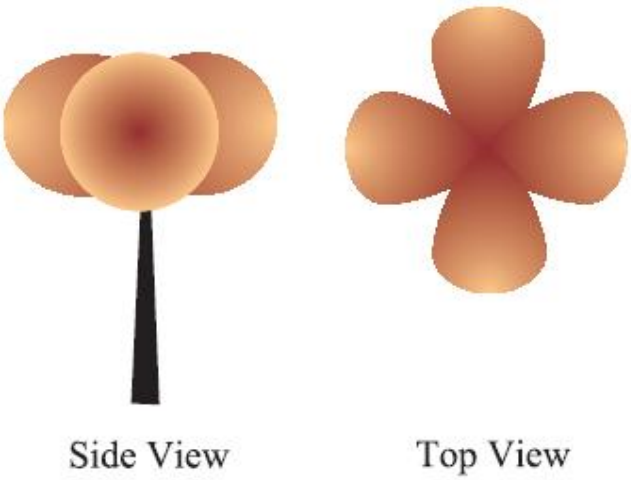


Figure 2.3: Coverage pattern for Sectorized antenna system

2.3.4 Antenna array

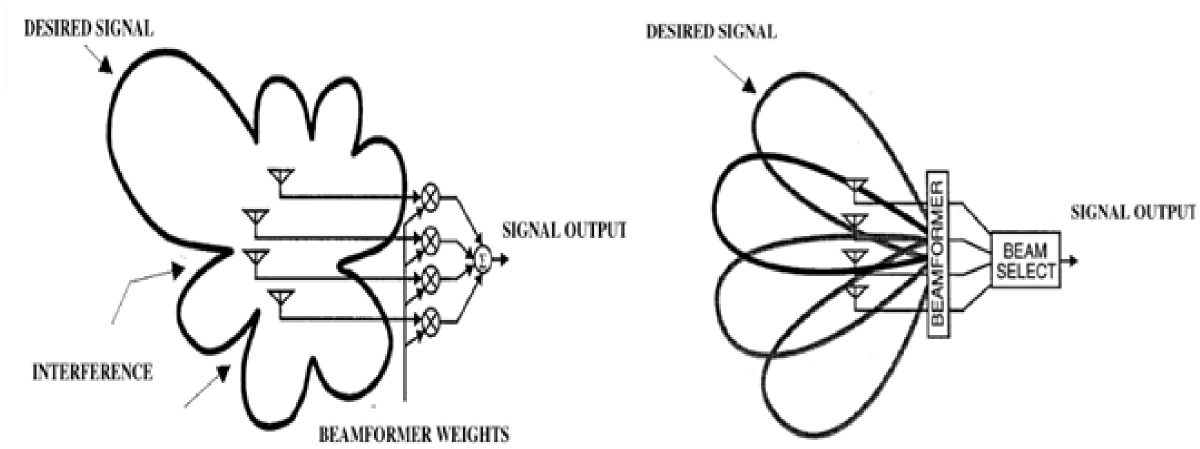
In order to overcome the drawbacks facing the conventional antennas in terms of inability to reject interference, the antenna array system came to be the solution, and generally fall in two categories.

2.3.4.1 Phased array

The phased array consists of several elements of radiation are arranged and linked in a certain way to give direction radiation model. This Array has wide applications in radar, communications, and at the present time in the microwave frequencies used in satellite communications, the main objective of this technique is to increase gain in the desired direction and suppression the radiation in the unwanted direction, by adjusting the phases of the signals that feed input elements in array. For illustration purposes it can be said that the total electromagnetic field of an array is obtained by vector addition of the fields emitted by the array elements, combined in both phase and amplitude. (Balanis & Ioannides, Introduction to smart antenna, 2007)

2.3.4.2 Adaptive array

In communication terms the “adaptive array” refers to the radiation properties of array which is characterized by its ability to change the radiation depending on changes and requirements of system, this array is distinct from traditional antennas through its ability to operate with high performance in dynamic environments which features that signals whether desired or unwanted arrive from different directions and different levels of energy. In addition, the use of adaptive arrays in communication system would provide reliability and better quality compared to the conventional systems, through the ability to reduce the level of side lobes in the direction of unwanted signals and reduce the interference while maximize the radiation pattern toward the desired user(Balanis & Ioannides, Introduction to smart antenna, 2007) .This adaptive technique which adopted by this array is mainly carried out through signal processing unit which improve the performance by adapting the weights based on the received signal in order to maximize reception in the desired direction and minimize the reception from unwanted users. Figure 2.4 illustrates the difference between the two antenna array techniques, where it is clear that adaptive array technique has ability to achieve better performance, which would ensure the suppression of interferences entirely.



(a) (b)

Figure 2.4: a) Adaptive antenna array. b) Phased antenna array.

2.3.4.3 Smart antenna

In wireless communication systems the term "smart antenna" refers to any antenna array equipped with signal processing unit, which makes the system able to receive and transmit in an adaptive manner(Das).The definition of spatial signal signature is a major step in this system for the sake of allocate and truck the target, while the subsequent stage based on adjust the weights using specific algorithms in order to form the maximum beam toward the desired user, this in turn reduces the interferences.

2.4 Antenna Systems and the Quest for More Capacity in Cellular Radio System

Over the past several decades, engineers have focused their efforts on the development of communication systems, and the capacity has been the most complex dilemmas facing them due to the limitations in the allocated frequency spectrum, in addition to the increasing number of subscribers and the need to ensure satisfactory service with high quality. The concept in cellular system design is based on the division the geographical areas into several clusters to be provided with the service, each cluster splitter into several cells equipped with base station for each cell with R radius, the full bandwidth of frequencies that allocated to communications company is distributed within the same cluster, while avoiding repetition of frequencies within a same cluster, however it is possible to re-use frequencies in neighboring cluster with (D) separation distance between two cells that have the same set of frequencies. Because of this way of frequency allocation, interference occurs and this is called co –channel interference.

In the past decades omni-directional antenna has been used in base station which led to pollute the environment with interference, this caused the concentration of efforts to find a solution through the replacement of omni-directional antenna system with systems called “sectorized system”, In this case the cell is divided into three or six sections by replacing the omni-directional antenna with several directional antennas and this technique called “cell sectoring”, and thus reduces the number of co-channel cells within the likely range for the occurrence of interference(Goldsmith, 2004).

cellular design technique depends on increasing capacity by decreasing the number of cells in cluster, decreasing the radius of cell R, or decreasing the distance D and thus the re-use frequency would increase to achieve an increase in capacity(Bellofiore, Balanis, Foufz, & Spanias, Smart-Antenna Systems for Mobile communication network, 2002). One of the technique has followed to improve capacity is “cell splitting “which relies on reducing energy that transmitted by antenna through the principle of the division of the cell into microcell and each small cell equipped with it is own omni-directional antenna in base station, where the full bandwidth is distributed within the splitted cell. In this way, the number of cells increases, thereby increasing the possibility of re-uses frequencies which lead to raise the capacity. Although it considered one of the methods that led to increase capacity, the design of this system is expensive due to the need for more base stations. This resulted in the quest for finding other solutions to the capacity.

CHAPTER 3

SMART ANTENNA SYSTEM

Over decades, designers and developers of wireless communications systems have been seeking continuously to overcome the obstacles facing the systems, co-channel interferences, multipath fading and inter-symbol-interference (ISI) are considered as main problems that lead to the decline in the quality of service and limit the numbers of subscribers served by system (Jain, Katiyar, & Agrawal, 2011)

Co-channel interference refers to the interference that occurs when signals that have same frequency reach to the receiver, where one of these signals is the desired, and the rest are unwanted signals due to the frequency reuse principle which depends on reassigning the same spectrum bands to other distant cells (The cellular concept-system design fundamental, 2002).Despite that omni-directional antenna systems provide high coverage due its in-directional radiation, however it leads to increase co-channel interferences.

The reliance on traditional systems such as omni-directional and diversity system has been shown that these solutions are not satisfactory to the growing demands for wireless systems as well as the need to reduce infrastructure and maintenance costs. On the other hand the performance of system is also affected and getting worse due to the interference caused by the reception of the signal from several tracks which is called multipath fading, only smart antenna system, which has passed through several stages of development before becoming commercial, exploit the problem of receiving the signal from different directions to improve reception by directions spatial processing that distinguishes this system(Azad & Ahmed, 2010). Wherefore recent research has concentrated on the development of algorithms that used in the design of “smart antenna system” which has the ability to develop various aspects of wireless communications systems including power control, quality of services and capacity. This system was able to outperform conventional systems in terms of spectral efficiency by achieving more capacity so that a larger number of subscribers can be served ,in addition to acquire greater coverage areas and raise the performance in terms of data rate.

In this chapter the concept of smart antenna and its types will be presented, the architectures of system will be described as well as the most important benefits, advantages, drawbacks of this system and its applications in communication field.

3.1 Smart Antenna System Concept

Smart antenna system is defined as a combination of elements constitute the hardware section which are also called antenna array, while the software part is represented by the digital signal processing unit that makes the system intelligent (Jain, Katiyar, & Agrawal, 2011).Over the last few years the research has tended to develop algorithms that give the system the ability to identify ,locate and truck user dynamically via DOA and Adaptive algorithms, in order to direct the main beam towards the desired target and nulls in unwanted directions via beamforming algorithms this would significantly reduce the noise and maximize the directivity of antenna (Bellofiore, Balanis, Foufz, & Spanias, Smart-Antenna Systems for Mobile for communication networks, 2002).

In other word, smart antenna system can be defined as a smart technology that can increase the gain of antenna array system which in turn reduces interferences, thus increases the quality of service and performance of the system, and the spectral efficiency is achieved.

3.1.1 Analogy for adaptive smart antenna

The human brain is often regarded as a source of inspiration for many intelligent systems that are trying to approximating the systems of the human, and that was the case with smart antenna system.

Scientists have observed that a human is able to identify and locate the desired sound as well as focus on it, even in the presence of other voices or sound source movement. This property is due to the presence of ears, which receive the vote with a time delay due to spatial difference between them, thus it can be said that ears are similar to the radiation elements in an antenna array while the brain act as a software part in smart antenna system through its calculation process for determining the direction of the desired speaker from the delay time that received by the two ears (Balanis & Ioannides, Introduction to Smart Antennas, 2007). Therefore, a person can locate and truck the interest speaker in dark room and suppress any other noise voices through this system which consists of two ears and the brain, which is equivalent to performance of smart antenna system that can transmits and receives signals in adaptive spatially manner and has the ability to maximize the reception toward the target while minimize the interfering signals. Figure 3.1 below illustrates the analogy for Adaptive Smart Antenna through blindfolded man in a dark room and two speakers.

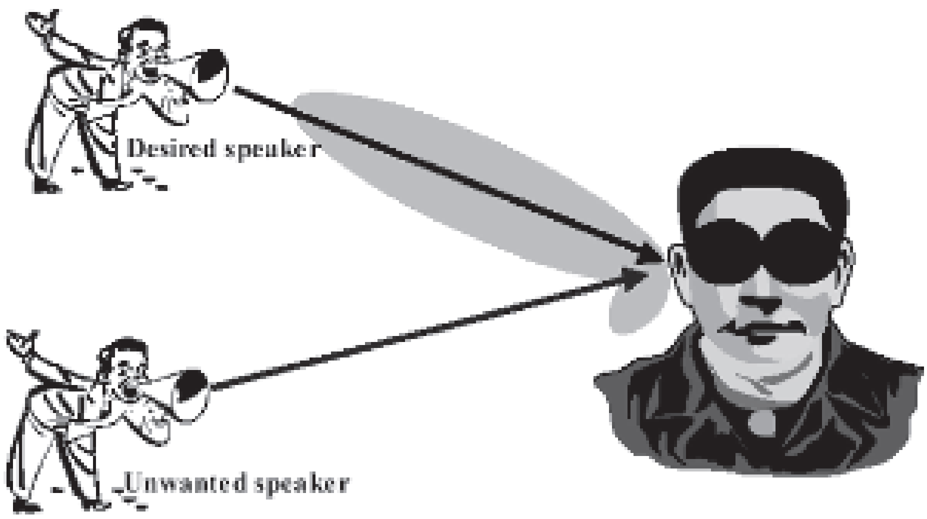


Figure 3.1: Smart antenna analogy

3.2 Types of Smart Antenna Systems

Smart antenna systems characterized by their ability to improve the quality of service and its ability to reduce the interference; however the performance evaluation of the system is related to the types of antenna array.

The following are the classification of smart antenna systems and the difference between them in terms of level intelligent, structural and performance:

3.2.1 Switched-beam systems

A switched-beam system is the simplest smart antenna technique. This system is based on the idea of cell-sectoring in dynamic manner, where it is characterized by fixed, predefined lobe-patterns as illustrate in Fig 3.2.This system is called “switched-beam” because of its ability to switch between multiple fixed beams, that formed by only phase adjustment, according to direction and movement of the user, in order to increase the gain and enhance the reception, these systems can superiority of the “sectorized antenna systems” in terms of its ability to choose the appropriate beam and achieve the characteristic of directivity without the need for a fixed metallic physical design (Jain, Katiyar, & Agrawal, 2011).

Despite the ability of this system to reduce interferences, it is unable to suppress these interferences entirely, therefore it is incapable of achieving the optimal gain, if the desired user does not exist in the center of the main beam, this allows to maximize the received power of the interference that is located in the center of the same fixed beam more than the desired target. (Bellofiore, Balanis, Foufz, & Spanias, 2002).

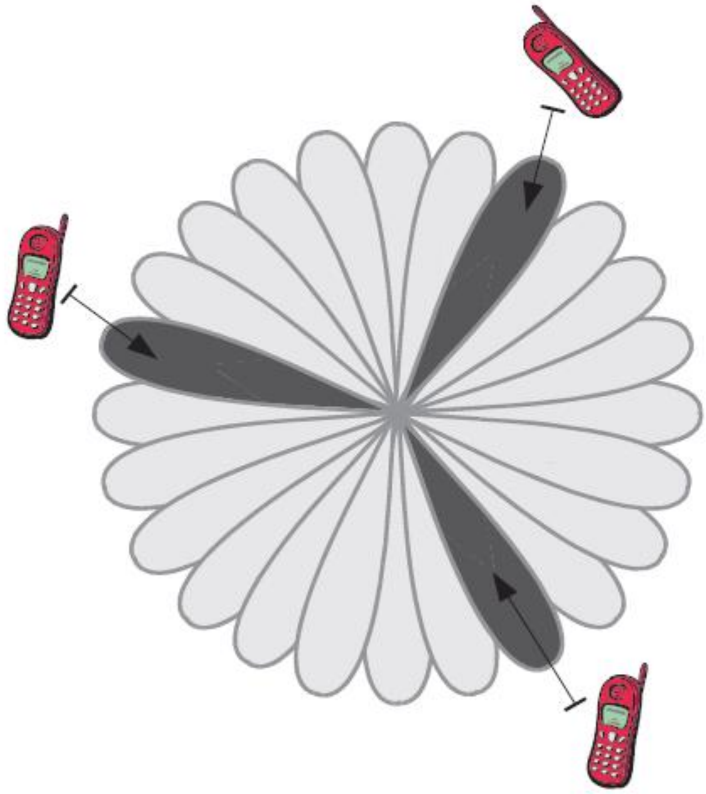


Figure 3.2: Switched-beam coverage pattern.

3.2.2 Adaptive-array systems

Adaptive array systems is classified as the most intelligent in smart antenna systems, this classification is due to its ability to adapt the radiation pattern in real time (Kawitkar & Wakdi, 2005) this system exploits the spatial signal signature in order to estimate the desired user's location and then directs the radiation towards it as well as tracks the signal of interest SOI while places null in all unwanted direction, thus can reduce the effect of noise, multipath fading and interferences on the system (Bevelacqua, 2008) .By signal processing unit ,this technology can adjust the parameters of the system adaptively in order to optimize the performance .Fig 3.3 shows the adaptive array coverage pattern which illustrate how it prove a high degree of freedom by its ability to customize the radiation pattern for each individual desired target in system and place nulls in interference directions.

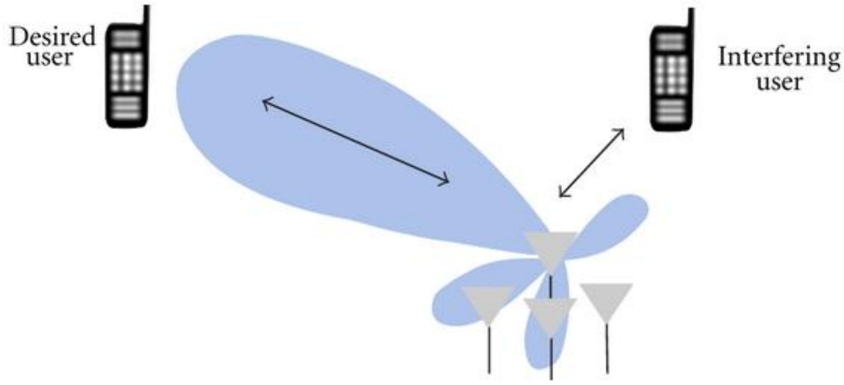


Figure 3.3: Adaptive array coverage

The main difference between adaptive antenna and switched-beam antenna systems is the ability of the adaptive array system to form the main beam by controlling the angle and amplitude of radiation pattern in adaptive manner to achieve an optimal gain in desired direction and suppress other interferences, while the second system is unable to form a shape of a main beam, it is only able to selects the appropriate fixed beam and switch between the predefined beams depending on the movement of the user, that makes the switched-beam system less efficient in dealing with interference close to the desired signal and less ability to increase the capacitance compared with the adaptive system as well as the intra-cell hand off must be handled among beams other than the intra-cell hand of in other system .On the other hand the adaptive array system is more complicated and costly(Kawitkar & Wakdi, 2005).

3.3 Architecture of Smart Antenna System

In general, smart antenna system consists of antenna array with radio unit part and software section. The following section explains in detail the parts of adaptive system.

3.3.1 Antenna array

Antenna array is geometrical arrangement of the set of individual sensors element "antenna" with same orientation and radiation pattern, these elements connected with each other to be used in transmission or reception part (Balanis & Ioannides, Introduction to Smart Antennas, 2007). Since the elements of this array are associated with the signal processing unit, it mainly affects the shape of radiation pattern in adaptive systems (Bellofiore, Balanis, Foufz, & Spanias, Smart-Antenna Systems for Mobile for communication networks, 2002), these elements in antenna array are placed closely in order that there will be no differences in amplitude of the received signals and the number of antennas must be the minimum number of required for designed system in order to avoid complexity.

3.3.1.1 Antenna array geometry

Types of antenna arrays are varied according to the geometrical arrangement of elements, when the distances between the elements is equal, then the antenna array is described as uniformly spaced arrays, while if the distances between adjacent elements are irregular, the antenna array would be non-uniform (Bevelacqua, 2009). The elements placed and the distance between them affect the radiation pattern, as an increase in the distance between the elements lead to decrease in beamwidth, furthermore, the array factor which represents the array out is influenced by the geometry of array.

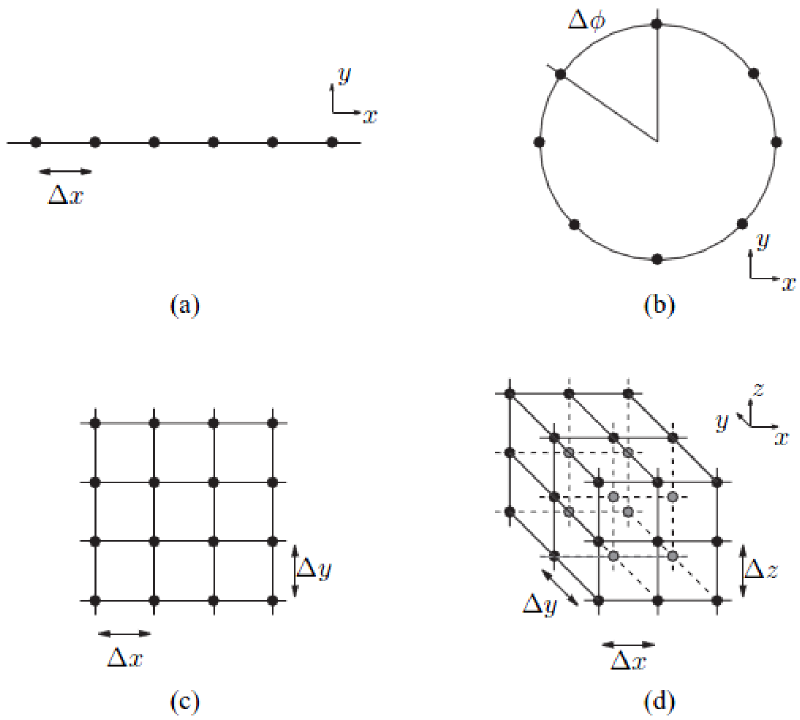


Figure 3.4: Different types of uniform array geometries.

Fig 3.4 shows four different types of array such as : uniform linear array ,circular ,planner. the first type (a) represents uniform linear array with one dimensional beamforming while (b) is uniform circular array ,type (c) can perform two-dimensional beamforming in both azimuthal and elevation angles (Balanis & Ioannides, Introduction to Smart Antennas, 2007), last one is a cubic array with separation of Δ x, Δ y, and Δ z. this structural is conceder as three dimensional array.

3.3.1.2 Theoretical model for an antenna array

The first mathematical rule that must be considered when designing the smart antenna design is the distance between the elements in uniform array, which likes to be constrained by the following law:

$$d \le \frac{\lambda}{2} \tag{3.1}$$

Where d is the distance between two adjacent antennas and λ is the wavelength, if the separation distance is greater than the half-wavelength then the grating lobes will occur, this term is refers to the sidelobe which has considerable amplitude with respect to main lobe and possibly up to its amplitude value (Bevelacqua, 2008), however this phenomenon is difficult to be controlled if the array is non-uniform.

Assuming ULA with N =5 elements smart antenna vector receiving three signal s1, s2, and s3; the steering vector defines the angle in which each one of the signal is received by each element of the antenna. The angle of one of the elements is considered as reference and the other elements angles are calculated as follow (supposing d=0.5λ).

$$a(\theta) = [1, e^{-j\frac{2\pi d}{\lambda}\sin\theta}, \ldots\ldots, e^{-j(N-1)\frac{2\pi d}{\lambda}\sin\theta}]^T \tag{3.2}$$

$$\begin{aligned}
\bar{a}_{S1} &= \begin{bmatrix} e^{-j2kd\sin(\theta_{s1})} & e^{-jkd\sin(\theta_{s1})} & 1 & e^{jkd\sin(\theta_{s1})} & e^{j2kd\sin(\theta_{s1})} \end{bmatrix}^T \\
\bar{a}_{S2} &= \begin{bmatrix} e^{-j2kd\sin(\theta_{s2})} & e^{-jkd\sin(\theta_{s2})} & 1 & e^{jkd\sin(\theta_{s2})} & e^{j2kd\sin(\theta_{s2})} \end{bmatrix}^T \\
\bar{a}_{S3} &= \begin{bmatrix} e^{-j2kd\sin(\theta_{s3})} & e^{-jkd\sin(\theta_{s3})} & 1 & e^{jkd\sin(\theta_{s3})} & e^{j2kd\sin(\theta_{s3})} \end{bmatrix}^T
\end{aligned} \tag{3.3}$$

where k is the wave vector (2π/λ) and θ is the elevating angle which could be more clarification in the Fig 3.5 that describe a uniform linear array with N elements .

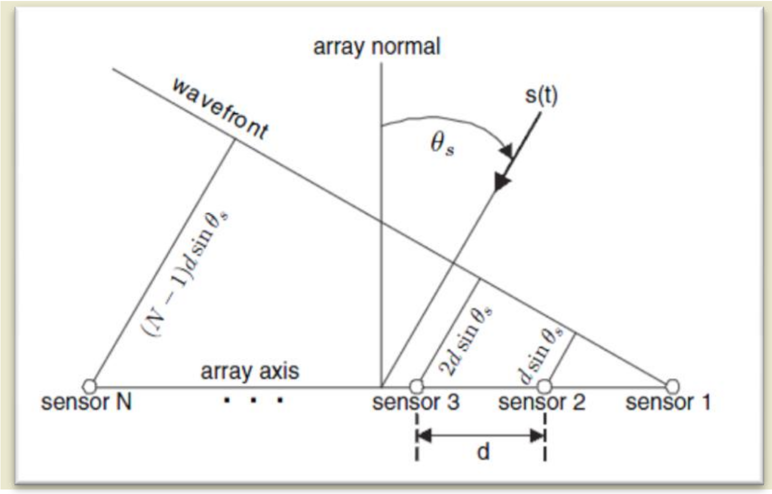


Figure 3.5: ULA with N sensors

By adjusting the weights and determine the array geometry, the system can achieve the optimal radiation and reception in desired direction while suppress the interferences from unwanted direction, and this idea can be expressed mathematically through the array factor equation, this term is a function of separation distance in array, their relative phase and magnitude as well as the weights used (Bevelacqua, The Array Factor, 2009).the array factor is given by:

$$AF(\theta) = \sum_{i=1}^{N} \omega_i a_\theta \tag{3.4}$$

Where

ω_i is complex array weight at element i.

θ is angle of incidence of electromagnetic plane wave from array axis.

N is the number of elements in antenna array.

a is steering vector.

3.3.2 Radio unit (hardware)

Radio unit represents the hardware section in the smart antenna system , it consists of chains of down/up converter, the number of converters must be equal to the number of elements in antenna array, where each converter is responsible for converting the radio signal into low frequency signal in order to make it suitable to be processed (Abdallah, Joumaa, & Kadry).Fig 3.6 illustrates the block diagram of the hardware part consisting of antennas elements that receive signals and then injects the signals into low-noise amplifier which is responsible of amplifying a very low-power signal without changing its signal-to-noise ratio. Second part in hardware is down/up converter and the last one is analog-to-digital block which digitize the signal to be Prepared to the digital signal processing stage.

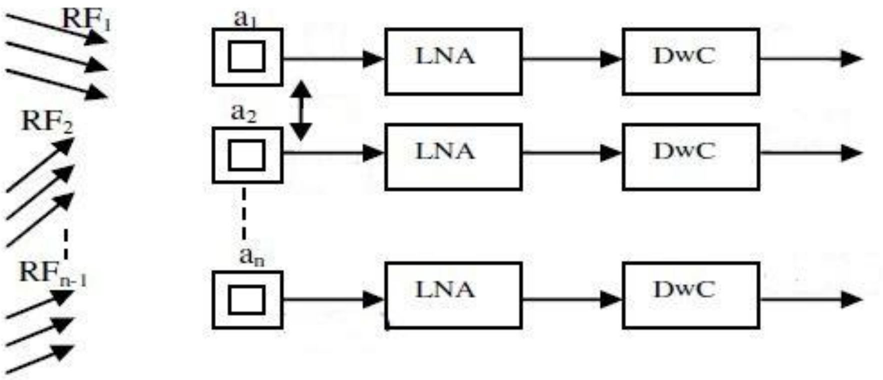


Figure 3.6: The hardware part in smart antenna (receiving section)

3.3.3 Signal processing unit

In Adaptive system, signal processing unit has the main role in enhancing the performance efficiency and make it an intelligent system. In this unit, the information is collected in order to extract the knowledge and applied through adaptive Signal-Processing algorithms (Bellofiore, Foutz, Balanis, & Spanias, 2002), furthermore, signal processing is responsible for identifying the location of the signal after it is captured and trucking it in order to maximize the reception in interest direction and filtering out the interferences from unwanted direction. This process is done by direction-of-arrival estimator (DOA estimator) and adaptive beam-forming.

3.3.3.1 DOA estimator

Direction of arrival estimation is refers to the technique that estimate the analog arrival of received signals from the time delays for each elements in the array and includes a correlation analysis of the array signals followed by Eigen analysis and signal noise sub-space formation (Bellofiore, Foutz, Balanis, & Spanias, 2002).The goal of AOA estimation techniques is to define a function that gives an indication of the angles of arrival based upon maxima vs. angle. This function is traditionally called the pseudo spectrum P (θ) and the units can be in energy or in watts (or at times energy or watts squared). There are several potential approaches to defining the pseudo-spectrum .In general, the DOA estimation algorithms can be categorized into several groups; the conventional techniques, subspace techniques, maximum likelihood techniques and integrated techniques(Joseph C.Libertii & S.Rappaport, 1999).

3.3.3.2 Adaptive beamformer

The most essential process in smart antenna system is beam forming, which it is also refer to spatial filter, since it has the ability to filter signals based on their spatial direction. Hence, the signal not of interest (SNOI) is filtered out while the signal of interest (SOI) is amplified (Stevanovic, Skrivervik, & Mosig, 2003).This spatial processing technique depends on the information that has been obtained from the previous steps from DOA estimator, in order to shape the beam pattern of an antenna array and nullify the signals in unwanted directions, this continuously changes process is done by adjusting and computing the optimal complex weight vector via adaptive algorithms. Thus, the performance efficiency of smart antenna system gets increased as well as the signal-to-noise ration. Algorithms and adaptive beamforming technique will be explained later in chapter 4.

Figure 3.7 illustrates the functional block diagram of adaptive array system as a receiver, which consists of two parts: the radio unit and digital processor, after the signals are captured by the antenna elements in the array, the down-converters convert the radio signals to baseband, then A/D digitizes the signal to prepare it for the digital processing, the direction-of-arriving estimator calculates the angles of the received signals, which include the desired signals and interferences signals by finding the time delays among the sensor elements. Basically, this gained information are relied and applied via adaptive algorithms in order to adjust the complex weights (amplitudes and phases of the signals) that result in an maximize the radiation toward the SOI and reject the interference(Balanis & Ioannides, Introduction to Smart Antennas, 2007).

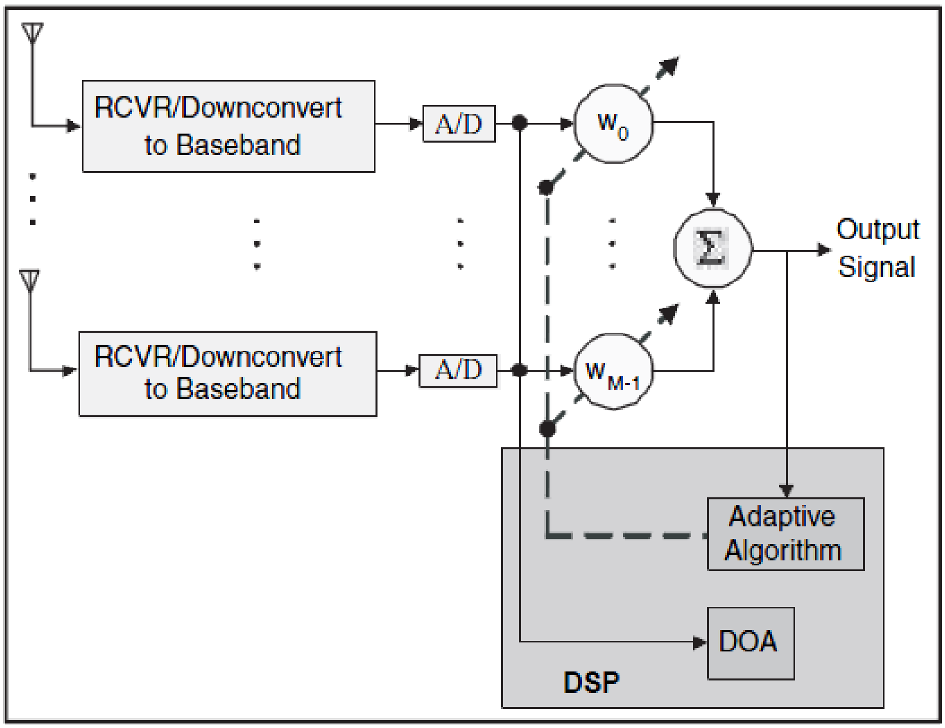


Figure 3.7: Functional block diagram (adaptive array system)

3.4 The goal of smart antenna

Smart antenna system has achieved a quantum leap in communications world because of the solutions that provided by this system, in addition to its features that make it superior to other traditional wireless systems.

- **Increasing the coverage**

Coverage area is refers to the area where the communication between a user and the base station is available, because smart antennas is more directive than convention systems such as omnidirectional antennas or sectoring systems ,it can achieve better coverage. This feature significantly associated with higher gain that is provided by the adaptive system. Moreover, it has been proved that this smart system achieves coverage greater by (M) than conventional systems, while the number of required base station has decreased by (1/M) by using smart antenna system with M antenna elements (Sallomi & Salim, 2009).it worth mentioning that the directivity characteristic of smart antenna system impacts on mobile devices through minimize the required level of power and thus prolonging battery life (Bellofiore, Balanis, Foufz, & Spanias, Smart-Antenna Systems for Mobile for communication networks, 2002)

- **Increasing capacity**

Adaptive array system is able to meet the growing need for capacity by being able to radiates and receives in desired direction while suppress the interference or noise that affect on the service and limit the possibility of re-use of frequency. Interference rejection feature enables the system to increase the signal-to-interference ratio which in turns increase the capacity, thus increasing the number of subscriber in designed system(Bellofiore, Balanis, Foufz, & Spanias, Smart-Antenna Systems for Mobile for communication networks, 2002)

- **Increasing bit-rate**

Depending on the spatial variation of the signals, the system can exploit this feature to reject signals coming from multiple paths, which cause multipath fading and ISI (Stevanovic, Skrivervik, & Mosig, 2003).Instead of using the equalizer to recover the signal, adaptive array system is used in order to reduce the delay spread of the channel and that would reject multipath and support the bit rate.

- **Security**

The security feature is considered a necessary issue in the field of communications to avoid intruding on users network data, the solution provided by the smart antenna lies in its ability to radiate in adaptive manner with high gain; thus, the transmission of signals is not in all directions and thereby reducing the probability of spying on data and increase security whereas the hacker must be in the same location of the users (Balanis & Ioannides, Introduction to Smart Antennas, 2007).

3.5 The drawbacks

Despite the many benefits realized by the smart antenna system, many of the problems facing this system and make it difficult to apply in some application.

- **Complexity**

The operations performed by the system on the receiving signals in order to optimize the service quality affect on the system and make it more complicated, especially in terms of the separation of incoming signals and synchronize them with real-time(Balanis & Ioannides, Introduction to Smart Antennas, 2007). In addition to the base station requirements to high-resolution powerful processors and controllers, this makes the system more complicated because of the need for complex mathematical operations in digital signal processing part.

- **Size**

The need to increase the number of elements in antenna array to provide better performance in addition to the fact that the separation distance between them restricted on condition ($d \leq \frac{\lambda}{2}$) and is depending on the operator frequency, lead to an increase in antenna array size, for example, the antenna array size would be approximately 1.2 meters wide at a frequency of 900 MHz and 60 cm at 2 GHz (Balanis & Ioannides, Introduction to Smart Antennas, 2007).

CHAPTER 4

BEAMFORMING ALGORITHMS

Adaptive Smart antenna structure is distinguished by the capability to form and object the radiation of the main beam in the direction of the desired user with eliminating the non desired signals and noise. This is used to increase the performance during the transmission and reception of communication signal.This technique, which constitute the array beam pattern is referred as the beam forming.

In this chapter, the fundamentals of fixed weight beam forming will be presented in addition to the adaptive beam forming strategies and then we will review some of the adaptive beam forming algorithms used in the system, which will be simulated to discuss the results in next chapter.

4.1 Fixed Weight Beam-forming Basics

Beam forming techniques are basically classified into two main approaches, the fixed weight beam forming and adaptive beam forming (Cohen, 2003). The former term refers to the process by which weights are fixed and the incoming signal does not change with the times, and thus the optimum weights is not based on the received data and won't need to be adjusted (Gross, 2005). In order to get the optimal weight we can follow several methods such as SIR, LM methods and MV that will be explained in the following sections.

4.1.1 Maximum signal-to-interference ratio approach

SIR can be known as the ratio between the power of wanted signal to that of undesired signal (Gross, 2005). This ratio indicates that the increase in SIR will lead to improve signal reception and reduce interference.

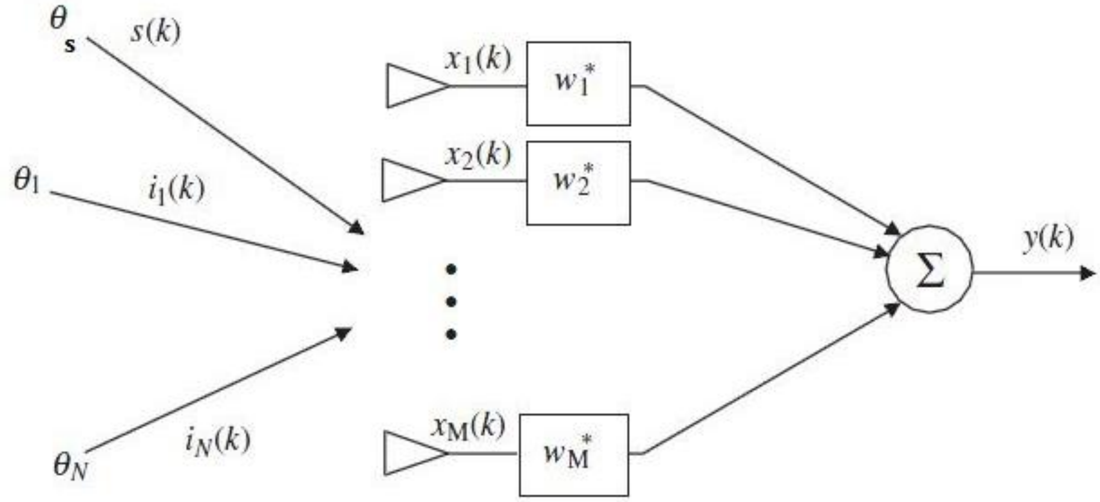


Figure 4.1: M-element array with desired signal and N interfering signals

In order to clarify that idea let's assume an array of M elements receive a desired signal from θs angle while the interfering signals arrives from $\theta_i,\ldots,\theta_N$ angles as it is illustrated in Fig 4.1 where time is expressed by the k^{th} time step. The weights in the array are expressed by:

$$\bar{w} = [w_1\ w_2 \qquad w_M]^T \tag{4.1}$$

And the desired signal vector is

$$\bar{x}_s(k) = \bar{a}_s s(k) \tag{4.2}$$

While the interfering signals vector is represented by:

$$\bar{x}_i(k) = [\bar{a}_1 \quad \bar{a}_2 \quad \ldots\ldots \quad \bar{a}_N] \begin{bmatrix} i_1(k) \\ i_2(k) \\ . \\ . \\ i_N(k) \end{bmatrix} \tag{4.3}$$

Then the array output with weights is:

$$y(k) = \bar{w}^H . \bar{x}(k) \tag{4.4}$$

Each received signal includes additive Gaussian noise $\bar{n}(k)$, and then the input signal vector is given by:

$$\bar{x}(k) = \bar{x}_s(k) + \bar{x}_i(k) + \bar{n}(k) \tag{4.5}$$

Then we can rewrite the equation (4.4) in equation (4.6)

$$y(k) = \overline{w}^H.[\overline{x}_s(k) + \overline{x}_i(k) + \overline{n}(k)] \tag{4.6}$$

In order to describe the correlation between the received signals by the antenna elements we can find the array correlation matrices for desired signals (Rss) correlation matrices for undesired signals (Ruu) through the following equations

$$\overline{R_{SS}} = E[\overline{x_s}.\ \overline{x_s}^H] \tag{4.7}$$

$$\overline{R_{uu}} = \overline{R_{ii}} + \overline{R_{nn}} \tag{4.8}$$

Where $\overline{R_{ii}}$ is correlation matrix for interferer and $\overline{R_{nn}}$ is correlation matrix for noise, while E[ ] is the expectation operator, and $()^H$ indicates the Hermitian transpose (Gross, 2005).The power of the weighted output array of the desired signal is defined by:

$$\begin{aligned} \sigma_s{}^2 &= E[\left|\overline{W}^H.\overline{x_s}\right|^2] \\ &= \overline{W}^H.R_{SS}.\overline{W} \end{aligned} \tag{4.9}$$

While the power of the output array in the undesired signals is expressed as:

$$\begin{aligned} \sigma_u{}^2 &= E[\left|\overline{W}^H.\overline{u}\right|^2] \\ &= \overline{W}^H.R_{uu}.\overline{W} \end{aligned} \tag{4.10}$$

SIR can be expressed by the following ratio:

$$SIR = \frac{\sigma^2{}_S}{\sigma^2{}_u} = \frac{\overline{W}^H.R_{SS}.\overline{W}}{\overline{W}^H.R_{uu}.\overline{W}} \tag{4.11}$$

The correlation matrix is defined as $\overline{R_{SS}} = E[|s|^2].\overline{a_s}.\overline{a_s}^H$, therefore Optimizing weight can maximize the SIR ratio, the weight vector in terms of optimum Weiner solution

$$\overline{w_{SIR}} = \beta\overline{R_{uu}}.\overline{a_s} \tag{4.12}$$

Where

$$\beta = \frac{E[|s|^2].\overline{a_S}^H}{SIR_{\max}}\overline{W_{SIR}} \tag{4.13}$$

4.1.2 Minimum mean-square error approach

This method is based on finding the optimum weight for adaptive system by minimizing the mean square error, as shown in the figure 4.2 the error signal ε(k) is the difference between the reference signal d(k) and array output y(k), where d(k) represent the desired signal s(k) or the correlated signal with s(k)(Gross, 2005). Equation (4.14) is representing the error:

$$\begin{aligned}\varepsilon(k) &= d(k) - y(k) \\ &= d(k) - \overline{w}^{H}.x(k)\end{aligned} \tag{4.14}$$

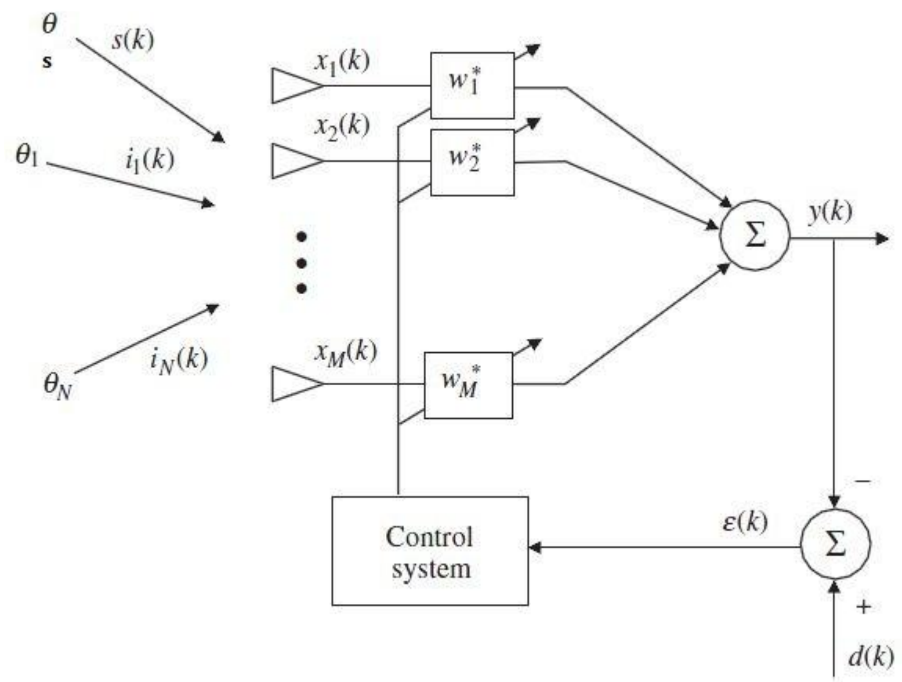


Figure 4.2: Block diagram for adaptive MSE structure

The MSE is given by following equation:

$$\begin{aligned}\left|\varepsilon(k)^2\right| &= \left|d(k)^2\right| - 2d(k)\overline{w}.^{H}\overline{x}(k) + \overline{w}^{H}\overline{x}(k)\overline{x}.^{H}(k).\overline{w} \\ &= \left|d(k)^2\right| - \overline{w}^{H}\overline{r} + \overline{w}^{H}\overline{R}_{xx}\overline{w}\end{aligned} \tag{4.15}$$

Where the correlation are defined:

$$\overline{r} = E[d.\overline{x}] = E[d.(\overline{x_s} + \overline{x_i} + \overline{n})] \tag{4.16}$$

$$\overline{R_{xx}} = E[\overline{x}\overline{x}^H] = \overline{R_{SS}} + \overline{R_{uu}} \tag{4.17}$$

While $\overline{R_{ss}}$ and $\overline{R_{uu}}$ have been defined in equations (4.7) and (4.8).

By using algebraic operations with Wiener-Hopf equation (4.19), it becomes possible to obtain the optimum weight which is the minimum MSE, thus the solution given as in the following equation:

$$\nabla_{\overline{w}}(E[|\varepsilon(k)^2|]) = 2\overline{R}_{xx}\overline{w} - 2\overline{r} = 0 \tag{4.18}$$

$$w_{MSE} = \overline{R}_{xx}^{-1}\,\overline{r} \tag{4.19}$$

4.1.3 Maximum likelihood approach

In this method the target is to estimate the desired signal, where ML method is based on the assumption that the desired signal $\overline{x_s}$ is unknown and there is no feedback to array elements while the unwanted signal $\overline{n}$ has a zero mean Gaussian distribution (Gross, 2005).The input signal vector is given by:

$$\overline{x} = \overline{x_s} + \overline{n} \tag{4.20}$$

The probability function is given by:

$$p(\overline{x}|\overline{x_s}) = \frac{1}{\sqrt{2\pi\sigma^2{}_n}} e^{-((\overline{x}-\overline{x_s})^H \overline{R}_{nn}{}^{-1}(\overline{x}-\overline{x_s}))} \tag{4.21}$$

Where the noise standard deviation referred to as σ_n and Rnn is correlation matrix of the noise signal, the log-likelihood expression can be defined as :

$$L[\overline{x}] = -\ln[p(\overline{x}|\overline{x_s})] = C(\overline{x} - \overline{x_s})^H \overline{R}_{nn}{}^{-1}(\overline{x} - \overline{x_s}) \tag{4.22}$$

By Taking the partial derivative of $L[\overline{x}]$ with respect to s and setting it equal to zero in order to find the maximum of L ,After doing some calculations we can get the optimum weight Where is expressed as follows:

$$\overline{w}_{ML} = \frac{\overline{R^{-1}}_{nn}\,\overline{a}_s}{\overline{a}_s{}^H\,\overline{R}_{SS}{}^{-1}\overline{a}_s} \tag{4.23}$$

4.1.4 Minimum Variance approach

This method is similar to the Maximum Likelihood solution, but the MV is more general than ML in its application, where minimum variance method can contain interferences signals and noise as unwanted signals within the input signal. However, all unwanted signals in ML methods are zero mean with Gaussian distribution.

The main target of minimum variance approach is to decrease the noise variance of the output array, thus it is supposed that the unwanted and desired signals have zero mean (Gross, 2005).

The output array with respective weight is expressed as:

$$y = \overline{w}^H \overline{x} = \overline{w}^H \overline{a_s}\, s + \overline{w}^H \overline{u} \tag{4.24}$$

For distortion-less response, the constraint is $\overline{w}^H \overline{a_s}$ = 1, and after applying this constraint to equation (4.25) the output array will given as:

$$y = s + \overline{w}^H \overline{u} \tag{4.25}$$

In order to find the variance of array output we can write:

$$\begin{aligned} \sigma_{MV}{}^2 &= E[\left|\overline{w}^H \overline{x}\right|^2] = E[\left| s + \overline{w}^H \overline{u}\right|^2] \\ &= \overline{w}^H \overline{R}_{uu} \overline{w} \end{aligned} \tag{4.26}$$

The Lagrange Method that is used in order to minimize the convergence depends on the cost function which is defined as:

$$\begin{aligned} J(\overline{w}) &= \frac{\sigma^2{}_{MV}}{2} + \lambda(1 - \overline{w}^H a_s) \\ &= \frac{\overline{w}^H \overline{R}_{uu} \overline{w}}{2} + \lambda(1 - \overline{w}^H a_s) \end{aligned} \tag{4.27}$$

Where Lagrange multiplier λ is:

$$\lambda = \frac{1}{\overline{a}_s R^{-1}{}_{uu} \overline{a}_s} \tag{4.28}$$

In order to find the minimum variance weight, the cost function must be minimize by setting gradient equal to zero such as:

$$\overline{w}_{MV} = \lambda R^{-1}{}_{uu} \overline{a}_s \tag{4.29}$$

After substituting equation(4.29) into equation. (4.30), the optimum minimum variance weight is:

$$\bar{w}_{MV} = \frac{R^{-1}{}_{uu}\,\bar{a}_s}{\bar{a}_s R^{-1}{}_{uu}\,\bar{a}_s} \tag{4.30}$$

4.2 Adaptive Beam forming

The term adaptive refers to the capability to update and adjust the weights continuously with the changing angles of arrived signals with time, while previous methods find the optimal weight without having to the re-calculations and that because the angles of arrived signals remain constant and do not change with the times(Gross, 2005).

In order to maximize the output signal power in desired direction and minimize the power in the unwanted direction, various powerful algorithms are used to adjust the weights of the smart antenna array adaptively, so that the output beam pattern is optimized for enhancing the system (RAO & SARMA, 2014). There are numerous algorithms used in beamformer optimization for the sake of reduction of interferences, side-lobes and noise such as lest mean square algorithm (LMS),recursive lest square (RLS), Sample matrix inversion algorithm (SMI) and the constant modulus algorithm (CMA).

In reception part of smart antenna system, the beam former implements the signal data of the training to establish the optimal vector of weights during the training time, data is then passed and the beam former investigates the computed weight vector to analyse any received signal. However, beamforming algorithms is classified as Blind algorithms and Non blind algorithms, where the first category (Blind Algorithm) doesn't use the desired signal d(t) a while the second category (Non blind algorithm)use the desired signal d(t) which is based on a knowledge of the nature of the received signals as a training signal in training period. (Mallaparapu, et al., 2011).In the following sections we will discuss the most popular optimization algorithms.

4.2.1 Least mean square algorithm (LMS)

LMS algorithm was created by Wirodw and Hoff in 1960 (Haykin, 2002). This method is classified as a non-blind adaptive algorithm because it requires training sequence.

By gradient method this algorithm can adjust the weights based on MSE(Minimum square Error) which is calculated from the difference between the input signal and desired signal, this ability to update the weights is based on the availability of information about desired signal and input vector, furthermore it doesn't need to correlation function or matrix inversion computation that makes this method simple and a reasonable choice for many application in ASP(Rahaman, Hossain, & Rana, 2013).

The output signal y(n) is the weighted sum of the input signals x(n), where these input signals are multiplied by the input complex weights W, and they are expressed in following equation: where x is the received input vector

$$\mathrm{y(K)}=\mathrm{w}^{H}(K).x(K) \tag{4.31}$$

Where x is the received input vector Where and w^{T} is the transpose of the weight vector $\mathrm{w}^{T}=[w(1)\ w(2)\ w(3)....w(n)]^{T}$.

The error signal is considered as a control signals in weights adaptation process and is defined as:

$$\begin{aligned} e(K) &= d(K)-y(K) \\ &= d(K)-\mathrm{w}^{H}.x(K) \end{aligned} \tag{4.32}$$

However, this algorithms aims to make the output response for each element equal or close to the desired response in each iteration until all weights converge (Hreshee D. S., 2013), this weight adaptation method is done by this equation :

$$w(K+1)=w(K)+\mu e^{*}(K)x(K) \tag{4.33}$$

Where μ is step size which controls the convergence of algorithms and the adaptation rate (Ramineni, Sagar, K.Abhishek Jain, T.V.Ramakrishna, & Kumar, 2012),this parameter is restricted is restricted as follows:

$$0\le\mu\le\frac{1}{\lambda_{\max}} \tag{4.34}$$

So that if the convergence of algorithm will be fast if μ is chosen to be large, while the convergence becomes slow if μ is small. Moreover, the step size is depends on $\lambda_{\max}$ which is largest Eigen value of autocorrelation matrix Ruu (Rahaman, Hossain, & Rana, 2013).

4.2.2 Recursive least square algorithm (RLS)

RLS is one of the most popular adaptive beam-forming algorithms based on recursive least square. This algorithm requires no matrix inversion because correlation matrix is found directly. It uses the sum of squared errors for the inputs to update the complex weights instead of using the mean square error minimization. The first adaptation of this algorithm was derived from KALMAN filter for multi tap transversal filtering where samples are taken over variable time frame. However, this algorithm is applicable for other systems where the inputs are extracted from different sources. The algorithm uses desired signal and correlation matrix in the adaptation. The following equation is used to update the weight values.

$$w(k) = \overline{w}(k-1) + \overline{g}(k)[d(k) - \overline{x}(k)\overline{w}(k+1)] \tag{4.35}$$

In order to solve the slow convergence speed in LMS algorithm, step size parameter is replaced by the gain vector $\overline{g}(k)$ which is defined as (Rani, Subbaiah, Reddy, & Rani, 2009):

$$\overline{g}(k) = \hat{R}_{xx}^{-1}\,\overline{x}(k) \tag{4.36}$$

And $\hat{R}_{xx}$ is the correlation matrix expressed as:

$$\hat{R}_{xx} = \sum_{i=1}^{K} \overline{x}(i)\overline{x}^{H}(i) \tag{4.37}$$

4.2.3 Constant-modulus (CM) algorithm

The Constant Modulus algorithm is called as blind algorithm because the desired signal is not available. The algorithm is performed through the use of three distinct steps in each turn. In the first step, the computation of the processed signal with the actual weights is performed. In the second step, an error is generated from the computed signal. Finally, the weights are adapted with new error data in the third step. The algorithm can be expressed mathematically in the following equations.

The error signal is calculated without resorting to the reference signal, this error is given by:

$$e(k) = y(k)\left|y(k)\right|^{p-2}(R_P - \left|y(k)\right|^{p}) \tag{4.38}$$

Where the weighted output y(k) is given as:

$$\text{y(K)=w}^{H}.x(K) \tag{4.39}$$

The Godard cost function is expressed as:

$$J(K) = E[(\left|y(k)\right|^{p} - R_P)^{q}] \tag{4.40}$$

When the gradient of cost function is zero, then the R_P is expressed as:

$$R_P = \frac{E[\left|s(k)\right|^{2P}]}{E[\left|s(k)\right|^{P}]} \tag{4.41}$$

Where q is a positive integer=1, p is positive integer, and $s(k)$ is the zero-memory estimate of $y(k)$. In this algorithm the weights are updated by following equation:

$$w(K+1) = w(K) + \mu e^{*}(K)x(K) \tag{4.42}$$

CHAPTER 5

ARTIFICIAL NEURAL NETWORKS (ANN) AND OPTIMAZATION OF ANTENNA ARRAY

Artificial neural networks (ANNs) are considered the artificial equivalent in function and construction of the real human brain. Human brain is a very complex and interconnected network of neural cells; this complex structure is capable to accomplish hard and complex tasks in an easy way that can't be imagined. This structure gives the brain a very important sense of creativity in the way it does the different tasks. Mathematic operations, logical thinking, decision making, and many other tasks are examples of the non linear tasks that brain can do in a soft manner. One important characteristic of the human brain and the neural system is its ability to learn things and to create things that didn't exist based on experience.

Scientists started studying the structure of the human brain early; however, the real steps toward imitating the structure of biological neural structure started in the 5th decade of the 20th century. McCulloch and Pitts have introduced the simplest structure of neurons in 1943 and presented it as models of real neurons. They were claimed to be the basic structure of the computational circuits of the future that exactly works like human brains do (Krose & Smagt, 1996). During the 1950s, real implementation of artificial neural networks started to be presented (Fyfe, 1996). In our days, artificial neural networks have become very famous and well known in the world of science. Many sciences use artificial neural networks in very advanced tasks. Artificial neural networks are mostly implemented in medical applications and image processing (Khashman, Automatic Edge Detection of DNA Bands in Autoradiograph Images, 1999) (Khashman & Dimililer, 2007). Artificial neural network are also used in control systems and procedures, prediction and prices estimation, communication systems, and weather forecasting. Artificial neural networks can also be used in the field of communication and more precisely in smart antenna applications (Hreshee S. , 2013) (merad, Bendimerad, & Sidi Mohamed Meriah, 2007) (Saleh, AL-Ali, & Alssarn, 2013).

The use of artificial neural network in any task implies starting by teaching the networks by updating the values of its neurons based on past experience or examples. The well known back propagation algorithm is one of the most powerful learning algorithms of artificial neural networks. This algorithm was firstly proposed in 1969 by Yu-Chi Ho and others; it was applied in ANN applications on 1974 by Rumelhart, Werbos, and others.

5.1 Overview of the Chapter

In this chapter, the idea and theoretical basis of artificial neural networks will be discussed. It presents a comparison between the real neural system and the artificial neural network from different aspects. A simplified description of the basic structure of an artificial network will be demonstrated, and then a view on the generalization of the theory will be explained throughout this chapter's work. As one of the most famous and efficient learning algorithms is the feed forward back propagation, it will then be discussed from the computational and mathematical backgrounds. At the end of the chapter, a resume on the different mathematical functions of neural networks will be presented and discussed.

5.2 Human Brain vs. Artificial Neural Networks

It is obvious that all the existing structures of the artificial computing based on the neural theory imitate an imagined process of the biological brain. The idea is to construct a similar structure in the form and function for the real human brain. The brain of a human being is a huge network of thousands of billions of neurons. This huge number of neurons is interconnected in a complex network to give the brain all its capabilities. Each individual neuron is simply connected with dozens of thousands of other neurons with whom it exchanges its information. Figure 5.1 demonstrates a portion of a biological neural network containing the body of the cells that are called soma. The lines connecting between different cells' soma are called axons and dendrites (Roberts, 2015). In a sensor neuron, electrochemical signals are obtained from the other cells by the dendrites. Dendrites transfer these signals to the cell's body. If the neuron feels that the power of the signal is high enough, it will be fired and generate another signal to the other cells via the axon of the cell. This signal will be collected by other cells' dendrites and will be treated in the same manner. The brain contains billions of these connections that can be fired in different degrees based the chemical and electrical signals they receive.

The different elements of the real human neurons are demonstrated in Figure 5.2 that presents the five parts of a biological neuron. These parts are body of the cell, cell's nucleus, dendrite, synaptic weights, and axons. The part that is connected directly to the cell's body is the dendrite. The cell's body itself is also known as Soma. Dendrites collect signals from the junction of synapse. Synapses connect between each two neurons to ensure the reception of signals between them. Signal transmission is complex and happens

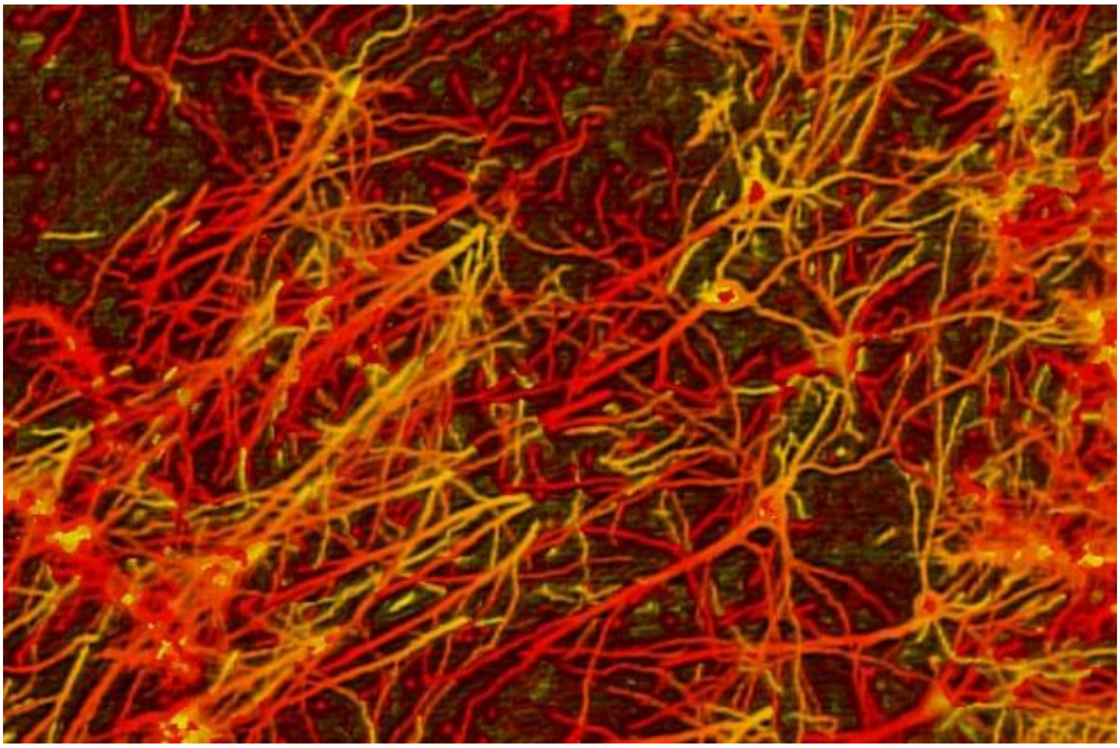


Figure 5.1: Connections between biological neurons (Trivedi, 2008).

in two different ways. The first way of transmission is the transmission between two neurons that happens chemically. The chemical materials received by the dendrites causes a proportional electric signal to appear in the inner side of dendrite. The generated signal's potential is transmitted to the cell's body activating it if it has enough power.

Artificial neural networks are considered as the imitation of function and structure of the biological neurons. The artificial neural networks have demonstrated a great efficiency in solving complex tasks. Figure 5.3 explains the similarities between the structure of the biological brain and the artificial neural networks. As the figure shows, artificial neural network receives its input signals and gives them some initial weights. The resultant signals are subject to a measure of their power through the use of different activation functions. Only the signals that have enough power are transmitted to the next set of neurons for further treatment. Same process is applied continuously until the signal reaches the output of the network.

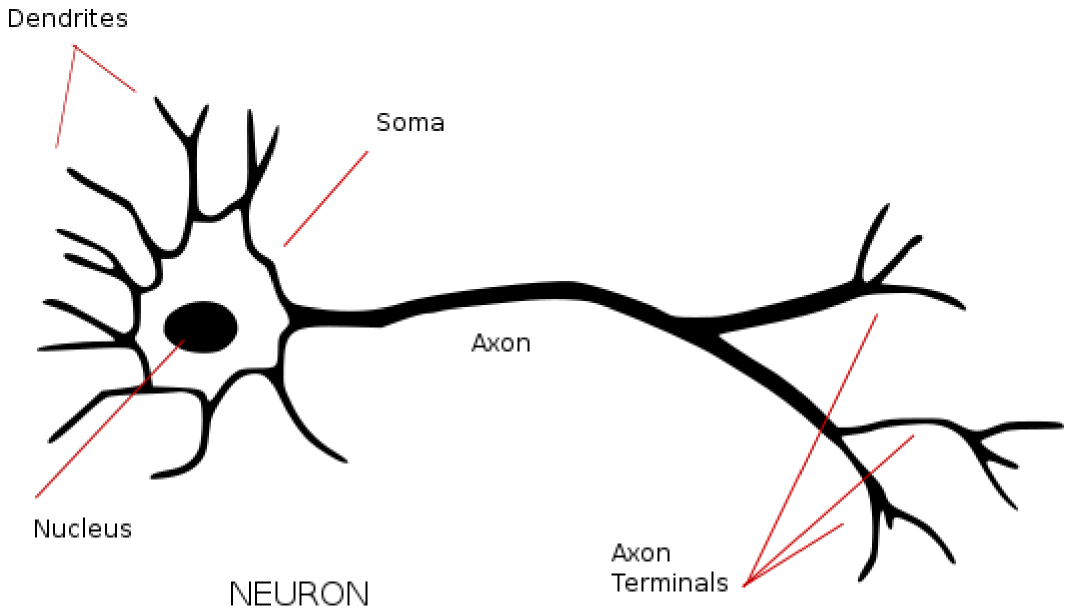


Figure 5.2: Elements of biological neuron (Sadhu, 2012).

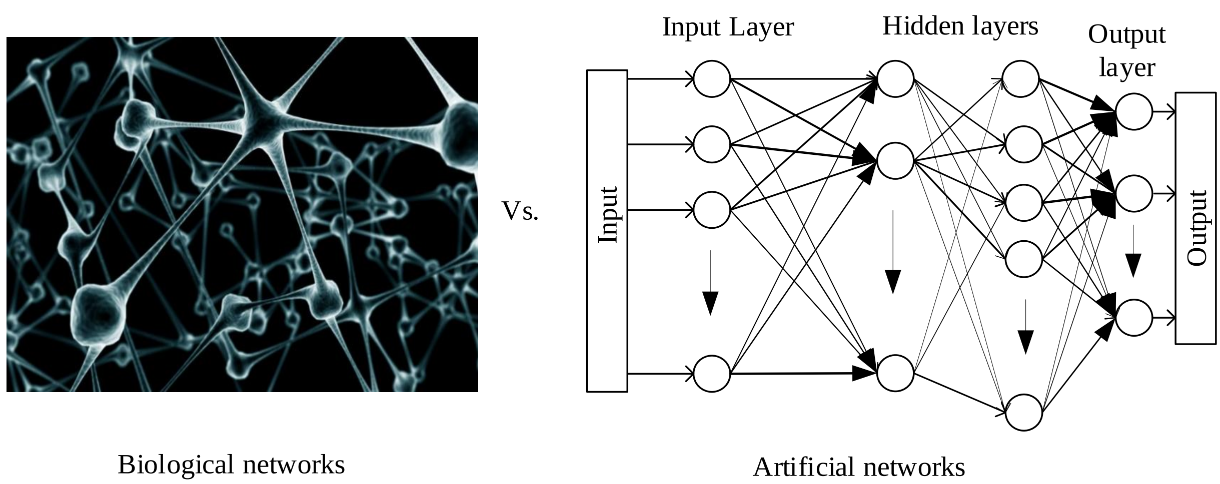


Figure 5.3: Analogy between human brain and neural networks

5.3 Artificial Neural Networks

Artificial neural networks are very powerful structures of computation units that were stimulated from the brain model. They were constructed to help solving non linear complex problems where normal mathematical approaches seem inefficient. The main similarity between a biological and artificial thinking structure is the need for learning. The same way in which biological neurons work, artificial neurons can accomplish their required tasks. Each single neuron’s signal worth to be transmitted if it receives signals with enough power to activate its output from the previous neurons; otherwise, the output from the neuron will not be generated and transmitted to the next neuron. In some cases, the power of an output signal generated by a neuron is proportional to the sum of its input signals. Figure 5.4 reveals the idea of power of signal and activation of the output signal. The input signals are given some arbitrary weights based on previous knowledge or training. The power of the neurons signal is measured by summing all received signals with respect to their weights. The total power is presented to the activation or transfer function to determine an appropriate output power. The total power received by a neuron can be expressed by:

$$S = \sum_{n=1}^{N} I_n * \omega_n \tag{5.1}$$

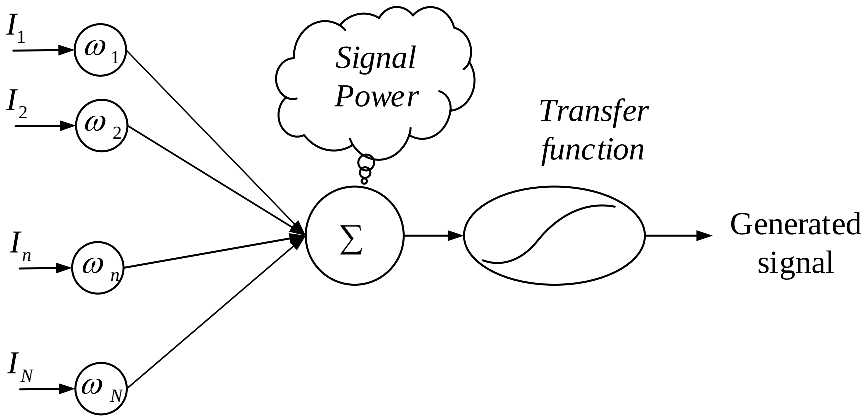


Figure 5.4: Construction of artificial neural network.

5.4 Basic Elements of Artificial Network

Any artificial network needs mainly three features and training algorithm to be able to perform a required task. These features are mainly the weights, transfer functions, and layers. These are the three main functional parts of an artificial neural structure. The learning method is the algorithm used to adapt the neural network to do the required task.

5.4.1 ANN layers

Layers are one of the important parts of any artificial neural network's structure. Connections between successive layers give the neural network its main functionality. Data is processed through different layers from one layer to another. Each layer receives some data from the previous layers, process this data, and transfer it to the next layer. Layers are divided into three different categories, input layers where input data is received from the systems, output layer where output results are displayed or submitted to other systems, and between these two layers one or more hidden layers ensures the flow of these data.

- Input layers: the input layer is the input interface in an artificial network structure. It passes the signal from the inputs to the hidden layers.
- Output layer: The last processing stage in a network is called output layer, its output is considered as the result of the processing. The results of this layer must be equal to the desired results in a well trained network.
- Hidden layers: this is the heart of the artificial neural network. It can have one, two or more number of layers in which different weight grids are used. On the contrary to the input and output layers where layer size is a function of the data set, the hidden layers sizes are limited just by the capability of the used processor. Weights in the hidden layers are updated in continuous manner until an acceptable output is achieved. Figure 5.5 presents the concept of layers in artificial neural networks. Figure demonstrates how inputs are received by input layers, then after being processed they will be transmitted to the hidden layers for processing again, the output layers generates the output of the ANNs.

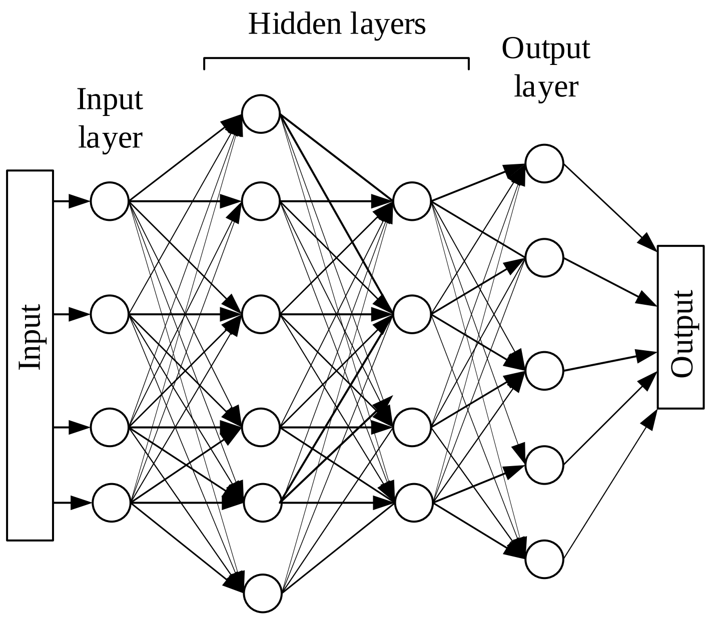


Figure 5.5: Layer concept in artificial neural networks.

5.4.2 Weights in ANNs

The weights in the neural network are the adaptive memory in which the knowledge is stored. The weights' values are changed iteratively throughout the process of learning until optimum values are obtained. These optimum values are obtained when the results obtained out of the neural network is equivalent to the desired output. The memory parameters are then stocked up as expert networks that can be used in future tasks.

Actually, the weights of an artificial network are of the main importance as they shape the function of network.

5.4.3 Transfer functions

Transfer functions are the measure of the power of inputs of an artificial neuron. At the moment inputs are received by the different layers with respect to the corresponding weights, the transfer functions decide the power of the output signal to the next layer. The use of transfer functions is very significant because they give a mean of deciding whether a given input is important or not. There are many types of transfer functions based on the application for which it is applied. Some transfer functions limit the output to the range from zero to one or in the band within the absolute value of 1.

5.4.3.1 Linear activation functions

The output of this transfer function is a linear function of its input; however, the output is limited within some band to avoid divergence. When the absolute value of the input to the transfer function is greater than the absolute value of the function's limit, the output value is fixed at that limit as shown in Figure 5.6. The formula for this transfer function is given by:

$$o(S) = \begin{cases} a & S > a \\ S & -a \le S \le a \\ -a & S < -a \end{cases} \tag{5.2}$$

The term "a" in the formula is the limit of the output of the linear transfer function.

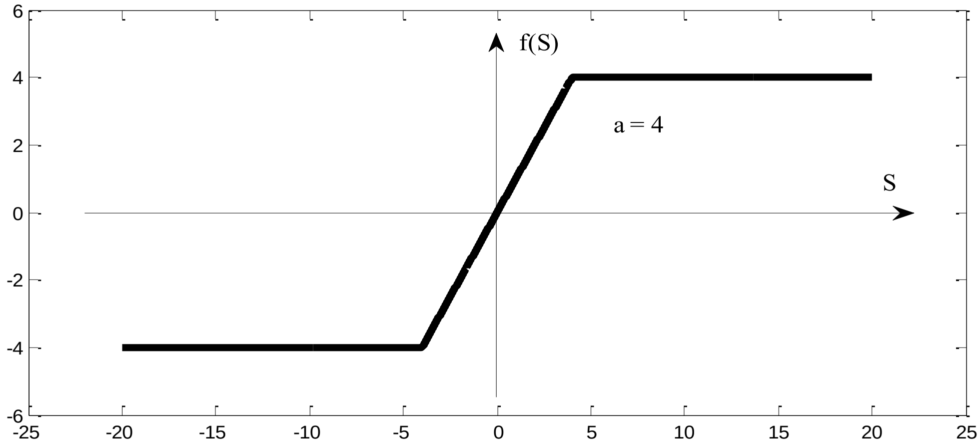


Figure 5.6: Linear ramped transfer function.

5.4.3.2 Threshold limit transfer function

In this type of transfer functions also called hard transfer function, the output can either exist or zero (or negative) with no other options. It looks like the output in binary logic systems where just two states are available. The threshold is the minimum power needed by the transfer function to become active. If the input power is higher than the threshold, the function is active; otherwise it is inactive. Figure 5.7 shows the curve of a threshold transfer function whose function is defined by:

$$o(S)=\begin{cases}-1 \, or \, 0, & S<T \\ 1, & S>T\end{cases} \tag{5.3}$$

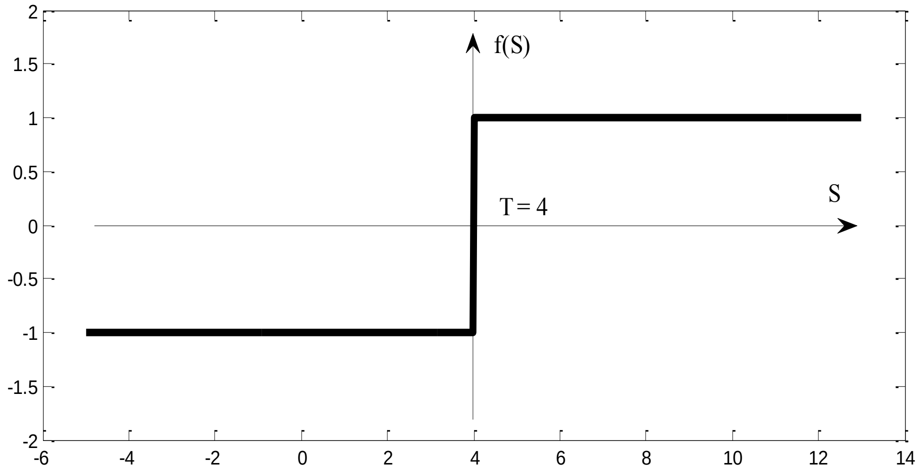


Figure 5.7: Threshold transfer function

5.4.3.3 Sigmoid transfer function

This type of function is a soft function that uses logarithmic mathematical functions to generate the output. Its output can either range from 0 to 1 or from -1 to 1 in some other cases. Different functions can be defined for ANN uses as sigmoid functions, however, logarithmic and tangential sigmoid are the most used. The formula for each one of these functions is given by:

$$\begin{aligned} o(S) &= \frac{1}{1+e^{-S}}, \quad \text{logarithmic sigmoid} \\ o(S) &= \frac{1-e^{-S}}{1+e^{-S}}, \quad \text{Tangential sigmoid} \end{aligned} \tag{5.4}$$

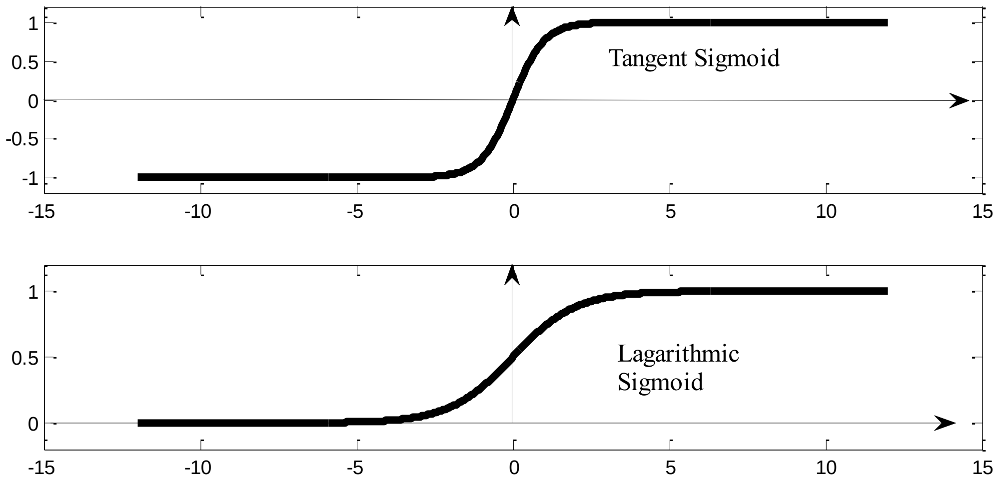


Figure 5.8: logarithmic and tangential sigmoid transfer functions.

Figure 5.8 presents the curves of tangent and logarithmic transfer functions. These two functions are the most used in ANN back propagation algorithms. The main reason is that their derivatives are easily calculated compared with the other functions. The derivative of these two functions can be given by:

$$o'(S) = o(S) * (1 - o(S)) \tag{5.5}$$

5.5 Learning of the Artificial Neural Networks

Learning or training process of a system is to teach that system to generate the desired output if fed with a given input. Learning an artificial neural network is a similar process where the network is trained using examples to converge toward some desired values. There are two distinct leaning methods for the ANNs; these are supervised learning and unsupervised learning. In the supervised learning algorithms, the network is fed with the input and desired information at once. The network then uses special algorithms to generate results, compare them with desired results, and update the structure until the desired output is achieved. The feed forward back propagation algorithm is one of the most famous supervised learning algorithms for neural networks applications. The unsupervised learning process uses other defined algorithms to adapt the structure of the network regardless the desired output of the network.

5.5.1 Feed forward back propagation training algorithm

The back propagation training algorithm is one of the supervised training algorithms of the ANNs. It uses a back propagation weight adjustment algorithm with supervised topology to learn the rhythms or patterns in different systems. The huge development in the sciences related to artificial neural networks is mainly due to the development of this algorithm. Although back propagation is highly capable in terms of target convergence, it requires huge processing capabilities to achieve training goals. A back propagation ANN can imitate any complex system to higher accuracy (Fyfe, 1996).

Back propagation algorithm is simple and easy to understand and implement algorithm. It is designed based on simple mathematic functions. Each one of the layers receives information from its precedent layer, process the information, and throw it to the next layer. The input layer receives its data from the input while the output layer submits its data as results. This result is the overall result of an iteration that should be equal to the desired output. However, the network can't initially generate values that are even very similar to the desired output; the need for an update topology for the contents of the whole network appears. This topology is the back propagation that uses the error between the outputs and the desired outputs to re-adjust the weights. The adjustment is done in a way that guarantees the minimization of the error. This process is done iteratively until the obtained error is small enough for the desired application. When the error is less than the desired value, the network is said to be learned. Figure 5.9 shows the structure of neural network using error back propagation technique.

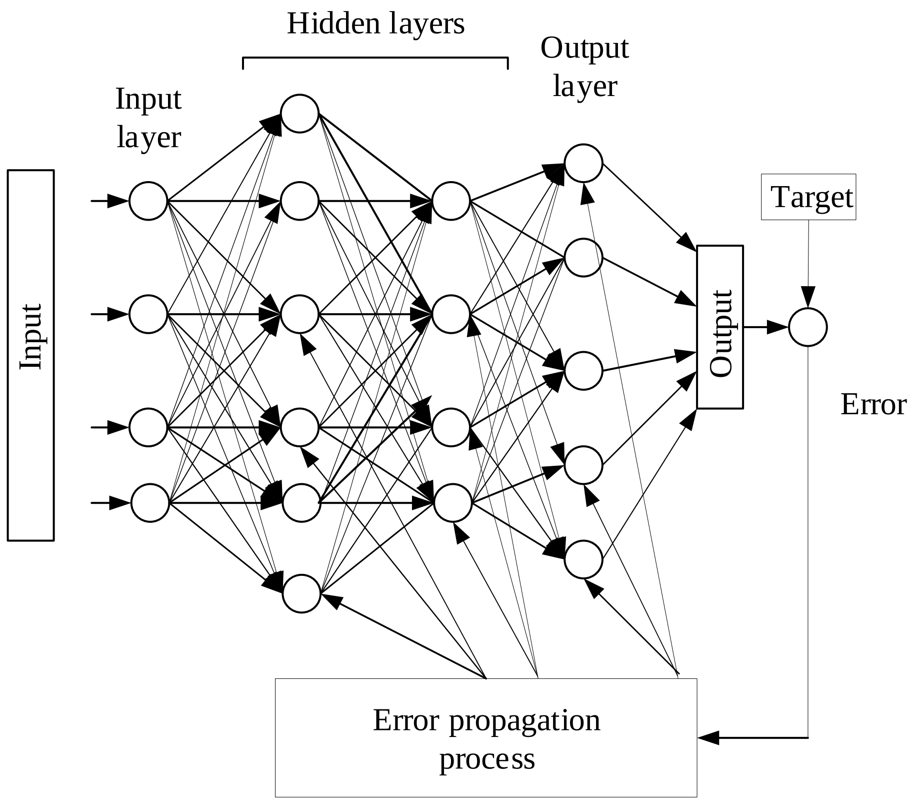


Figure 5.9 : Structure of network and error propagation.

5.6 Back Propagation Algorithm's Model

The back propagation is designed based on the gradient descent theory to find the least square error. To track the least square error and minimize it is important to calculate the error's gradient at each new iteration. Mathematically, this implies that the error function should be continuous for all the desired range; in addition to the existence of its derivative at all points. In order to ensure the existence of these two conditions, special continuous derivable transfer functions are used in back propagation. As discussed earlier, sigmoid tangent and logarithm are of the main transfer functions used in ANN, the formula of sigmoid logarithm is:

$$o(S) = \frac{1}{1+e^{-cS}} \tag{5.6}$$

Where S denotes the input for the transfer function and c is a constant used to control the slope of the transfer function. This function is continuous for all real values and its derivative is given by:

$$o^{\backslash}(S) = \frac{ce^{-cS}}{(1+e^{-cS})^2} = \frac{1+ce^{-cS}-1}{(1+e^{-cS})^2} \tag{5.7}$$

This function can then be written as:

$$o^{\backslash}(S) = \frac{1+ce^{-cS}}{(1+e^{-cS})^2} - \frac{1}{(1+e^{-cS})^2} \tag{5.8}$$

Hence, if we choose the value of c=1, the function reduces to (Rojas, 1996):

$$o^{\backslash}(S) = \frac{1+e^{-S}}{(1+e^{-S})^2} - \frac{1}{(1+e^{-S})^2} = \frac{1}{1+e^{-S}}(1-\frac{1}{1+e^{-S}}) = o(S)(1-o(S)) \tag{5.9}$$

The forward calculations of the network can be described for each layer by:

$$S = \sum I_n \omega_n + b_n \tag{5.10}$$

Where, I_n is the vector of all inputs, w_n is a matrix containing all weights of the layer, and b_n is a vector of bias values used to stabilize the function of the network. The activation is used to determine the output power of the calculated sum. The output of the network is observed at the last activation function. This output should be similar to the desired output.

The difference between the output and its desired value is the error that will be used in error propagation, it is defined by:

$$E = (o_d - o) \tag{5.11}$$

Where, o_d is the desired output. An error function is extracted from the value of error E such that:

$$\Delta_k = (o_{dk} - o_k)o_k(1 - o_k) \tag{5.12}$$

Using this calculated value, the new values of the last weights are calculated again.The weights of the output layer are then given by:

$$\omega_{k\,new}^{h} = \omega_{k\,old}^{h} + \eta \Delta_k^h o^{h-1} + \alpha(\delta \omega_{k\,old}^{h}) \tag{5.13}$$

To update the hidden layers, another function is used that consider the error in the output layer. The update term is given by:

$$\Delta^h = o^h(1 - o^h)\sum \omega_k^h \Delta_k \tag{5.14}$$

The new weights values are then given by:

$$\omega_{k\,new}^{h} = \omega_{k\,old}^{h} + \mu \Delta^h o_k^h + \alpha(\delta \omega_{k\,old}^{h}) \tag{5.15}$$

In ANN α and μ are two essential parameters. They control the training of a back propagation network. The learning rate μ is adjusts how fast the learning process is. It can increase or decrease the rate of learning of a neural network. This factor is very important because its choice is very complicated. A higher value of learning rate can cause the network to converge faster; however, the fast convergence can cause the phenomena of memorizing instead of learning. A low learning rate can increase the training time incredibly. The momentum factor α is another important parameter of the ANN learning based on error back propagation. This variable controls the effect of error on the change of the weights for each iteration. It helps avoiding some false or non real minimums where the error fall trapped in a local minimum (Fyfe, 1996).

CHAPTER 6

SIMULATION AND RESULT FOR UNIFORM LINEAR ARRAY

This chapter presents simulation for ULA antenna array by using MATLAB. This simulation process analyses and compare the performance of popular adaptive techniques such as LMS, RLS and CMA. The comparison considered different criterions including amplitude response, convergence time, acquisition and tracking of desired signal .The parameters that were used during the simulation are:

Table 6.1: Parameters of the desired and interference AOA

DOA of desired signal	30˚
DOA of interference signal	-60˚

6.1 Comparison of Amplitude Responses of LMS, RLS and CMA Algorithms

In this part, simulation was carried out for the same algorithm with different antenna array parameters such as number of sensor elements and distance between each two elements in the antenna array. The simulation results for various numbers of elements and different distances between successive elements are shown in the next figures. 5, 8, and 10 elements arrays were used at distances of d=0.125λ, 0.25λ, and 0.5λ were carried out. The maximum distance between two elements was restricted to 0.5λ to avoid spatial aliasing.

6.1.1 LMS algorithm

FIGURE 6.1 presents the amplitude response of the Least Mean Square algorithm for different number of elements of array at distance d=0.5λ. It is obvious that using LMS algorithm the response has given amplitude of one at the desired angle and cancelled totally the unwanted signal. The use of 10 elements in the array has ameliorated the response of the algorithm by narrowing the band of the response. Figure 6.2 shows the same results for the case of using d=0.25 and d=0.125λ. The obtained results show that the higher the number of array elements the better the response of the algorithm. However, the response accuracy decreases with the decrease of the distance between elements of the array. As seen from Figure 6.2 to the left, the passing band is wider than the case of 0.5λ. This band becomes wider in the case of 0.125λ as in Figure 6.2 to the right.

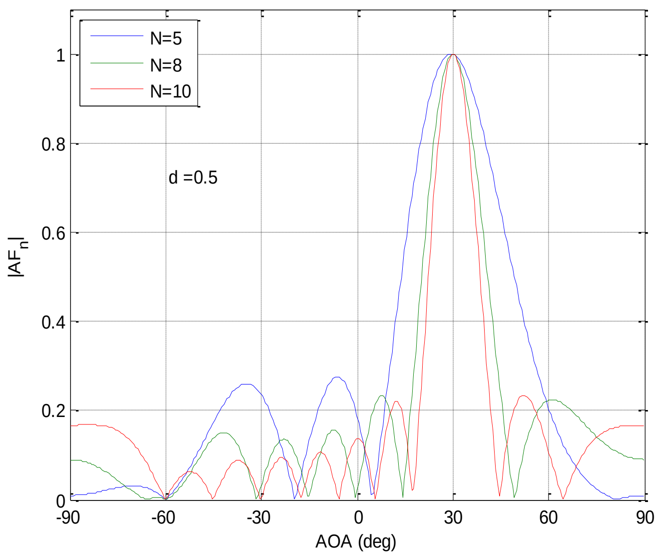


Figure 6.1: Array Factor plots for LMS algorithm (d=0.5λ)

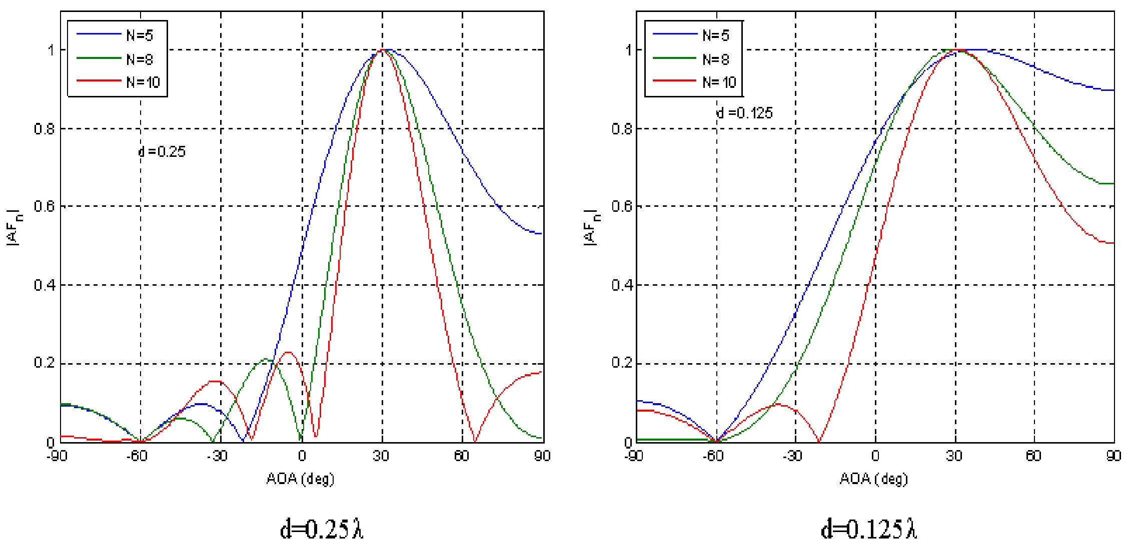


Figure 6.2: Array Factor plots for LMS algorithm

6.1.2 RLS algorithm

In this part, the same experiments were applied by using the RLS algorithm. The results are shown in Figure , Figure 6., and Figure . The results show that the response is better when using higher number of elemnts. The response is showing amplitude of approximately 0.4 at some undesired angles of arrival. Such values are considered as drwbacks of the algorithm. The results of N=10 were better in the case of d=0.5λ; however, this was not the case when using d=0.25λ and d=0.125λ. the case of N=8 has given better performance. The performance in term of passing band has shown better performance for smaller inter-element distance.

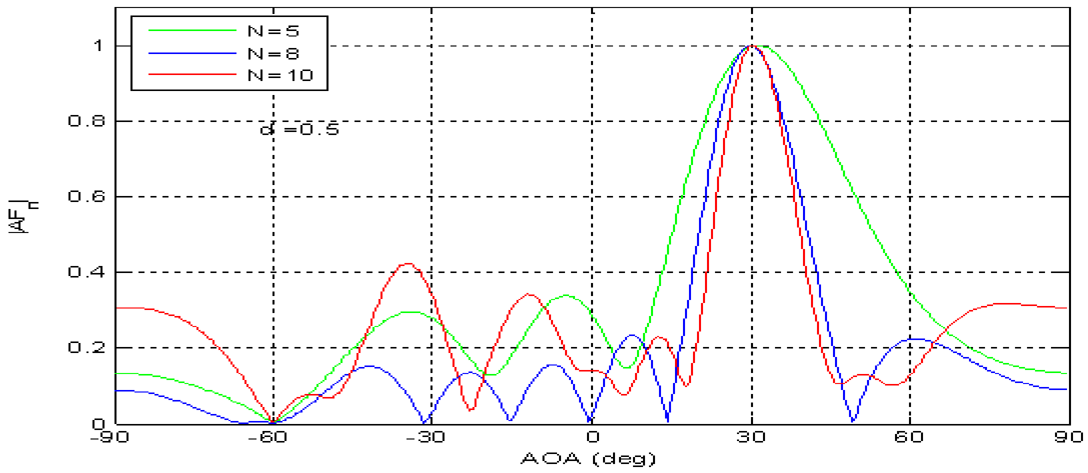


Figure 6.3: Amplitude response by using RLS algorithm with d=0.5λ and different N

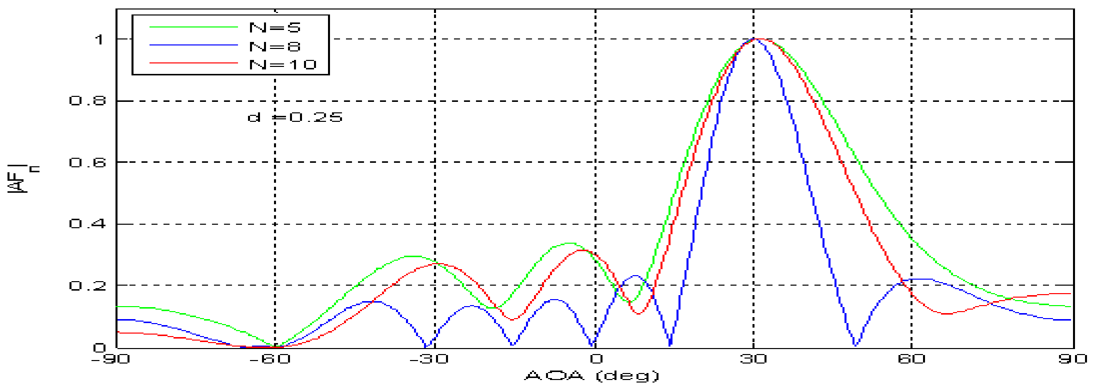


Figure 6.4: Amplitude response by using RLS algorithm with d=0.25λ and different N

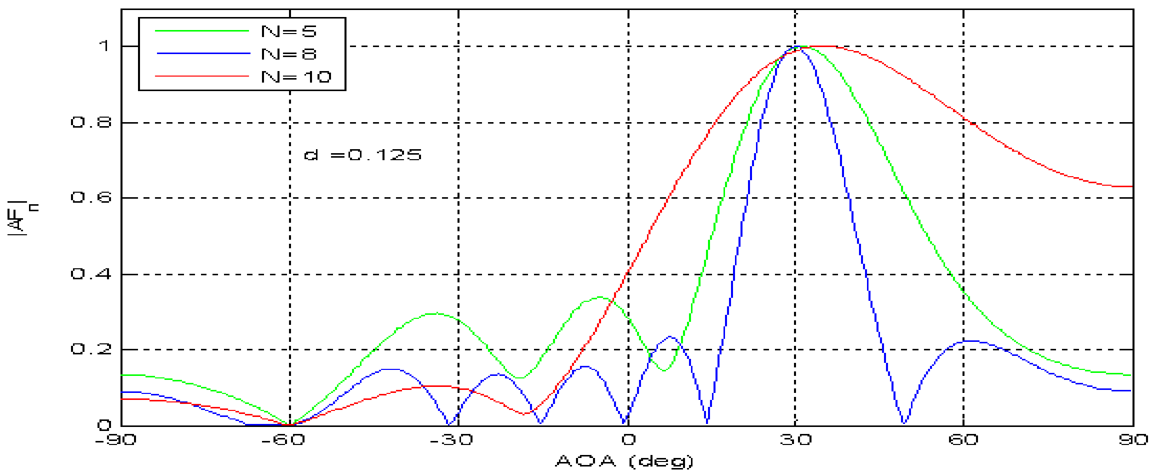


Figure 6.5: Amplitude response by using RLS algorithm with d=0.125λ and different N.

6.1.3 CMA algorithm

In order to plot Array factor for CMA algorithm for different number of element and spacing, same experiments were applied by using matlab, Through Figure 6.6, Figure 6.7, and Figure 6.8 it is evident that this algorithm is suppress the unwanted signal but not completely cancel it. It is also noted that the selection of the appropriate space between element can improved the shape of amplitude responce for the array ,while the choice of the number of elements affect the ability of the algorithm to supress the unwanted signal and decrease the level of interferance. Moreover it is obvious that in order to choose distance between element in antenna array eighth wavelength (d=0.125λ), the number of elements must be increased to achieve a reasonable system performance

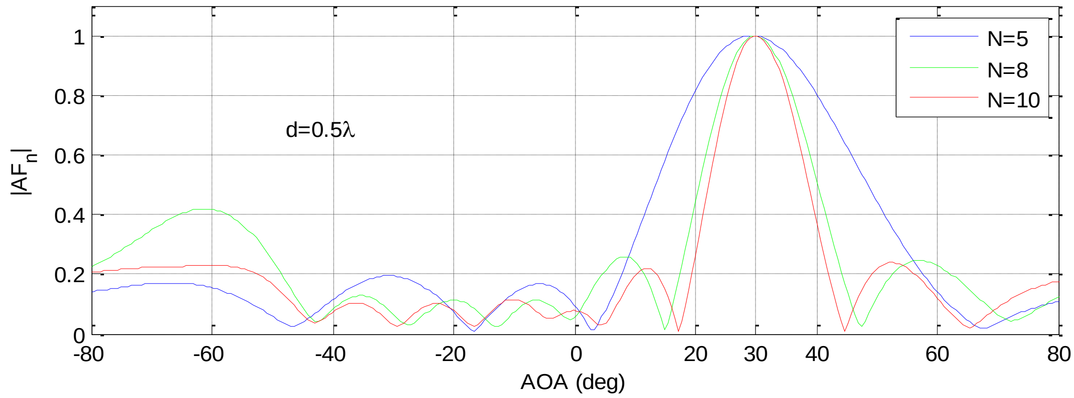


Figure 6.6: Amplitude response by using CMA algorithm with d=0.5λ and different N.

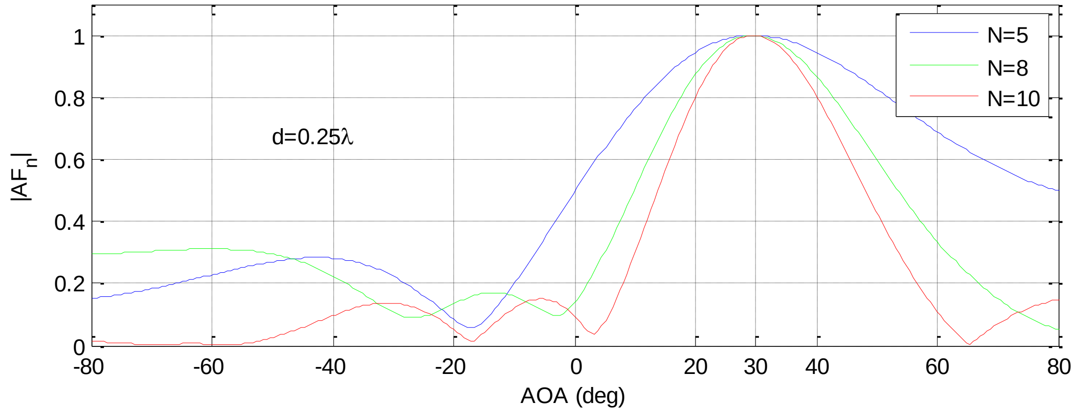


Figure 6.7: Amplitude response by using CMA algorithm with d=0. 25λ and different N.

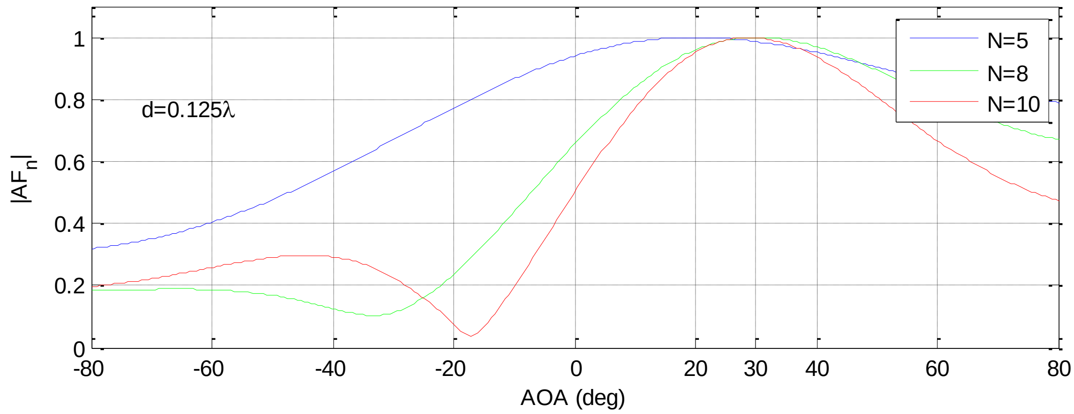


Figure 6.8: Amplitude response by using CMA algorithm with d=0.125λ and different N.

by comparing the performance of the algorithms in terms of suppressing unwanted signal, it is evident from the figures that LMS and RLS algorithms place adaptively the maxima radiation pattern in the desired direction of signal which arrives at 30◦ and nulls at the AOA of the interferer signal at -60, however, CMA algorithms did not succeed in suppressing the signal completely. Moreover, RLS algorithm can be considered the best algorithm in terms of suppression of unwanted signals even with angles arriving from Convergent direction.

In order to increase the characteristic of distinction between the AOA's even they close in values, the width of main lobe must be narrow enough to truck desired signal, this is done by increasing the number of element N in antenna array as it is shown in the figures. But the bad impact in increasing the number of elements lies in the increasing of side lobes number, which leads to increase the level of interference due to the radiation of power in unwanted directions. It is also observed from the pictures that the optimum value for distance between element in antenna array is half wavelength (d=0.5λ) Where the algorithms still have reasonable performance with the changes in the values of rest parameter.

6.2 The Tracking Performance of Adaptive Beam-Forming Algorithm

In this part the analysis of LMS and RLS is done by using eight antennas with half wavelength space using MATLAB. The desired signal is arriving at an angle AOA=30°, while the interferer at AOA=-60°. LMS adaptive scheme is that the algorithm must go through much iteration before satisfactory convergence.

The magnitude of the weights vs. iteration number is shown in Fig. 6.9. Figure 6.11 shows how the array output acquires and tracks the desired signal after about 60 iterations for LMS algorithm. Figure 6.10 shows the resulting mean square error which converges to near zero after 60 iterations.

By applying the same parameters using RLS algorithm, we find that the magnitude of the weights vs. iteration number is shown in Figure 6.12. Figure 6.14 shows how the array output acquires and tracks the desired signal after about 13 iterations for RLS algorithm. Figure 6.13 shows the resulting mean square error which converges to near zero after about13 iterations.

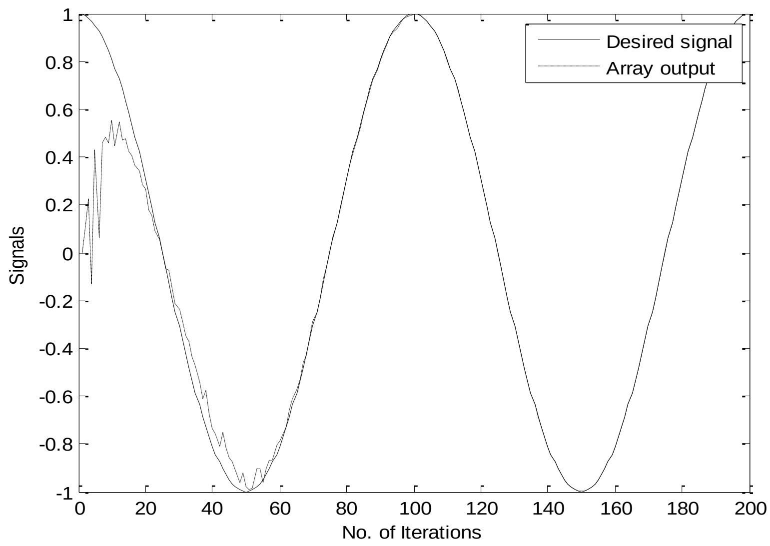


Figure 6.9: Acquisition and tracking of desired signal for LMS algorithm

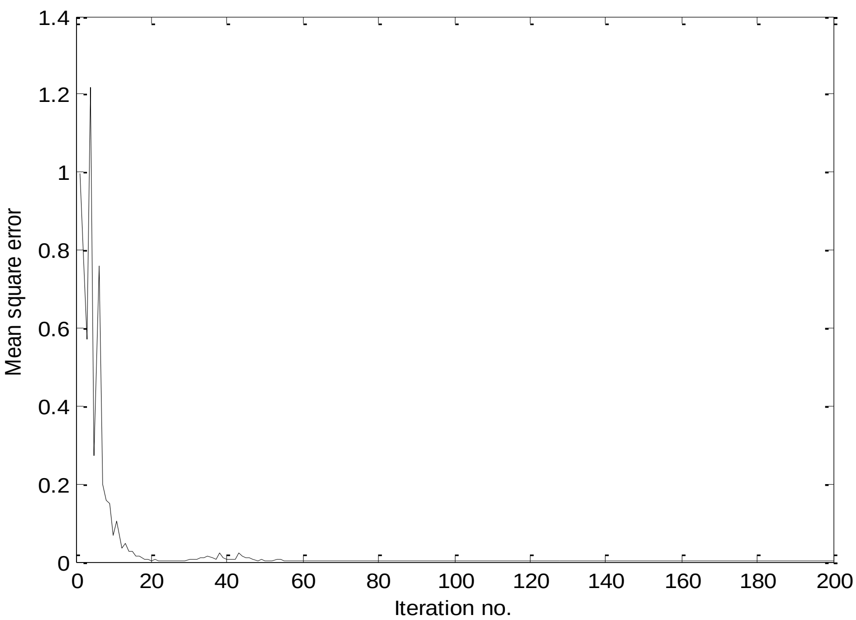


Figure 6.10: mean square error in LMS algorithm(N=8,d=0.5)

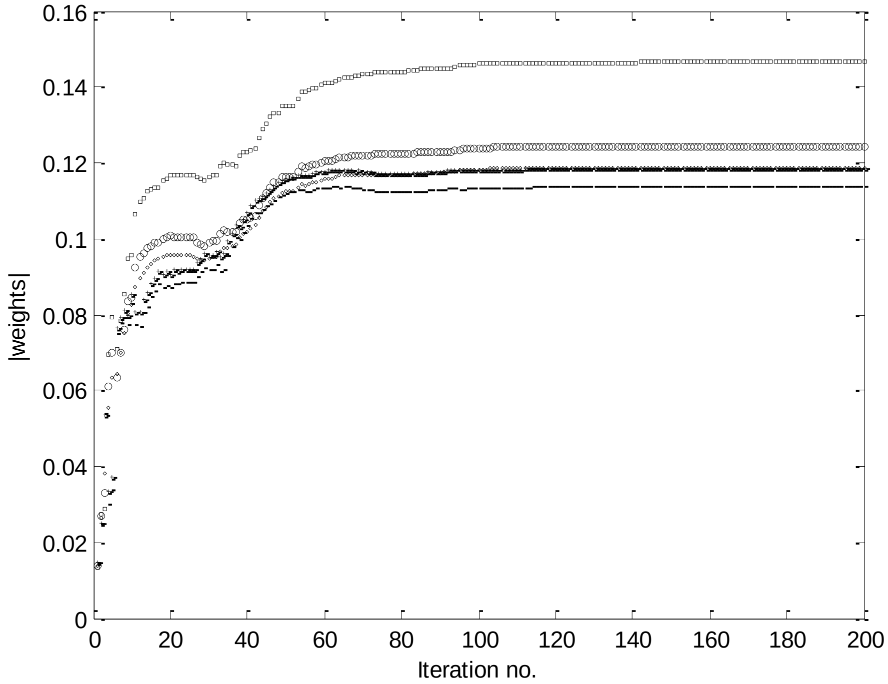


Figure 6.11: Magnitude of array weights in LMS algorithm

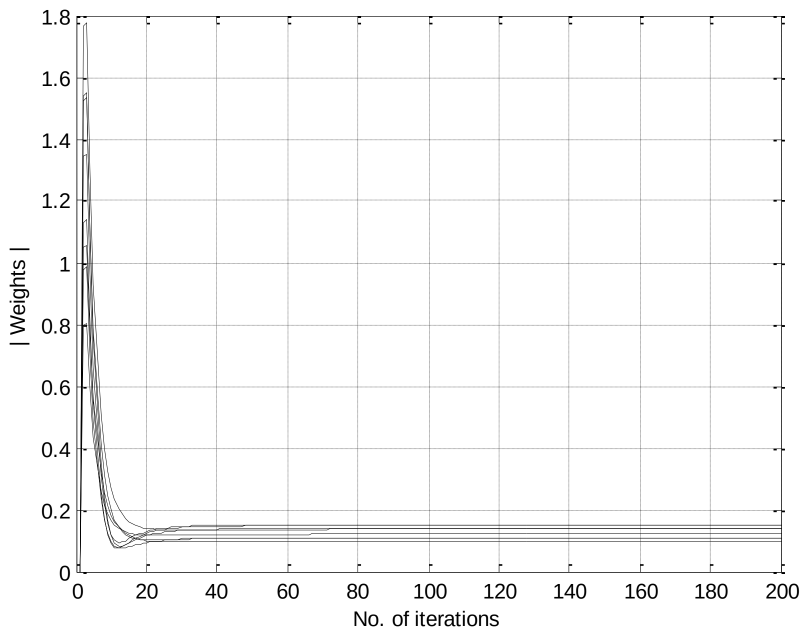


Figure 6.12: Magnitude of array weights in RLS algorithm

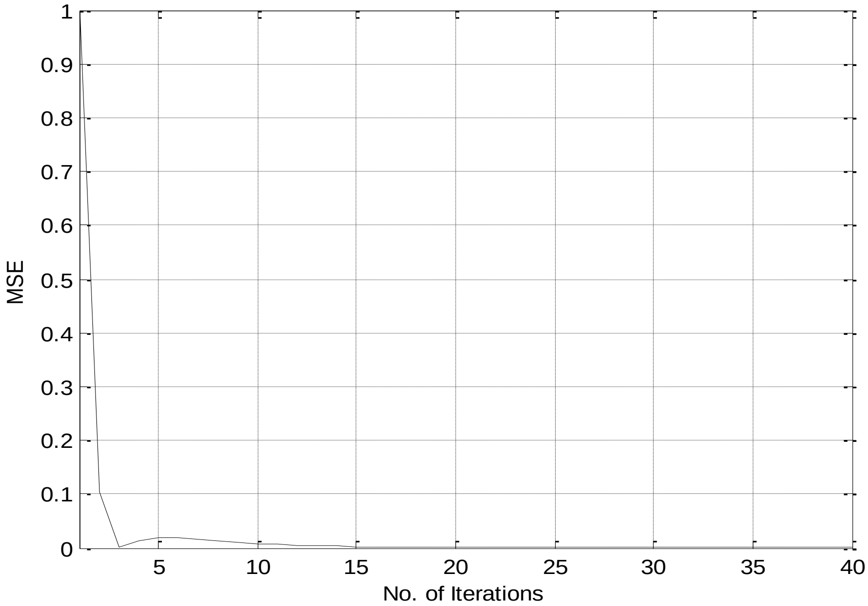


Figure 6.13: Mean Square Error in RLS algorithm

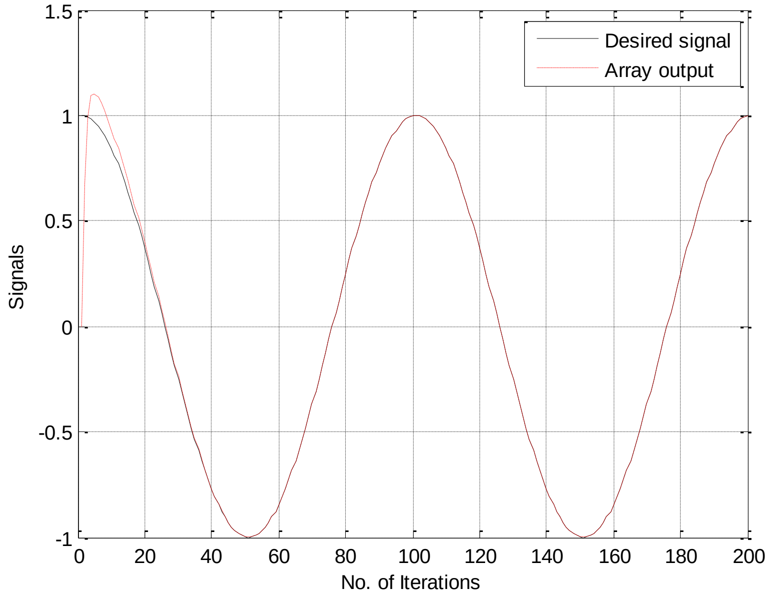


Figure 6.14: Acquisition and tracking of desired signal for RLS algorithm

6.3 Scope on the Results

By comparing the simulation results, it is evident that LMS algorithm shows output with more fluctuations. While in case of RLS number of iterations needed for errors to converge is less. So the convergence takes more time in the case of LMS than RLS as well as the error convergence is more stable and shows quick convergence for RLS algorithm that lead to make RLS is the best choice for wireless communication application which need high speed in signal tracking.

Because the LMS algorithm did not converge until after 70 iterations .this adaptive algorithm may not allow tracking of the desired signal in a satisfactory manner this reason make LMS algorithm not useful in dynamic environment where the signal must be computed quickly and the channel condition are rapidly changing.

In spite of the performance of RLS is the best in terms of converge speed compared with CMA and LMS algorithms, RLS is conceder as complicated algorithms comparing with LMS which is the simplest one.

6.4 Neural Networks for Smart Antenna Optimization

Adaptive beam-forming methods based on estimating the angle of desired signal and maximize the radiation toward it, while reject the signals from other directions. This technique gives a satisfactory performance especially in the ideal case. In reality, when applying the adaptive algorithms the performance may become worse under the real environment and this leads to a mismatch between the assumed array response and real array response.

In order to improve the robustness against mismatches, neural network have found efficient solutions for synthesis and optimization of antenna array by taking into account several predetermined criteria, furthermore, neural network can yield fast convergence rate and high speed computational capability in real time, and that makes the system available to be applied in the real environment.

Artificial neural networks are adaptive systems that can adapt to simulate any linear or non linear system. In order to use the neural networks for adaptive beam-forming smart antenna technology the structure of the neural network must be established initially. The initial weights of the network were chosen randomly to be complex weight to suit the function of the smart antenna. The network consists of four layers among which two layers are hidden in addition to one input and one output layer. The size of the input layer is equal to the number of array elements and is updated automatically based on the input of the array. The output layer contains a single neuron that will submit the output signal of the network. However, multi signal outputs are possible using the neural networks for adaptive beam-forming. The hidden layers are defined and can be changed based on the experience of the user and the efficiency of the network system. In this work, different experiments were applied to examine the efficiency of the ANN for our purpose. Different parameters were varied to optimize the results and increase the speed of training process. Final parameters of the used neural network are presented in the next table and the Fig shows the BPNN diagram.

Table 6.2: Final parameters of the used neural networks

Layers	4	Second hidden layer	5
Hidden layers	2	Transfer functions	Linear
MSE	1e-5	Bias weights	No
Maximum Iteration	1000	Learning rate	0.04
First hidden layer	4	Momentum factor	0.01

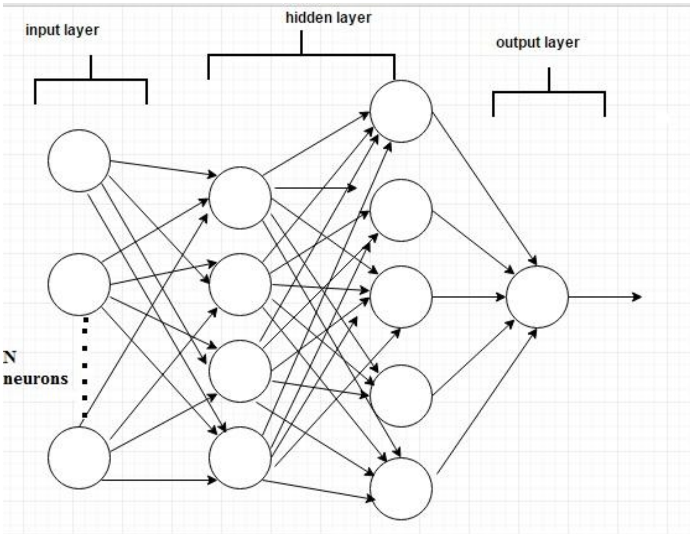


Figure 6.15: Neural network diagram.

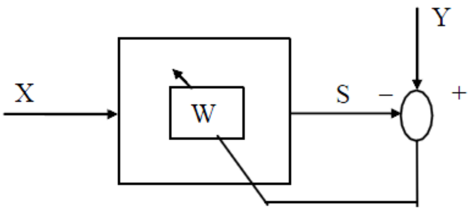


Figure 6.16: Back-propagation learning

During the training of the neural network, a sample of the input signals was used as input for the neural network. The correspondent desired output sample was used as output during the training. The training of the network continues until the result output is similar to the desired output with an accepted MSE level or after some defined number of iterations without success to reach the required MSE. At the end of training, the final parameters of the training are saved and used to treat the rest of the incoming signal.

6.5 Effect of N and d on the Amplitude Factor

In order to plot Array factor for ANN for different number of element and spacing, same experiments were applied by using matlab.The desired signal is arriving at an angle AOA=30°, while the interferer at AOA=-60°. Through Figure 6.17, Figure 6.18, and Figure 6.19 it is evident that this method is suppress the unwanted signal but not completely cancel it. It is also noted that the selection of the appropriate space between element can improved the shape of amplitude responce for the array with best result for (d=0.5),while the choice of the number of elements affect the ability to supress the unwanted signal and decrease the level of interferance.

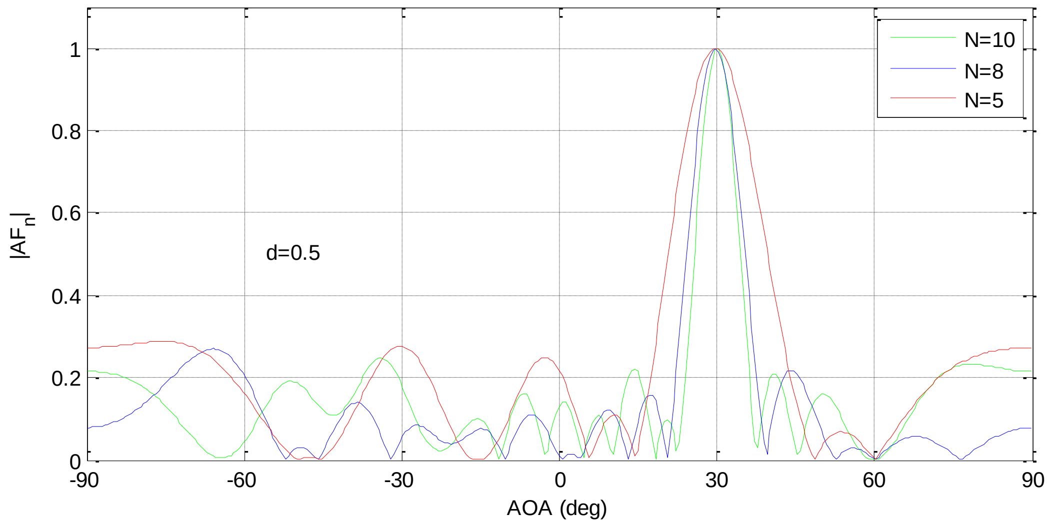


Figure 6.17: Amplitude response by using ANN with d=0. 5λ and different N

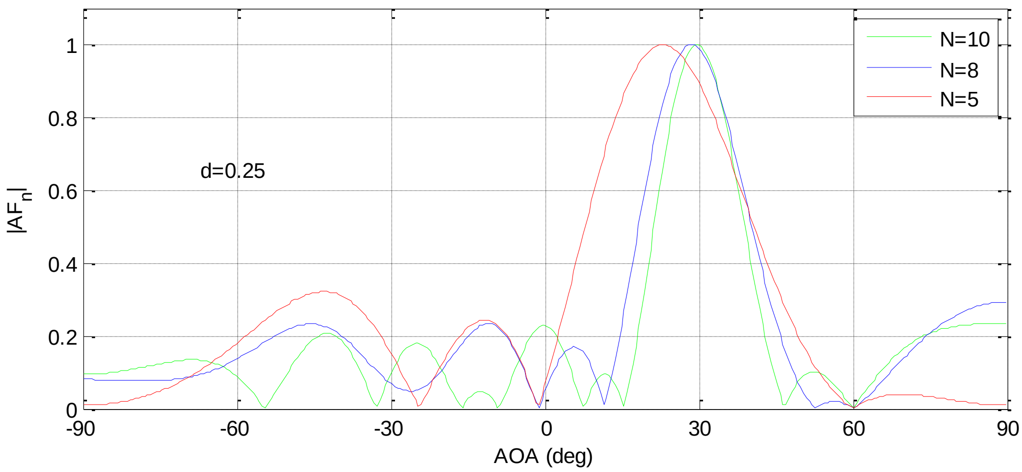


Figure 6.18: Amplitude response by using ANN with d=0. 25λ and different N

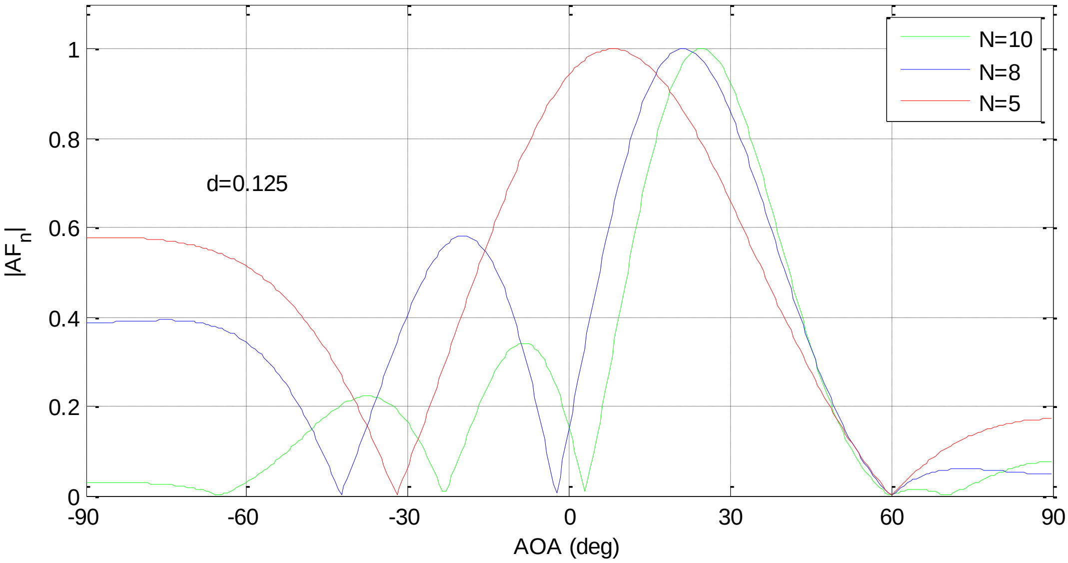


Figure 6.19: Amplitude response by using ANN with d=0. 125λ and different N

The use of 10 elements in the array has ameliorated the response of the neural network by narrowing the main band of the response, this feature is important in some applications that require accurate tracking as in mobile communication system. However, it is evident that the response accuracy decreases with the decrease of the distance between elements of the array and the passing band becomes wider in the case of 0.125λ than the case of 0.5λ. It is also obvious that increasing the number of elements leads to increase the number of side-lobes, which is one of the disadvantages which lead to increased opportunities for receiving signals from unwanted directions.

6.6 ANN Performance in Acquisition and Tracking of Desired Signal

In order to evaluate the performance of ANN in term of tracking of the desired signal, the analysis is done by using eight antennas (N=8) with half wavelength space (d=0.5) by using MATLAB. The desired signal is arriving at an angle AOA=30°, while the interferer at AOA=-60°. Figure 6.20 shows how the array output acquires and tracks the desired signal after about 8 iterations which strongly proves the satisfactory performance in terms of speed of convergence, Figure 6.21 shows the resulting mean square error which converges to near zero after about 8 iterations

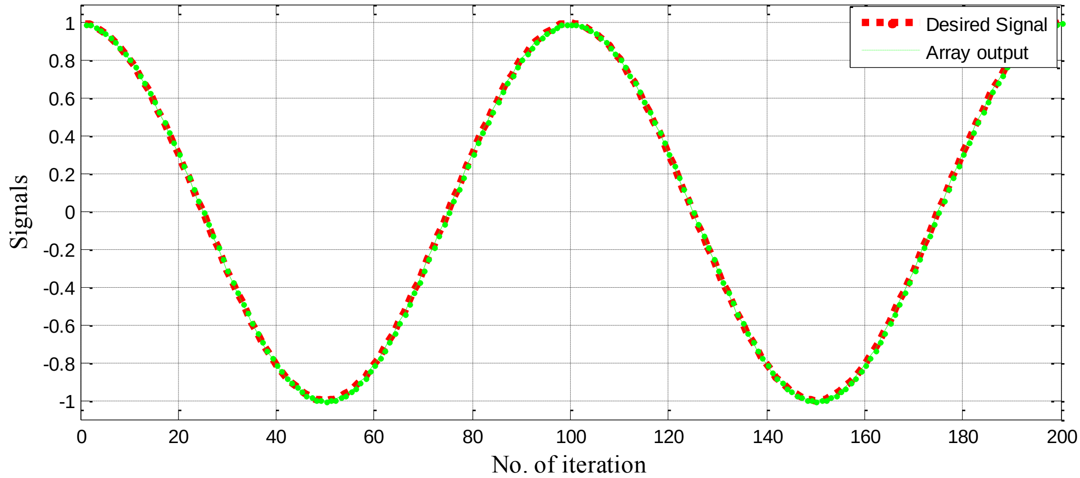


Figure 6.20: Acquisition and tracking of desired signal for ANN

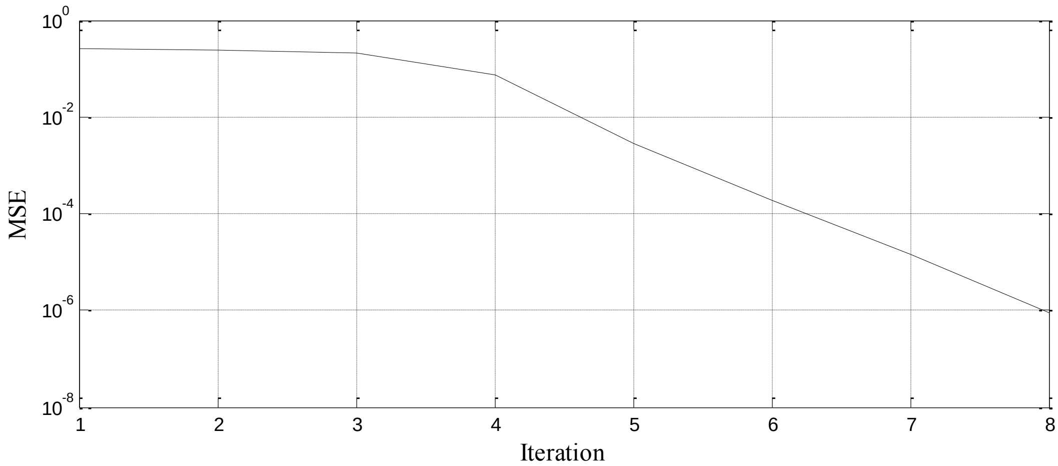


Figure 6.21: Mean Square Error in ANN method

6.7 Array Factor with Variation of Network Parameters

In order to evaluate the performance of the system with the change in the network structure the analysis is done by using MATLAB with eight antennas (N=8),half wavelength space(d=0.5), desired signal is arriving at an angle AOA=30°,the interferences signals arrive with angles AOA=[-80, -85, -70, -60, -55, -50, -40, -30, -25, -20, -10, 0, 10, 20, 40, 50, 60, 70, 80, 85] degrees. In the first experiment the parameters were as described in the table xx while in the second experiment the parameters were as described in the table 6.3.

Table 6.3: Parameters of the used ANN

Layers	3		
Hidden layers	1	Transfer functions	Linear

MSE	1e-5	Bias weights	No
Maximum Iteration	1000	Learning rate	0.04
Size of hidden layer	10	Momentum factor	0.01

Figure 6.22 and Figure 6.23 show how a network structure affects the amplitude response of antenna array. It was obvious that applying the first experiment has given a good performance of the system in terms of reducing unwanted signals, while second experiment has given low quality performance in suppressing interferences signals. For example, the incoming signal from an angle of approximately -25° will be strongly suppressed when using the first experiment, while in the second experiment; the system has the ability to only attenuate 60 percent of this signal strength.

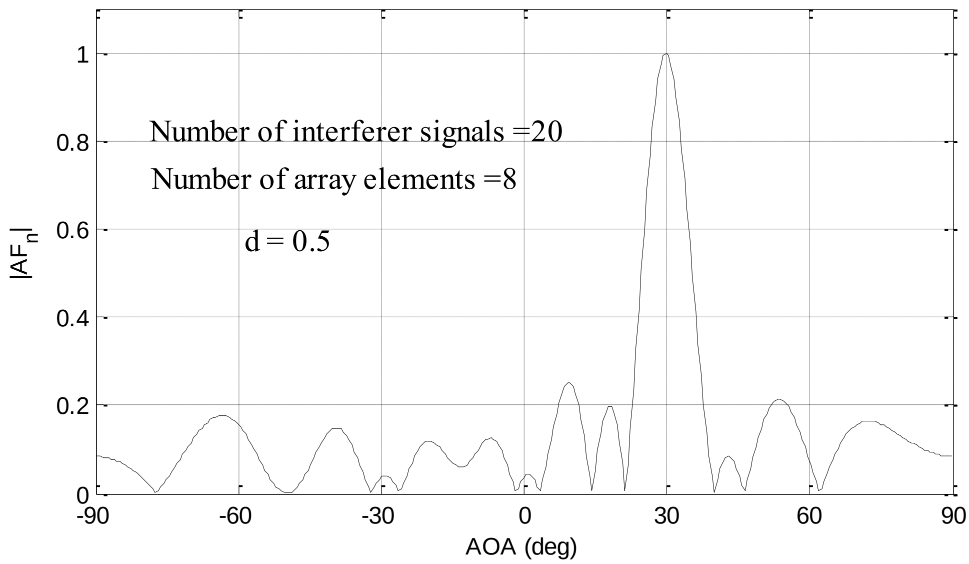


Figure 6.22: Amplitude response for the first expirment by using ANN with two hidden layers(4,5) respectively.

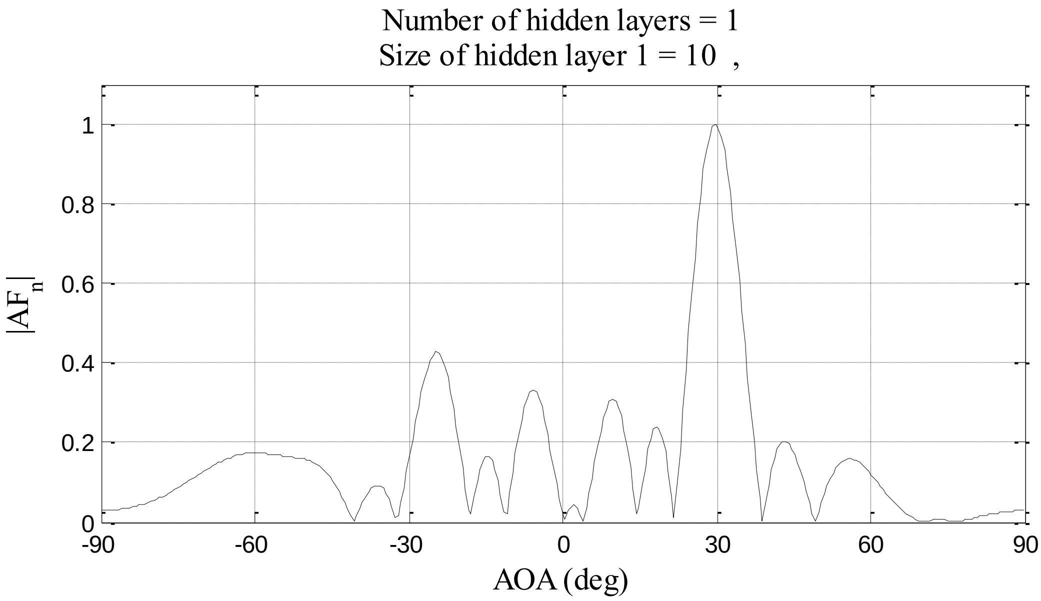


Figure 6.23: Amplitude response for the second expirment by using ANN with one hidden layers of size=10

Through experimentation it was obvious that the network structure affects the system performance but there is no rule to choose the number of hidden layers or define the neural network architecture. In spite of this disadvantage, the ANNs provide very fast and very precise results of smart antenna system.

6.8 Evaluation of Adaptive Beam forming Methods

Through the previous results we can clearly compare the difference in performance of the adaptive beam-forming algorithms and neural network in terms of complexity, stability, convergence speed, amplitude response and tracking of desired signal. The Results can be summarized in the following points

- The number of elements N affects the ability to suppress the interferences signals, increasing N leads to better output amplitude response by forming more narrow main beam toward desired signal which is important in some applications that require accurate tracking ,while has a bad affect on increasing the level of interference by increasing the number of side-lobes.
- The distance between elements d must be selected between d=0.125λ and 0. 5λ ,decreasing the distance affects the shape of output response and its accuracy by making the passing band wide for small value of d, array with best result was for (d=0.5).

- The Speed of convergence is one of the most important criteria for evaluating the performance of the algorithms and the reason for that is applying the communications system in dynamic environment need to be high speed in trucking target, which is available in RLS algorithms, while LMS and CMA are considered as a slow convergence methods which limits their use in some application. Neural networks are superior to other methods in terms of speed where this method can truck signal very quickly and this makes ANN applicable to different applications and have Promising future in the field of communications.

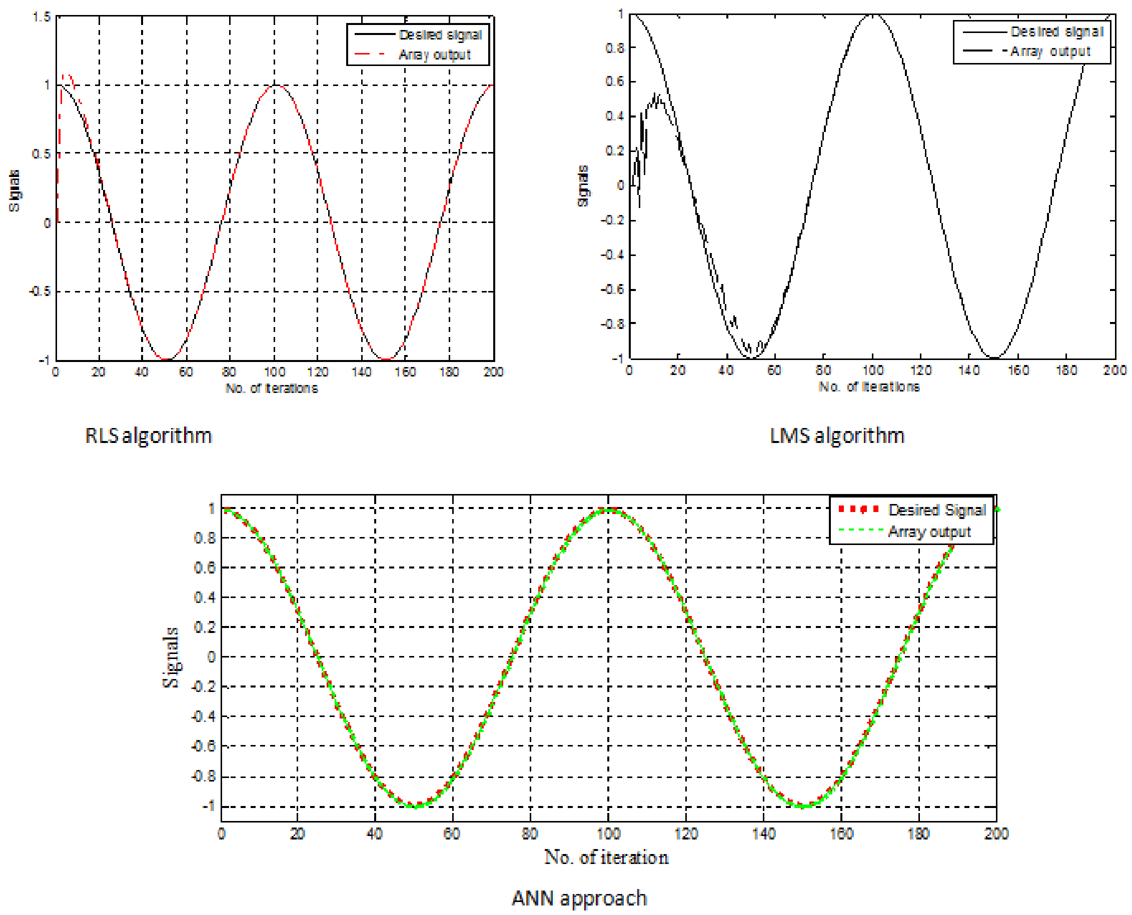
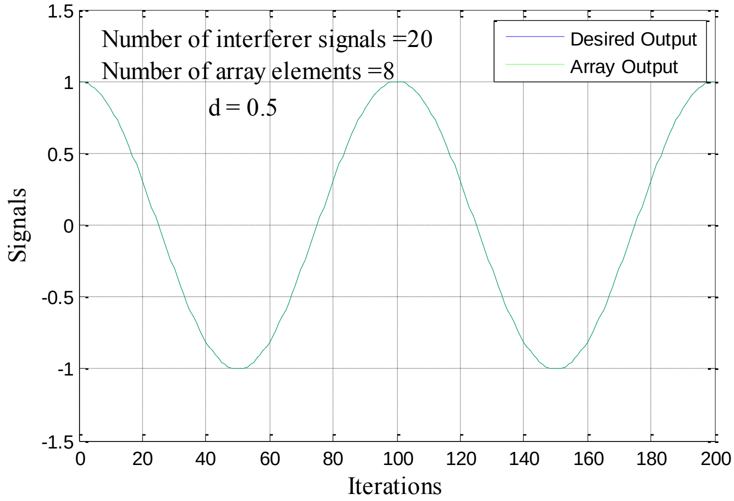
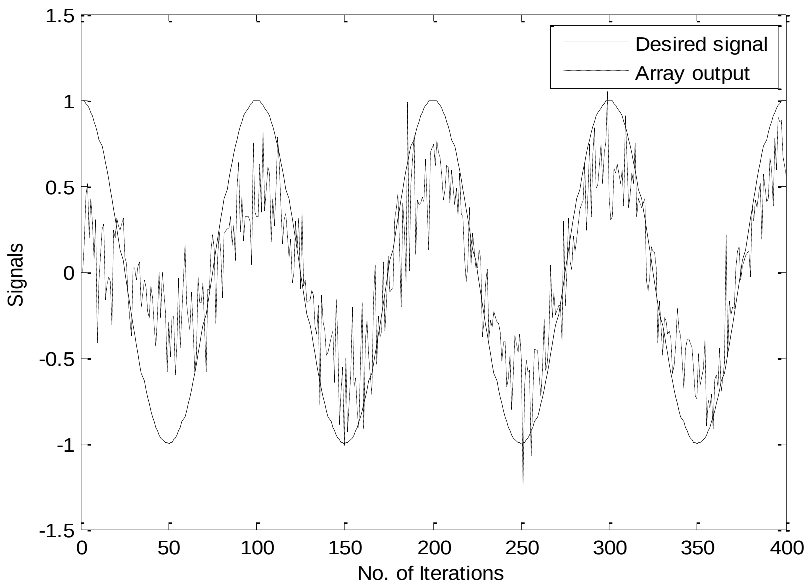


Figure 6.23: Acquisition and tracking of desired signal for LMS,RLS and ANN

- Despite the ability of adaptive beam-forming algorithms to achieve good performance in terms of the form of the amplitude response and suppression interference, the number of rejecting signals is restricted condition ,array elements with N antenna can null-out only N-1 signals or less (Balanis & Ioannides, introduction to smart antenna). By using ANN, the system can overcome this problem and achieve a good performance compared with other algorithms. Figure 6.24 shows the difference between neural networks and LMS algorithm in term of acquisition and tracking of desired signal when applied to ULA with N= 8 and 20 unwanted signals. The figure shows the failure of the LMS algorithm when increasing the number of interferer signals



(a)



(b)

Figure 6.24: a) Acquisition and tracking of desired signal for ANN. b) Acquisition and tracking of desired signal for LMS.

CONCLUSIONS

Recent years have witnessed remarkable exploitation of smart antenna technology in the development of wireless communications industry due to the high efficiency of these systems, which rely on the integration of antenna array with digital signal processing unit to increase the efficiency of systems in terms of the range, speed, and capacity. It was evident that the adaptive beamforming technique was the major responsible for controls the directionality of the radiation patterns in both the receiver and transmitter, this signal processing technique has the ability to shape and direct the main beam of radiation toward the desired target while suppress other unwanted signals by using adaptive algorithms .

This work compared and analyzed three popular adaptive techniques including LMS, RLS, and CMA with Back-propagation Neural Networks as a powerful tool in optimization of the antenna array performance

The Results obtained could be summarized as follows:

- LMS algorithms is the simplest method with reasonable performance in term of stability, and suppression of the interferences, furthermore**,** it can be considered as an ideal choice for many applications that need the robustness and simplicity, However LMS cannot be considered the best choice with regard to speed, since it needs a high number of iterations before convergence.
- RLS algorithms has a faster convergence and a good performance for the suppression of interference compared to other conventional adaptive beamforming algorithms, so it is considered as a reasonable choice for some applications where quick tracking of the desired signal is required, However, the complexity of calculations in this method is one of the main obstacles limiting its use in some applications.
- Some techniques are more suitable to be used in situations where no reference signal is available. These techniques are said to be blind to the received signal’s exact content. CMA algorithm is one of the main algorithms of this category. The results obtained showed that this method is not the best in terms of speed and suppression of interference signals.

The performance of these algorithms is discussed and experimented with a series of simulations for varying parameter of uniform linear arrays such as, number of antenna elements, and the spacing between elements in order to discover the extent effect of the array geometries on the performance.

Finally, a neural network back propagation algorithm is proposed to overcome tracking problem and other limitations in using the conventional methods in light of the results obtained previously by using (LMS, RLS, and CMA) algorithms, The use of ANN in beamforming has proved better performance; the fastest convergence to the desired signal and flexibility, Moreover, this method has ability to reject greater number of interferer compared with other algorithms, which leads to making the SAS applicable to different applications.

REFERENCES

Abdallah, A., Joumaa, C., & Kadry, S. (N.d.). *Design and Performance study of Smart Antenna Systems for WIMAX applications.* Kuwait.

Antenna Basic Concepts. (s.d.). Found at: www.pulseelectronics.com/products/antennas.

Azad, D. M., & Ahmed, A. H. (2010, October). Development of Smart Antenna for Future Generation Wireless. *International Journal of Computer Science and Network Security*, 212-222.

Balanis, C. A., & Ioannides, P. I. (2007). *Introduction to smart antenna.* Arizona.

Bellofiore, S., Balanis, C. f., Foufz, J., & Spanias, a. A. (2002). Smart-Antenna Systems for Mobile communication network. *IEEE Antenna's and Propagation Magazine Part1*, 145-154.

Bevelacqua, P. J. (2008). *Antenna Arrays: Performance Limits And Geometry.* Arizona.

Bevelacqua, P. J. (2009). *Introduction to Antenna Array Geometry*. Found on antenna-theory: http://www.antenna-theory.com/arrays/geometry/basics.php

Bevelacqua, P. J. (2009). *The Array Factor*. Found on Antenna-Theory.com: http://www.antenna-theory.com/arrays/arrayfactor.php

Boyle, k., & Huang, Y. (2008). *Antenna from theory to practice.* UK: Jouhn wiley&sons LTD.

Chang, D.-C., & Hu, C.-N. (2012). Smart Antennas for Advanced Communication Systems. *Proceedings of the IEEE*, 2233 - 2249. doi:10.1109/JPROC.2012.2187409

Christodoulou, C. G., Tawk, Y., Lane, S. A., & Erwin, S. R. (2012). Reconfigurable Antennas for Wireless and Space Applications. *IEEE proceedings, 100*(7), 2250 - 2261. doi:10.1109/JPROC.2012.2188249

Cohen, D. I. (2003). *Digital Speech Processing in Noisy.* Australia.

Das, S. (s.d.). *Smart Antenna Design for Wireless Communication using.* Rourkela.

Fonda, C., & Zennaro, M. (2004). *The Radio Laboratory Handbook.* International Centre for Theoritical Physics ICTP.

Fung, C. (2011). *Basic Antenna Theory and Application.* United States: Worcester Polytechnic Institute Univesity.

Fyfe, C. (1996). *Artificial Neural Networks*. University Of Paisley.

Garcia, L. G., Ariet, L. D., & Rodriguez-Osorio, R. M. (2004). Implementation of a neural network-based digital beamformer for a UMTS smart antenna. *IEEE Sensor Array and Multichannel Signal Processing Workshop Proceedings*, 119-123. doi:10.1109/SAM.2004.1502920

Goldsmith, A. (2004). *Wireless Communications.* California.

Gross, F. B. (2005). *Smart Antennas for wireless communication.* Virginia: The McGraw-Hill Companies.

Haykin, S. (2002). *Adaptive filter theory* (ed. 4). Ontario, Canada: Pearson education asia.

Hreshee, D. S. (2013, October). LMS Algorithm for Optimizing the Phased Array Antenna Radiation Pattern. *JOURNAL OF TELECOMMUNICATIONS*, 20-24.

Hreshee, S. (2013). LMS Algorithm for Optimizing the Phased Array Antenna Radiation Pattern . *JOURNAL OF TELECOMMUNICATIONS*, 20-24.

Jain, R., Katiyar, u., & Agrawal, N. (2011). Smart Antenna for Cellular Mobile Communication. *VSRD International Journal of Electrical, Electronics & Comm. Engg*, 530-541.

Joseph C.Libertii, J., & S.Rappaport, T. (1999). *Smart Antenna for Wireless Communication: IS-95 and Third Generation CDMA Applications.* New Jersey: Prentice Hall .

Karmakar, N. C. (2011). *Handbook of Smart Antennas for RFID Systems.* John Wiley & Sons.

Kavak, A., Yigit, H., & Ertunc, H. M. (2005). Using adaline neural network for performance improvement of smart antennas in TDD wireless communications. *IEEE Transactions on Neural Networks*, 1616 - 1625. doi:10.1109/TNN.2005.857947

Kawitkar, R., & Wakdi, D. (2005, September). Advances in smart antenna system. *Journal in Scientific &Industrial research*, 660-665.

Khashman, A. (1999). Automatic Edge Detection of DNA Bands in Autoradiograph Images. *International Symposium on Industrial Electronics* (pp. 1184 - 1188). Bled: IEEE. doi:10.1109/ISIE.1999.796864

Khashman, A., & Dimililer, K. (2007). Neural Networks Arbitration for Optimum DCT Image Compression. *International Conference on Computer as Tool* (pp. 151 - 156). Warsaw: IEEE. doi:10.1109/EURCON.2007.4400236

Khasim, N. S., Krishna, Y., & Thati., J. (s.d.). Analysis of Different Tapering Techniques for Efficient Radiation Pattern. *e-Journal of Science & Technology*, 47-53.

Krose, B., & Smagt, P. v. (1996). *An Introduction to Neural Networks* (éd. eighth). (U. o. Amsterdam, Éd.) Amsterdam: University of Amsterdam.

Mallaparapu, U., Nalini, K., Ganesh, P., Vishnu, T. R., Khan, P. H., Lakshmi, D., & Madhav., B. (2011, March). Non-Blind Adaptive Beam Forming Algorithms for Smart Antenna. *International Journal of Research and Reviews in Applied Sciences*, 491-496.

merad, L., Bendimerad, F., & Sidi Mohamed Meriah, S. A. (2007). Neural Networks for Synthesis and Optimization of Antenna Arrays. *Journal of Radioengineering*, 23-30.

Olenewa, J. (2013). *Guide to Wireless Communications.* Cengage Learning.

Orakwue, S. I., Ngah, R., Rahman, T. A., & Hashim, S. Z. (2014). Neural network based switch beam smart antenna. *IEEE Conference Publications*, 292-296. doi:10.1109/APWiMob.2014.6920300

Pei, B., Han, H., Sheng, Y., & Qiu, B. (2013). Research on smart antenna beamforming by generalized regression neural network. *IEEE conference publications*, 1-4. doi:10.1109/ICSPCC.2013.6663990

Rahaman, D. M., Hossain, M. M., & Rana, M. M. (2013). Least Mean Square (LMS) for Smart Antenna. *Universal Journal of Communications and Network*, 16-21.

Ramineni, 1., Sagar, G., K.Abhishek Jain, M. G., T.V.Ramakrishna, & Kumar, K. (2012, may). Comparison and performance evaluation of different adaptive beam forming algorithms in wireless communications with smart antenna. *International Journal of Engineering Research*(3), 630-633.

Rani, C. S., Subbaiah, P. V., Reddy, K. C., & Rani, S. S. (2009, AUGUST). Lms and Rls Algorithms for Smart Antennas in a W-Cdma Mobile Communication Environment. *ARPN Journal of Engineering and Applied Sciences*, *4*, 78-88.

RAO, A. P., & SARMA, N. (2014). Adaptive Beamforming Algorithms for Smart Antenna Systems. *WSEAS TRANSACTIONS on COMMUNICATIONS*, 44-50.

Rawat, A., Yadav, R. N., & Shrivastava, S. C. (2009). Neural Modeling of 15 Element Dynamic Phased Array Smart Antenna. *IEEE publications*, 45 - 48. doi:10.1109/ACT.2009.21

Rojas, R. (1996). *Neural Networks, a systematic introduction.* Berlin: Springer-Verlag.

Sadhu, T. (2012, Dec 2). *machine learning*. Seen on Jul 20, 2016, at Durofy: http://durofy.com/machine-learning-introduction-to-the-artificial-neural-network/neuron-2/

Saleh, A., AL-Ali, A., & Alssarn, M. (2013). Neural Networks Application in Smart Antenna Systems For Obtaining an Optimal Output. *Tishreen University Journal for Research and Scientific Studies*, 215-226.

Sallomi, A. H., & Salim, S. R. (2009). Range-Coverage Extension Using Smart Antennas in Mobile Communications systems. *Iraqi Journal of Applied Physics*, 25-28.

Sarevska, M., Milovanovic, B., & Stankovic, Z. (2004). Alternative signal detection for neural network-based smart antenna. *Neural Network Applications in Electrical Engineering, IEEE*, 85-89. doi:10.1109/NEUREL.2004.1416541

Stevanovic, I., Skrivervik, A., & Mosig, J. R. (2003). *Smart Antenna Systems for Mobile Communications.* lausanne.

(Rappaport, 2002). The cellular concept-system design fundamental. Dans T. S. Rappaport, *Wireless Communications principle and practice* (pp. 25-67).

Trivedi, S. (2008, feb 15). *The Motivation behind Artificial Neural Networks*. Seen on 7 27, 2016, Onionesque reality: https://onionesquereality.wordpress.com/2008/02/15/the-motivation-behind-artificial-neural-networks/

Yigit, H., Kavak, A., & Ertunc, H. .. (2004). Using Autoregressive and Adaline Neural Network Modeling to Improve Downlink Performance of Smart Antennas. *Proceedings of IEEE international conference on mechatronics*, 165-170. doi:10.1109/ICMECH.2004.1364431

Zooghby, A. H., Christodoulou, C. G., & Georgiopoulos, M. (2000). A Neural Network-Based Smart Antenna for Multiple Source Tracking. *IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION*, 768-776.