ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

FEASIBILITY STUDY OF SMART ANTENNA SYSTEMS FOR MOBILE COMMUNICATION: THE CASE OF ETHIOTELECOM

By
Abraham Wudu Mekonnen
Advisor
Dr.Murad Ridwan

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Communication Engineering

February, 2016
Addis Ababa, Ethiopia

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Approval by Board of Examiners

Chairman, Dept. Graduate Committee	Signature
Dr.Murad Ridwan Advisor	Signature
Internal Examiner	Signature
External Examiner	Signature

Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

Abraham Wudu ____________________
Name Signature

Place: Addis Ababa

Date of Submission: ________________

This thesis has been submitted for examination with my approval as a university advisor.

Dr. Murad Ridwan ______________
Advisor‟s Name Signature

Acknowledgement

First and foremost, I would like to express my sincere thanks to my advisor Dr. Murad Ridwan for his excellent advice and continuous support during the work of this thesis. Without his guidance and encouragement several breakthroughs in this thesis would be impossible to be achieved.

I also would like to express my gratitude to staff and students at the School of electrical and computer engineering, Addis Ababa Institute of Technology, for their friendship and help by any means during my years at the university.

I would also like to take this opportunity to acknowledge my friends for their support and encouragement. I am especially indebted to my parents for their love, sacrifice and support. At last, I would like to give thanks to God since He has given me wisdom, health and all the necessities that I need for all these years.

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List of Abbreviations

CAPEX: Capital Expenditure

CAS: Conventional Sector Antenna Systems

CDR: The Call Drop Rate

CMA: Constant Modulus Algorithm

CSSR: The Call Set up Success Rate

FDD: Frequency Division Duplex

HO: Hand Over

HSDPA: High-Speed Downlink Packet Access

HSUPA: High-Speed Uplink Packet Access

ISI: Inter symbol Interference

KPI: Key Performance Index

LMS: Least Mean Square

MIMO: Multiple Input Multiple Output

MISO: Multiple Input Single Output

MLSE: Minimal Least-Squares Error

MMSE: Minimal Mean-Squared Error

MSINR: Maximal Signal-To-Interference-Plus-Noise Ratio

OPEX: Operational Expenditures

QoS: Quality of Service

SAS: Smart Antenna Systems

SIMO: Single Input Multiple Output

SNR: Signal to Noise Ratio

UMTS: Universal Mobile Telecommunications System

Abstract

This thesis work describes performance investigation of smart antenna systems and its viability for the deployment in the major 3G networks of Ethiotelecom. The work starts by exploring the performance and the major challenges in the current mobile communication network in Ethiotelecom regarding capacity, coverage and quality of service in connection to the antenna types that are deployed in the Base Stations. This is followed by an outline of how smart antenna systems can be utilized to improve cell coverage, capacity and overall network performance.

The performance of adaptive smart antenna system using Constant Modulus Algorithm (CMA) and Least Mean Square (LMS) algorithm is investigated which can enhance the overall mobile communication performance through suppressing the interference.

A business case analysis for the conventional antennas and smart antenna based telecom systems is studied in a comparative manner in which the result shows that deploying smart antenna base station in the major 3G networks in Addis Ababa is feasible i.e. a range increase, capacity increase, number of Base Station reduction, Capital Expenditure (CAPEX) and Operational Expenditures (OPEX) reduction will be gained by recuperating the capital spent on infrastructure with the deployment of smart antennas.

Keywords: Smart antenna systems, Base Stations, Interference, 3G networks, CMA, LMS, CAPEX, OPEX

Chapter 1: Introduction

1.1 Motivation and Background

The demand for wireless mobile communications services is growing at an explosive rate, with the anticipation that communication to a mobile device anywhere on the globe at all times will be available in the near future. Hence, increased services and lower costs have resulted in an increased air time usage and number of subscribers. Service providers are becoming increasingly concerned with the limited capacities of their existing networks [4].

While the radio (spectral) resources are limited, system capacity is a primary challenge for current wireless networks. Other major challenges include: (1) an unfriendly transmission Medium, due to interference from other users (co channel interference), the inter-symbol interference (ISI) and signal fading caused by multipath. Co-channel interference limits the system capacity, defined as the number of users which can be serviced by the system. (2) The limited battery life of the user's hand-held terminal. (3) Efficient radio resource management to offer high quality of service.

There is an increasing demand on mobile wireless operators to provide voice and high speed data services and to support more users per base station to reduce overall network cost and make the services affordable to subscribers. As a result, wireless systems that enable higher data rates and higher capabilities are pressing need. Unfortunately because the available broadcast spectrum is limited, attempts to increase traffic within a fixed bandwidth create more interference in the system and degrade the signal quality [15], [17].

The existing Ethiotelecom network uses sectored antennas at the base station, which typically split their transmissions into three arcs of 120 degree. Each antenna radiates most of its power in its own sector; it is a waste of signal power because it is broadly radiated in directions other than towards a particular user. Moreover the power radiated in other directions is experienced as interference by other users. Accordingly three sector antennas couldn"t overcome the major challenges of the mobile radio network regarding capacity, coverage and quality of service and making the overall system interference limited.

These concerns has led to the need for the deployment of smart antenna systems throughout major cellular networks that is either using Switched beam or Adaptive Array smart antenna. Switched beam antenna system forms multiple fixed beams with heightened sensitivity in particular directions that detect the signal strength, choose from one of several predetermined fixed beams, and switch from one beam to another as the mobile moves throughout the sector. Switched beam systems combine the outputs of multiple antennas in such a way as to form finely sectored (directional) beams with more spatial selectivity than can be achieved with conventional, single-element approaches. Adaptive Array smart antenna system combines multiple antenna elements with a signal processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment. The adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception [3], [11], [17].

Both smart antenna systems attempt to increase gain according to the location of the user by combating the effects of multipath propagation or constructively exploiting the different paths, and increase capacity by mitigating interference and allowing transmission of different data streams from different antennas [13] and [16]. More specifically, the smart antennas system can overcome the major challenges encountered in the current mobile network regarding better range / coverage, increased capacity, multipath rejection, reduced expense and new services while the capital spent on infrastructure can be recuperated quickly with deployment of smart antennas [15], [19], [23].

1.2 Objective of the Thesis

1.2.1 General Objective

The general objective of this thesis work is to investigate the performance problems encountered in the existing Ethiotelecom 3G networks and propose an alternative solution which is feasible and can enhance the performance of the networks.

1.2.2 Specific Objective

Specifically the aim of this thesis is:

- Investigating the performance of three Sectored antenna which is deployed in Ethiotelecom Base Stations regarding capacity, coverage and quality, basically aiming the 3G network in Addis Ababa
- Exploring and identifying the areas which encounter performance problem and propose an alternative solution which can overcome those problems
- Investigating the performance of adaptive array type smart antenna systems
- Explore a signal processing algorithm that best suit for mobile communication
- Study Business case analysis of conventional antennas and smart antenna based systems regarding range increase, Base Station reduction, cost increase, capacity increase and CAPEX and OPEX reduction
- Examining the implementation of smart antenna systems in the major 3G networks of Ethiotelecom.

1.3 Methodology

The methodology used in doing this thesis comprises the following parts: the first part encompasses the reviews and study of different books, articles, simulations tools and other resources related to the topic which helps to understand the necessary theoretical background for the thesis work. The second part encompasses data collection and performance evaluation of the existing network and the third part is conducted through system modeling, Simulations and performance analysis of antenna systems while in the fourth part a business case analysis is carried out.

1.4 Literature Survey

The literature survey covers topics that form the basis of the work in this thesis. In light of the thesis aims identified in the previous section, these topics are considered in the following order (i) Performance of existing networks, the growing demand for wireless services and performance of SAS based networks (ii) Business case analysis of smart antenna system implementation.

1.4.1 Performance of Existing Networks, SAS Based Networks and the Growing Demand for Wireless Services

There is an ever-increasing demand for services via wireless communication systems [15]-[18]. This has led to more base stations to be erected, meaning high costs and more visual pollution. With subscribers ever increasing, the demanding technological challenge is to increase the spectrum efficiency of wireless networks [5] [11].

When Omni-directional & sectored antennas are used at the base station, the transmission and reception of each user signal becomes a source of interference to other users located in the same cell, making the overall system interference limited[16].

Multipath propagation and co-channel interference are major limiting factors on the capacity of wireless systems, resulting from the reuse of the available network resources (e.g., frequency, time) by a number of users. These limiting factors are widely discussed in [3], [10]–[18] and it also motivates them to study and propose smart antenna systems to overcome the challenges in mobile communication.

G.Prajapati and K.Mahajan [11] investigated a smart antenna array system using wideband compact smart antenna and their result shows that smart antenna system can steer beams for reception in the direction of desired signals and nulls in the direction of interferers.

F.E.Fakoukakis, and G.A.Kyriacou [13] studied Adaptive and Switched Beam Smart Antenna System for SDMA schemes using 2-D Butler matrix method for switched beam and vector modular method for adaptive system in which their result shows that an increased beam steering capability gained in the adaptive system and satisfactory beam switching and steering capability is gained with the switched beam type.

P.Kumar, S.Padhi and S.Sethi [14] compared the BER vs. $\mathrm{E_b/N_0}$ performance with and without beam forming techniques for BPSK modulation in Rayleigh channel. The simulation result shows better result when beam forming technique is implemented.

The adoption of Adaptive smart antenna techniques in the existing and future wireless systems is expected to have a significant impact on the efficient use of the Spectrum, the minimization of the cost of establishing new wireless networks, the optimization of service quality and realization of multi technology wireless systems [2], [3], [5], [11] [14], [16], [22].

1.4.2 Business Case Analysis of Smart Antenna System Implementation

Enabling new and better services in a cost effective manner is a main goal for mobile operators. In order to achieve this goal by the introduction of 3G & 4G technologies, the posed problems such as network capacity shortage must be solved by the operators. Adding more base station sites is not the most efficient means of solving the capacity shortage, coverage and QoS problems. Traditional cell splitting with more sites could also reduce the throughput per site due to complex management of co-channel interference. The primary advantages of using smart antennas in wireless networks is to gain increased capacity together with extended range, to avoid interference, ease network management, and enhanced QoS [3], [15], [21],[22].

J. Rugamba and W. Snyman [23] have shown the viability of using smart antennas in GSM cellular networks in Africa. Their research has shown the following; with use of M element array smart antennas, the outage probability is reduced from 1 to 0.001 meant less co-channel interference is experienced even when frequencies have to tightly be reused in high traffic areas, the output power from amplifiers is reduced by M^{-2} and total transmit power is reduced by M^{-1} due to smart antenna high gain and lobe steering capabilities it is possible to exchange the antenna array gain in order to reduce the maximum output power of the base station and subsequently of the power amplifiers(PAs). Their study also showed cell capacity increase when smart antennas are used in 15% of a 20 BTS urban cluster that led to a profit difference of R80 million over 5year period. The total revenue difference amounted to more than R108million/5year period, where 1R is one Rwandan Rand. In overall a definite viability is demonstrated in their research for the implementation of smart antenna systems in both urban and rural areas in Africa. However they don"t incorporate 3G technologies in their research.

I.Stevanovi´c and J.Mosig [16] conducted a cost-benefit comparative study for sector antenna and smart antenna deployment scenarios. Their research has shown an incremental increase in capacity gain of 500% and payback period of 1.7 years with Smart Antenna and 6.7 years without smart antenna for 100% Dedicated Internet type service in a system which operate on sixteen channels, deployed in a full 360^0 configuration, previously operating with 12 - fixed 30^0 sector antennas, powered to cover the maximum distance(35 mile radius) allowed by the Federal Communications Commission (FCC, USA), with a fixed cost for the base station infrastructure of 1 million dollar, incremental wireless equipment cost of 1 million dollar and incremental cost to add the "Smart Antenna" application of 500,000 US dollar.

ITU-R M.1678 [6] presents a report on the implementation and key technical aspects of an adaptive antenna system in which the system involves trade-offs amongst many parameters from the technical aspect and implementation aspect as well. Adaptive antenna technologies are best implemented with an overall system approach, where all the system components including the antenna system are integrated in an optimal way, leading to substantial coverage improvements, superior mitigation of interference problems and substantial system capacity improvements. Researches on smart antenna architecture, algorithms and practical implementations are ongoing both in academia and industry for further advancement meanwhile; it is already commercialized through the following major companies: Metawave Communication Corporation, Ericsson, Lucent, Wireless Online and Array Comm. [16]. Metawave Communication Corporation has deployed over 300 of its smart antenna systems in wireless networks in USA and commercial installations have demonstrated up to 50 and 75 percent capacity gains in three- and six-sector deployments respectively [16] and [20].

Antenna based solution is not considered and studied yet for the case of Ethiotelecom to enhance the performance of mobile communication network. In this thesis a smart antenna based base station system is proposed as an alternative solution to enhance the performance of the mobile communication network. Basically this thesis work focuses on investigation of performance problems encountered in the existing 3G networks of Ethiotelecom in connection to the antenna types deployed in the base stations and to evaluate the technical performance of smart antenna system using selected adaptive array algorithms. Furthermore, Viability of smart antenna system deployment in the major 3G network of Ethiotelecom is assessed in the last section of this thesis.

1.5 Thesis Organization

This thesis report is arranged into six chapters, following the Introduction Chapter is Chapter Two which presents Fundamental of Antenna Systems. Technical performance of Antennas deployed in Ethiotelecom Base stations is addressed in Chapter Three. Performance of smart antenna systems for mobile communication is presented in Chapter Four. Chapter Five presents the Business case analysis of Conventional Antennas and Smart Antenna based Base Stations, the feasibility of smart antenna system deployment in the major 3G networks of Ethiotelecom is also presented in this chapter.

Finally, Chapter Six discusses conclusions based on the results obtained and recommendations to future works are given.

Chapter 2: Fundamental of Antenna

2.1 Antenna Performance Metrics for Mobile Communication

In antenna terminology, the frequency bandwidth of an antenna is generally characterized either with the lower and upper limits of frequency band (f_L and f_u) or the percentage (%) bandwidth for a center frequency, which is given as:

$$\%\, bandwidth = \frac{f_u - f_L}{f_c} \times 100 \dots\dots\dots\dots\dots (2.1)$$

Where f_c is the center frequency of the band as the arithmetic mean of lower and upper frequency limits. The bandwidth of an antenna is defined as the frequency range in which the performance of antenna satisfies specified standards of some antenna parameters. Therefore, in order to operate properly at the specified frequency bandwidth, the antenna should meet the given standards of these parameters for all frequencies within the frequency bandwidth. Although there are many parameters for different antenna applications, only the important ones regarding to the performance standards for mobile communication systems are mentioned briefly here.

2.1.1 Input Impedance

Depending on the impedance of the antenna and the line feeding the antenna, a certain fraction of transmitted power to the antenna reflects from antenna without radiation. This power fraction is usually described as the return loss (RL) (sometimes called as mismatch loss) in decibel scale as:

$$RL(dB) = -20\log|\Gamma| \dots\dots\dots\dots\dots\dots\dots\dots\dots (2.2)$$

Where Γ is the reflection coefficient which is given by

$$\Gamma = \frac{Z_{ANT} - Z_0}{Z_{ANT} + Z_0} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.3)$$

Where Z_{ANT} is the complex input impedance of the antenna and Z_0 is the characteristic impedance of feeding line. As the alternative way of describing the reflected power from the antenna, the term of voltage standing wave ratio (VSWR) is also used with a formal definition given by

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2.4)$$

VSWR provides a more quantitative indication about mismatch between the antenna and feeding line impedances in that VSWR= 1 indicates perfect matching. Because the complex impedance of antenna is a function of frequency, both return loss and VSWR depend on the operating frequency. Thus, if the antenna operates at a given frequency bandwidth, the impedance of the antenna should satisfy application-specific criterion such as VSWR ≤ 2 or equivalently RL ≥ 10 dB ($|\Gamma| \geq 0.316$) at all frequencies within the bandwidth. In base station systems, the constraint of VSWR ≤ 2 (or sometimes shown as VSWR 2:1) is usually sufficient, which corresponds to about 10% reflected power from the antenna.

2.1.2 Radiation Pattern and Beamwidth

An antenna radiation pattern is defined as a graphical representation of power distribution or field strength of the antenna as a function of space coordinates. These coordinates are usually selected as elevation and azimuth angles of spherical coordinate system.

There are many types of representation of radiation pattern of an antenna. One of them is the three dimensional (3D) graph. However, the drawing of 3D graph is usually difficult and unnecessary due to the symmetry of antenna radiation pattern. Therefore, instead of 3D radiation pattern, a more comprehensive representation of radiation pattern called as polar plot is used.

In antenna terminology, planar cuts from 3D pattern are considered for two main planes, which are E-plane and H-plane for linearly polarized antennas. The E-plane is defined as the plane containing the electric field vector and the direction of maximum radiation; and H-plane is the plane containing the magnetic field vector and the direction of maximum radiation. Therefore, by representing plots of an antenna in both planes, which are orthogonal, power distribution of the antenna in whole space can be comprehended well without drawing 3D pattern.

The Beamwidth of the antenna is defined as the angular distance (width) between two half power points in the radiation patterns, where half power level is 3 dB below the maximum radiation power. The beamwidth parameter is usually expressed as "3 dB beamwidth" in the antenna applications for both E plane (elevation beamwidth) and H plane (azimuth beamwidth). This parameter can be also considered as effective angular width of the antenna in that important portion of radiated antenna power is focused within this angular beamwidth. In indoor or outdoor base station applications, antennas having wide 3 dB beamwidth (90° or 120°) are preferred to provide sufficient angle coverage in azimuth plane; whereas, the elevation beamwidth of these antennas varies typically between 10° or 70° within the frequency bandwidth of the antenna.

When radiation pattern of an antenna is handled, the front-to-back (F/B) ratio of antenna is also an important parameter in mobile communication applications. This parameter is roughly defined as the ratio of maximum radiated field in forward (main lobe) direction (0°) to the radiated field in the opposite (back lobe) direction (180°). This ratio is generally desired to be about 30 dB in outdoor base station applications in order to minimize the interference between back-to-back oriented antennas. On the other hand, the required F/B ratio for indoor applications can be low.

2.1.3 Gain

The gain of an antenna is defined as the ratio of the power intensity radiated by the antenna in a given direction (usually in spherical coordinate angles θ and $\emptyset$) divided by the intensity radiated by a lossless isotropic antenna, which radiates the power at all angles equally. In a mathematical form, it can be formulated as

$$gain = G(\theta, \emptyset) = 4\pi \frac{U(\theta, \emptyset)}{P_{in}} \dots\dots\dots\dots\dots\dots..(2.5)$$

Where $U(\theta, \emptyset)$ is the radiation (power) intensity and P_{in} is total input (accepted) power of the antenna. In antenna applications, gain is usually considered as maximum gain taken in the direction of maximum radiation. Therefore, gain drops at most 3 dB below maximum gain within the beamwidth of the antenna. Gain requirements may vary according to different applications of mobile communication.

2.1.4 Polarization

The polarization of the antenna is roughly defined as the orientation of electric field vector of the radiated wave of the antenna with time. In general, most antennas radiate either linear or circular polarization. The electric field in linearly polarized wave oscillates in either horizontal or vertical directions. In a circular polarized antenna, the plane of polarization rotates in a circle making one complete revolution during one period of the wave. In order to transfer maximum power between transmitter and receiver antennas, both antennas should have same polarization.

However, in general, the polarization of receiver antenna is not the same as the polarization of the incident wave radiated by transmitter antenna. Consequently, power transfer is reduced, which is called as polarization loss factor (*PLF*). In communication link, the *PLF* has to be expressed by the polarization vectors of the transmitting and receiving antennas,$\overrightarrow{\mathrm{p_r}}$ and $\overrightarrow{\mathrm{p_t}}$ respectively. The *PLF* is then equal to:

$$PLF(dimensionless) = |\overrightarrow{p_r} . \overrightarrow{p_t}|^2 = \left|\cos\varphi_\rho\right|^2 (dimensionless) \dots\dots\dots (2.6)$$

Where φ_ρ is the angle between the two unit vectors

Mathematically, this loss is expressed in decibel scale as:

$$PLF(dB) = 10\log PLF(dimensionless) = 20\log|\overrightarrow{p_r} . \overrightarrow{p_t}| \dots\dots\dots\dots (2.7)$$

Where p_r and p_t are unit (polarization) vectors of receiver and transmitter antenna, respectively. Accordingly, when the case, where linearly polarized transmitter and receiver antennas are orthogonally oriented, theoretically no power is transferred between antennas.

Therefore, a single linearly polarized antenna cannot be used directly in mobile communication systems because a linearly polarized mobile phone antenna, can be hold in any tilted position even orthogonal to base station antenna and this case results in zero transferred power due to polarization mismatch and the PLF will be zero or -∞ dB. On the other hand, in circular polarization case, there exists no complete power loss (mismatch) that some portion of transmitted power is always transferred to linearly polarized receiver antenna for any spatial orientation. For this purpose, circular polarization is frequently used in mobile communication systems in order to prevent complete mismatch. However, achieving circular polarization within wide frequency bandwidth is difficult; therefore, as compared to linearly polarized antennas, circularly polarized antennas in mobile communication systems have relatively narrow frequency bandwidth. Consequently, in order to optimize polarization mismatch and frequency bandwidth, dual-polarized antenna systems, which include either two orthogonal (in this case, two orthogonal sets of antenna are located in the base station for the purpose of avoiding complete mismatch with the mobile phone antenna) linearly polarized antennas or an antenna excited by two orthogonal feeds, are commonly used in base station applications for the reason that the signal transmitted by a mobile phone is reflected in the propagation field and reaches the base station via different paths and phase angles. As a result the signal at the base station receiving antenna is the sum of various vectors with different amplitudes, phases and polarization. If two orthogonal linearly polarized antennas used in the base station, then it is highly likely that one of them will provide the required signal strength. Moreover, dual-polarized antennas can provide space-saving polarization diversity at the base station point to increase the performance of mobile systems in that ±45° dual-polarized (slant-polarized) antennas are currently in almost universal use for base station systems.

2.1.5 Mutual Coupling

When identical antenna elements are placed in an array or multiple different antennas are used, they interact with each other. This interaction between elements due to their close proximity is called mutual coupling, which affects the input impedance as well as the radiation pattern. It is noted previously that in base station applications, more than one similar antenna can be implemented to either acquire higher gain with array structures or at least provide dual-polarization with two antenna elements. Mathematically, in *N* element antenna system, the mutual coupling S_{ij} in between *i*th and *j*th antenna elements can be evaluated in decibel scale as

$$S_{ij}(dB) = 20\log\frac{b_i}{a_j}\bigg|_{a_{k=0\ for\ k\neq j}} \quad \dots\dots\dots\dots\dots\dots\dots (2.8)$$

Where a_j is the amplitude of transmitted wave from *j*th antenna and b_i is the amplitude of received wave from *i*th antenna in which transmitted waves on all other antennas except *j*th antenna are set to zero. In base station systems, the specification for mutual coupling between antenna elements is typically -20 dB (or 20 dB isolation) within the frequency bandwidth.

2.1.6 Cross Polar Discrimination

Most dual polarized antenna systems employed for polarization diversity purpose are required that each antenna port receives signals only from its designated linear polarization (co-polarization). However, unfortunately practical antennas also receive unwanted signals from orthogonal polarization called as cross polarization (X-polarization). Cross polar discrimination is the ratio of received co-polar signal level to cross polar signal level.

2.1.7 Intermodulation

When the signals with multiple frequencies$(f_1, f_2, .., f_n)$ are received by a nonlinear device, intermodulation frequency terms (f1-f2, f1+f2, 2f1-f2...) are generated. Although an antenna is actually a linear device, it may slightly deviate from linearity when sufficiently high power is transmitted or received by the antenna. This nonlinearity is usually formed due to mechanical joints or nonlinear materials used in the antenna.

2.1.8 Specific Absorption Rate (SAR)

For a mobile phone or notebook computer antenna located to the position, which is nearby to a human body, some portion of transmitted power is absorbed by the human body. The specific absorption rate (SAR) is basically defined as the absorbed power density at a particular point of the human body. SAR can be quantitatively expressed as

$$SAR = \frac{dP_{abs}}{pdV} = \frac{\sigma |E|^2}{2\rho} \dots\dots\dots\dots\dots\dots\dots\dots\dots (2.9)$$

Where dP_{abs} is absorbed power within an infinitesimal volume of dV; E is the peak electric field strength within dV; ρ and σ are mass density and conductivity of the human body. The IEEE standard about SAR indicates that maximum allowed SAR is 1.6 W/kg and whole-body averaged peak SAR is 0.08 W/kg.

2.2 Channel Model

In order to evaluate the performance of antenna system, it is necessary to have detailed knowledge of the channel and the channel parameters. This is because the propagation channel is the principal contributor to many of the problems and limitations that beset mobile radio systems.

The propagation of radio signals on both the forward (base station to mobile) and reverse (mobile to base station) links is affected by the physical channel in several ways.

A signal propagating through the wireless channel usually arrives at the destination along a number of different paths, referred to as multipath. These paths arise from scattering, reflection, refraction or diffraction of the radiated energy of objects that lie in the environment. The received signal is much weaker than the transmitted signal due to phenomena such as mean propagation loss, slow fading and fast fading. Multipath propagation results in the spreading of the signal in different dimensions. These are the delay (or time) spread, Doppler (or frequency) spread and angle spread. These spreads have significant effects on the signal. The mean path loss, slow fading, fast fading, Doppler, delay and angle spread are the main channel effects and are described in the following sections.

2.2.1 Mean Path Loss

The mean path loss describes the attenuation of a radio signal in a free space propagation situation, due to isotropic power spreading, and is given by the famous inverse square low (or Friis free space link equation)

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 . G_t G_r \dots\dots\dots\dots\dots\dots\dots\dots (2.10)$$

Where P_r and $P_t$are the received and transmitted powers, λ is the radio wavelength, d is the range and G_t and G_r are the gains of the transmit and receive antennas respectively.

2.2.2 Fading

In addition to path loss, the received signal exhibits fluctuations in signal level called fading. As these variations represent the change of the strength of the electrical field as a function of the distance from the transmitter, a mobile user will experience variation in time. It is typically composed of two multiplicative components, α_s and α_r:

$$\alpha(t) = \alpha_s(t)\alpha_r(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.11)$$

$\alpha_s(t)$ is called slow fading and represents the long-term time variations of the received signal, whereas $\alpha_r(t)$ represents the short-term (or multipath) fading. The slow fading $\alpha_s(t)$ is the envelope of the signal level $\alpha(t)$.

2.2.2.1 Slow fading

Slow fading is caused by long-term shadowing effects of buildings or natural features in the terrain. It can also be described as the local mean of a fast fading signal. The statistical distribution of the local mean is influenced by the antenna height, the operating frequency and the type of environment. It is therefore difficult to predict. However, when all the above mentioned parameters are fixed, then the received signal power averaged over Rayleigh fading approaches a normal distribution when plotted in a logarithmic scale (i.e., in dB‟s). Such a distribution is called log-normal and it is described by the following probability-density function [16].

$$p(x) = \begin{cases} \frac{1}{\sqrt{\pi}\,\sigma x} e^{\frac{-(\log x-\mu)^2}{2\sigma^2}}, & x > 0 \\ 0, & x < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.12)$$

In the above equation, x is a random variable representing the slow signal level fluctuation and μ and σ are the mean and standard deviation of x expressed in decibels, respectively. A typical value for the standard deviation of shadowing distribution is 8 db.

2.2.2.2 Fast fading

The short-time fading $\alpha_r(t)$ corresponds to the rapid fluctuations of the received signal in space. It is caused by the scattering of the signal off objects near the moving mobile. If we assume that a large number of scattered wave fronts with random amplitudes and angles of arrival arrive at the receiver with phases uniformly distributed in $[0, 2\pi)$, then the in-phase and quadrature phase components of the vertical component of the electric field *Ez* can be shown to be Gaussian processes[16].

The envelope of the received signal has a Rayleigh density function given by

$$p(y) = \begin{cases} \dfrac{y}{\sigma^2} e^{\frac{-y^2}{2\sigma^2}}, & y > 0 \\ 0, & y < 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.13)$$

If there is a direct path present, then it will no longer be a Rayleigh distribution but becomes a Rician distributed instead. The corresponding probability density function is given by [16].

$$p(y) = \begin{cases} \dfrac{y}{\sigma^2} e^{\frac{-(y^2+s^2)}{2\sigma^2}} J_p\left(\dfrac{ys}{\sigma^2}\right), & y > 0 \\ 0, & y < 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots (2.14)$$

Where s^2 is the mean power of the direct (line-of-sight) path and J_p is the modified p-th order Bessel function of the first kind. Note that in the absence of a direct path ($s^2 = 0$) the Rician pdf reduces to the Rayleigh pdf.

2.2.3 Doppler Spread: Time-Selective Fading

When the mobile is in motion, the radio signal at the receiver experiences a shift in the frequency domain (also called Doppler shift), the amplitude of which depends on the path direction of arrival. In the presence of surrounding scatterers with multiple directions, a pure tone is spread over a finite spectral bandwidth. In this case, the Doppler power spectrum is defined as the Fourier transform of the time autocorrelation of the channel impulse response, and the Doppler spread is the support of the Doppler power spectrum.

Assuming scatterers distributed uniformly by n angle, the Doppler power spectrum is given by the so-called classical spectrum [16].

$$S(f) = \frac{3\sigma^2}{2\pi f_m}\left[1 - \left(\frac{f - f_c}{f_m}\right)^2\right]^{-1/2}, f_c - f_m < f < f_c + f_m, \dots\dots\dots..(2.15)$$

Where $f_m = \frac{v}{\lambda}$ is the maximum Doppler shift, v is the mobile velocity, f_c is the carrier frequency and σ^2 is the signal variance.

2.2.4 Delay Spread: Frequency-Selective Fading

Multipath propagation is often characterized by several versions of the transmitted signal arriving at the receiver with different attenuation factors and delays. The spreading in the time domain is called delay spread and is responsible for the selectivity of the channel in the frequency domain. The coherence bandwidth, which is the maximum range of frequencies over which the channel response can be viewed as constant (or the maximum frequency separation for which the frequency domain channel responses at two frequency shifts remain strongly correlated), is inversely proportional to the delay spread. Significant delay spread may cause strong inter-symbol interference which makes necessary the use of a channel equalizer [16].

2.2.5 Angle Spread: Space-Selective Fading

Angle spread at the receivers refers to the spread of angles of arrival of the multi paths at the antenna array. Likewise, angle spread at the transmitter refers to the spread of departure angles of the multi paths. The angle of arrival (or departure) of a path can be, in some cases, statistically related to the path delay. The larger the angle spread, the shorter the coherence distance.

2.2.6 Multipath Propagation

Multipath scattering underlies the three spreading effects described above (mobile motion is also required to produce Doppler spread). It is important to understand the types of scatterers and their contribution to channel behavior.

2.3 Evolution from Omni Directional to Smart Antennas

An antenna in a telecommunications system is the port through which radio frequency (RF) energy is coupled from the transmitter to the outside world for transmission purposes, and in reverse, to the receiver from the outside world for reception purposes. To date, antennas have been the most neglected of all the components in personal communications systems [16]. Yet, the manner in which radio frequency energy is distributed into and collected from space has a profound influence upon the efficient use of spectrum, the cost of establishing new communications networks and the service quality provided by those networks. The goal of the next several sections is to answer the question "Why to use anything more than a single omnidirectional (no preferable direction) and traditional three sectored antennas at a base station?". This is done by describing, in order of increasing benefits, the principal schemes for antennas deployed at base stations.

1. Omnidirectional Antennas

Since the early day of wireless communications, there has been the simple dipole antenna, which radiates and receives, equally well in all directions (direction here being referred to azimuth) [16]. To find its users, this single-element design broadcasts omnidirectional in a pattern resembling ripples radiation outward in a pool of water.

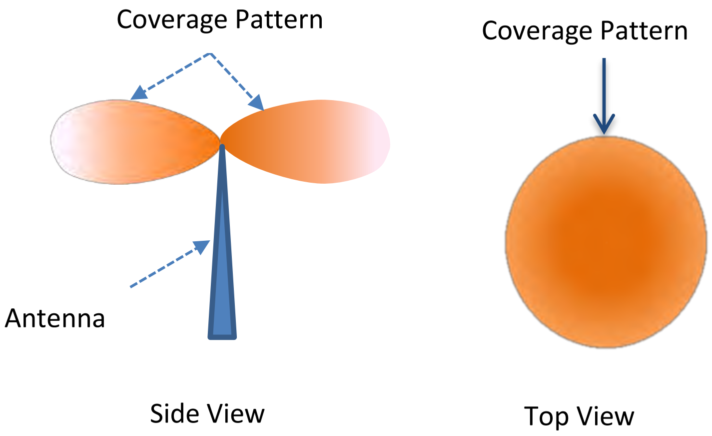


Figure 2.1: Omnidirectional Antennas and Coverage Patterns

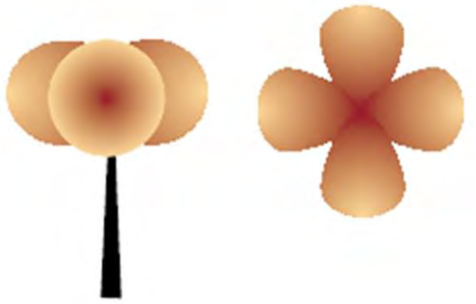
While adequate for simple RF environments where no specific knowledge of the users' whereabouts is available, this unfocused approach scatters signals, reaching desired users with only a small percentage of the overall energy sent out into the environment. Given this limitation, omnidirectional strategies attempt to overcome environmental challenges by simply boosting the power level of the signals broadcast. In a setting of numerous users (and interferers), this makes a bad situation worse in that the signals that miss the intended user become interference for those in the same or adjoining cells. Also, this single-element approach cannot selectively reject signals interfering with those of served users and has no spatial multipath mitigation or equalization capabilities. Therefore, omnidirectional strategies directly and adversely impact spectral efficiency, limiting frequency reuse. These limitations of broadcast antenna technology regarding the quality, capacity, and geographic coverage of wireless systems and the requirements of the next generation wireless communications as well has recently prompted an evolution in the fundamental design and role of the antenna in a wireless system in addition to the efforts that are undergoing in the other components of the communication system.

This Omni directional antenna type doesn‟t exist in Ethiotelecom network as three sectored antennas are deployed throughout the network.

2. Directional Antennas and Sectorized Systems

A single antenna can also be constructed to have certain fixed preferential transmission and reception directions. Sectorized antenna system take a traditional cellular area and subdivide it into sectors that are covered using directional antennas looking out from the same base station location. Operationally, each sector is treated as a different cell in the system, the range of which can be greater than in the Omni directional case, since power can be focused to a smaller area. This is commonly referred to as antenna element gain. Additionally, sectorized antenna systems increase the possible reuse of a frequency channel in such cellular systems by reducing potential interference across the original cell. While sectorized antenna systems multiply the use of channels, they do not overcome the major disadvantages of standard omnidirectional antennas such as filtering of unwanted interference signals from adjacent cells.

In the case of Ethiotelecom three sector antenna systems are deployed throughout the network.



Side View Top View

Figure 2.2: Sectorized Antenna System and Coverage Pattern [16].

3. Switched Beam Smart Antennas

Switched beam antenna systems form multiple fixed beams with heightened sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams, and switch from one beam to another as the mobile moves throughout the sector. Instead of shaping the directional antenna pattern with the metallic properties and physical design of a single element (like a sectorized antenna), switched beam systems combine the outputs of multiple antennas in such a way as to form finely sectorized (directional) beams with more spatial selectivity than can be achieved with conventional, single-element approaches.

In terms of radiation patterns, switched beam is an extension of the current microcellular or cellular Sectorization method of splitting a typical cell. The switched beam approach further subdivides macro-sectors into several micro sectors as a means of improving range and capacity. Each micro-sector contains a predetermined fixed beam pattern with the greatest sensitivity located in the center of the beam and less sensitivity elsewhere.

The design of such systems involves high-gain, narrow azimuthal beamwidth antenna elements.

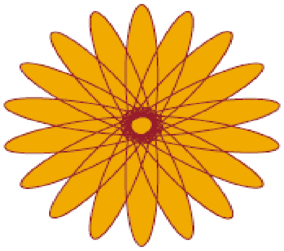


Fig. 2.3: A Switched Beam System that Radiate Several Overlapping Fixed Beams Covering a Designated Angular Area [16].

4. Adaptive Array Smart Antennas

Adaptive antenna technology represents the most advanced smart antenna approach to date. Using a variety of new signal-processing algorithms, the adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception.

Adaptive arrays utilize sophisticated signal-processing algorithms to continuously distinguish between desired signals, multipath, and interfering signals as well as calculate their directions of arrival. The ability to track users smoothly with main lobes and interferers with nulls ensures that the link budget is constantly maximized. Both types of smart antenna systems provide significant gains over conventional sectored systems.

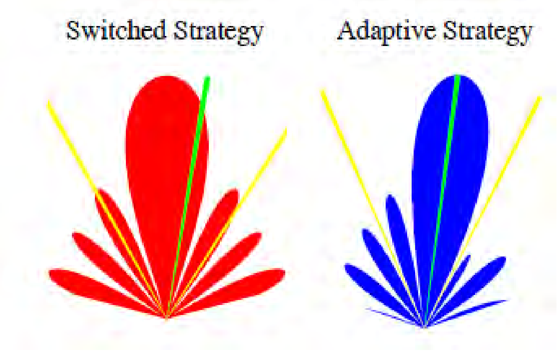


Fig. 2.4: Beam forming Lobes and Nulls that Switched Beam (Red/Left) and Adaptive Array (Blue/Right) Systems Might Choose for Identical User Signals (Green Line) and Co-channel Interferers (Yellow Lines) [16].

Chapter 3: Technical Performance of Antennas Deployed in Ethitelecom Base Stations

3.1 Introduction

The performance of a Base Station Antenna (BSA) is a key factor in the overall performance and quality of the cellular communication link between a handset and the radio, and by extension, the performance of a cell, or of an entire cellular network. The BSA"s influence on coverage, capacity, and QoS is extensive, and yet there exists no comprehensive, global, standards focusing on the base station antenna.

Ethiotelecom has deployed three types of base station antennas, which are single band(900MHz), dual band(1800MHz& 2100MHz) and triple band(900MHZ,1800MHz & 2100MHz) that supports three mobile technologies (GSM, UMTS and LTE), to meet the requirement of coverage, capacity and QoS. Regarding coverage to provide 2G signal coverage to 85% of the geographical area of the country, 3G up to rural, that is to support 56 million subscribers and 6 million wireless broad band services (HSPA+ and LTE).

Meanwhile the network coverage and capacity in Addis Ababa for different mobile technologies that was planned and deployed is presented as follow:

GSM Network Output

For Addis Ababa, dense urban area (70.45 km^2) continuous coverage with 1,748,726 users, urban area (170.36 km^2) continuous coverage with 2,022,291 users and sub urban area (539.12 km^2) continuous coverage with 856,421 users, in which the network is deployed to support a maximum capacity of 4,627,438 GSM users with 614 GSM BS sites.

UMTS Network Output

For Addis Ababa, dense urban area (70.45 km^2) continuous coverage with 541,632 users, urban area (170.36 km^2) continuous coverage with 604,800 users and sub urban area (539.12 km^2) continuous coverage with 356,160 users, that is the network is deployed to support a maximum capacity of 1,502,592 UMTS users with 722 UMTS BS sites.

LTE Network Output

For Addis Ababa, dense urban area (70.45 km^2) continuous coverage with 242,623 users, and hotspots in urban area (170.36 km^2) coverage with 157,377 users, that is the network is deployed to support a maximum capacity of 400,000 LTE users with 329 LTE BS sites.

3.2 Antenna Types Deployed in Ethiotelecom

Antenna Height Design in Ethiotelecom

In Addis Ababa, triple band antennas are used for rooftop sites and single band and dual band antennas are used for Greenfield sites, different antenna heights that are deployed in different scenarios is shown in the following table:

Scenario	Dense urban	Urban	Suburban
Antenna Height (m)	25-30	30-35	35-45

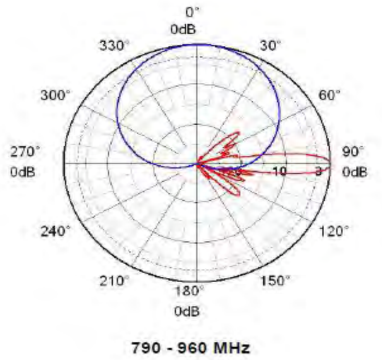
Table 3.1 Ethiotelecom Network Equipment Statistics

Technologies	BTS/NodeB	TRX	Antenna				CE
			Triple band	900M	Dual band	2100M	
GSM	614	21312	104*3	510*3			
UMTS	722	6708			510*3	108*3	315776
LTE	329	987					
IBS(GSM&UMTS&LTE	3	28TRX+14Cell+7Cell					

The Radiation pattern for different bands are shown below:

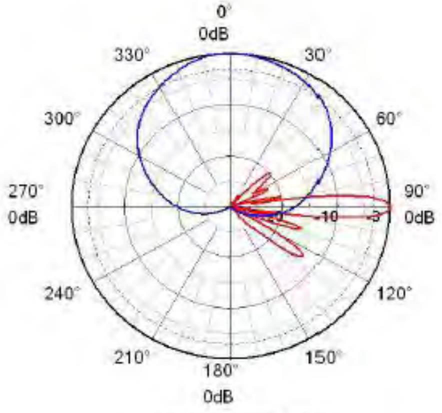
A. **Single Band(900MHz)[8]**

Radiation Pattern for Single Band Antenna (790 – 960 MHz) of Ethiotelecom with Horizontal 3dB Beam Width $65^{\circ} - 69^{\circ}$ and Vertical 3dB Beam Width $7.3^{\circ} - 8.3^{\circ}$ [8]



B. Dual Band(1800MHz and 2100 MHz)[8]

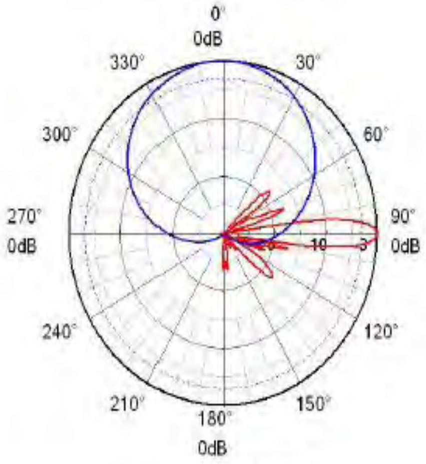
Radiation Pattern for Dual Band Antenna (1710 - 2200 MHz) of Ethiotelecom with Horizontal 3dB Beam Width $60^\circ - 67^\circ$ and Vertical 3dB Beam Width $6.2^\circ - 7.5^\circ$ [8]



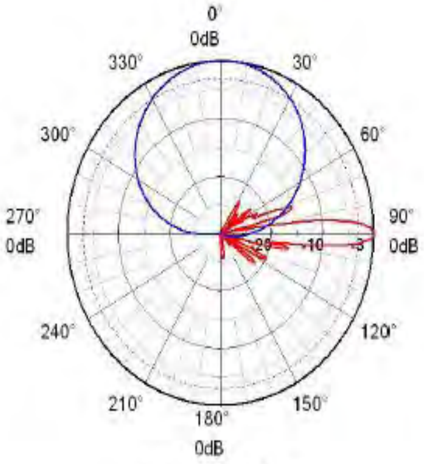
1710 - 2200 MHz

C. Triple Band(900MHz,1800MHz and 2100MHz)[8]

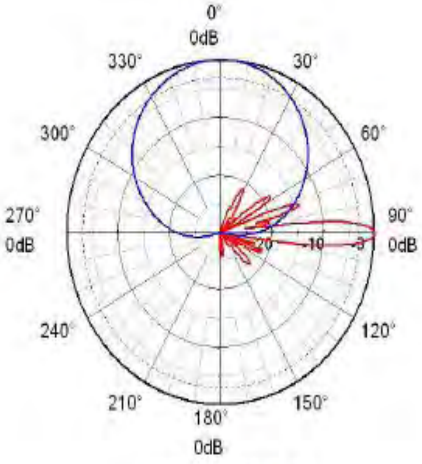
Radiation Pattern for Triple Band Antenna (790 – 960, 1710 - 2180 MHz Bottom and Top) of Ethiotelecom with Horizontal 3dB Beam Width $60^\circ - 69^\circ$and Vertical 3dB Beam Width $6.1^\circ - 8.4^\circ$ [8]



790 - 960 MHz



1710 - 2180 MHz
(Bottom)



1710 - 2180 MHz
(Top)

3.3 Technical Performance of Antennas Deployed in Ethitelecom Base Stations

3.3.1 UMTS Capacity in Addis Ababa

The entire network contains five Radio Network Controller (RNCs) and 725 Node Bs. It needs to support 1,499,456 subscribers and the average capacity is 2069 subscribers per site and the Traffic Usage in GB/Month/User is indicated as follow:

Traffic Usage in GB/Month/User	HSPA+		Voice
	Dongle	Smart Phone	SP
Traffic per user per month in GB	10	1	0.025 erl

Table 3.2 UMTS Cell Load Dimension Result

Bear	Cell Load	Traffic per subs	Active Subs/Cell	Total Subs/Cell
HSDPA + Voice	3.6 Mbps	23.5 Kbps	157	224
HSUPA + Voice	1.9 Mbps	10.1 Kbps	193	276

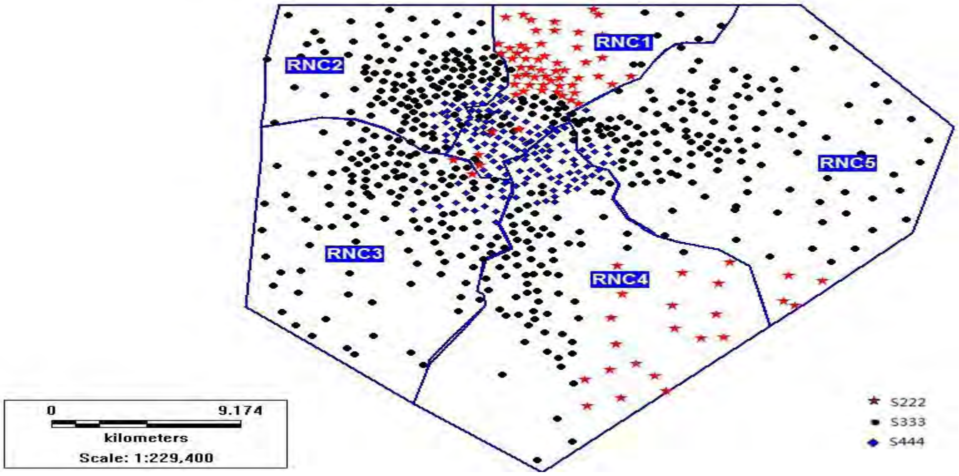


Figure 3.1 RNC Divisions [9]

Table 3.3 Distribution of Node Bs

RNC	Site Config	Site Qty	Cell Qty	Subs
111055.RNC_01.HW.ADTEL.NAAZ.AA	U2	2	4	896
	U222	54	324	72576
	U22222	1	10	2240
	U333	41	369	82656
	U444	54	648	145152
111051.RNC_02.HW.MWTEL.CAAZ.AA	U333	128	1152	256032
	U444	24	288	64512
111168.RNC_03.HW.KKTEL.SAAZ.AA	U222	2	12	2688
	U333	118	1062	237888
	U444	16	192	43008
111007.RNC_04.HW.NFTEL.SAAZ.AA	U222	19	114	25536
	U333	73	657	147168
	U444	46	552	123648
111136.RNC_05.HW.BLTEL.SAAZ.AA	U222	4	24	5376
	U333	134	1206	268128
	U444	9	108	24192
Total		725	6722	1499456

3.3.2 UMTS Coverage in Addis Ababa

For Addis Ababa, dense urban area (70.45 km^2) continuous coverage with 541,632 users, urban area (170.36 km^2) continuous coverage with 604,800 users and sub urban area (539.12 km^2) continuous coverage with 356,160 users using 722 UMTS BS.

Scenario	Dense Urban	Urban	Sub urban
Cell Radius (km)	0.19	0.42	1.11
Site Distance(km)	0.285	0.63	1.665

3.4 Performance Assessment Using Key Performance Indicators (KPIs)

3.4.1 Key Performance Indicators

The success of a network depends on its three factors: coverage, capacity and quality. Capacity is based on an assessment of dropped calls and congestion. Quality can be improved by eliminating interference from both external and internal sources.

A drive test shall be performed to assess capacity and coverage. The quality of the radio network depends on its coverage, capacity and frequency allocation. Most severe problems in a radio network can be attributed to signal interference, dropped calls and the amount of congestion.

Key Performance Indicators (KPIs) are a valuable tool for improving overall business operations. Key performance indicators in GSM, UMTS, and LTE are defined through the definition and measurement of key parameters of input and output of internal network system and/or maintenance & operation progress of mobile network operations.

Key Performance Indicators are a set of quantifiable measures used in GSM, UMTS, and LTE networks to gauge or compare performance in terms of meeting mobile network's strategic and operational goals. KPIs vary between management, marketing, operations and network engineering people depending on their priorities, perspectives or performance criteria sometimes referred to as "key success indicators (KSI)".

The KPIs are collected along with field measurements such as drive tests. For the field measurements, tools that can analyze the traffic, capacity, and quality of the calls, and the network as a whole are used. For drive testing, a test mobile is used. This test mobile keeps on making calls in a moving vehicle that goes around in the various parts of the network. Based on the DCR, CSR, HO, etc., parameters, the quality of the network can then be analyzed.

After the network is deployed and network initial tuning service completed, it needs to conduct the radio network optimization activities that comprise the following major phases:

- ✓ **Coverage and Interference**

Ensure satisfactory coverage performance in terms of sufficient Rx/RSCP and signal quality, and keep interference at a minimum level.

- ✓ **Accessibility**

To improve end-user‟s success rate of call access, e.g. increasing call setup success rate while reducing the call setup delay

- ✓ **Retainability**

To enhance the call retainability of which the performance can be quantified with KPIs such as call drop rate and handover success rate, etc.

- ✓ **Integrity**

To maintain the integrity of radio network elements with appropriate radio network design and engineering. The integrity of UTRAN/BSS can be measured with certain quality-related KPIs.

WCDMA KPI

- ✓ **Accessibility**
  Call setup Success rate (CS)
  Call setup Success rate (PS)
- ✓ **Retainablity**
  Ratio of CS Call Drop (%)
  Ratio of PS Call Drop (%)
- ✓ **Mobility**
  Ratio of SHO success (%)
  Cell Inter-RAT CS Outgoing Handover Success Rate (WCDMA–GSM)
  Cell Inter-RAT PS Outgoing Handover Success Rate (WCDMA–GSM)

3.4.2 UMTS Performance Analysis in Addis Ababa

I. CSSR AMR

Call Setup Success Rate Adaptive Multi-Rate (CSSR AMR) is one of the KPIs for analyzing the UMTS voice call performance regarding network accessibility. The bulk drive test data is conducted by Ethiotelecom using the drive test tools in the field which represent a true picture of network condition as per the output of Operational Support System (OSS) and the feedback gained from the users. The analysis for the KPIs shown from I to IV is carried out in this thesis selectively for the areas which have relatively poor performance in a one week period through referring the target KPI set by Ethiotelecom for the corresponding KPI parameters, in the case of CSSR AMR the target KPI is 98 while Cluster 10 is performing below the target KPI due to DL CE congestion.

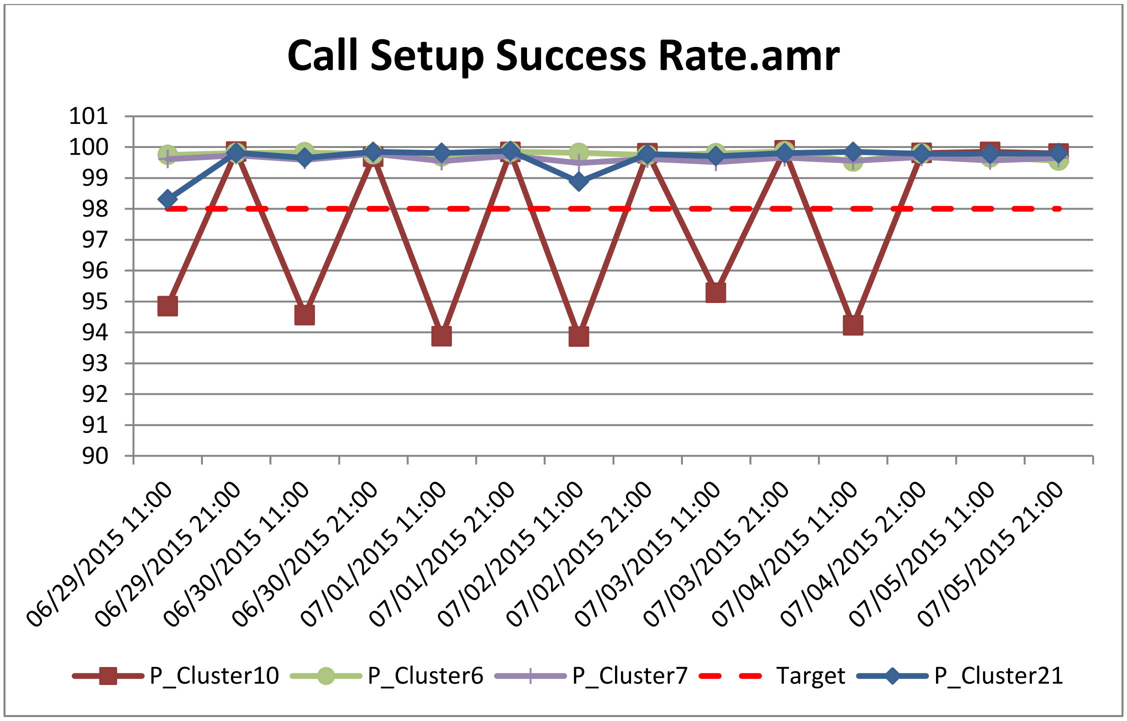


Figure 3.2 Call Setup Success Rate Adaptive Multi-Rate Performance

II. CSSR – HSDPA

Call Set up Success Rate High-Speed Downlink Packet Access (CSSR –HSDPA) is one of the KPIs for analyzing and evaluating the UMTS Packet Switched (PS) data interactive services performance regarding network accessibility. The target KPI set by Ethiotelecom for CSSR–HSDPA is 98 while as it can be seen on the underneath chart the performance of Cluster 5 and 20 is lower than the target KPI due to DL CE congestion.

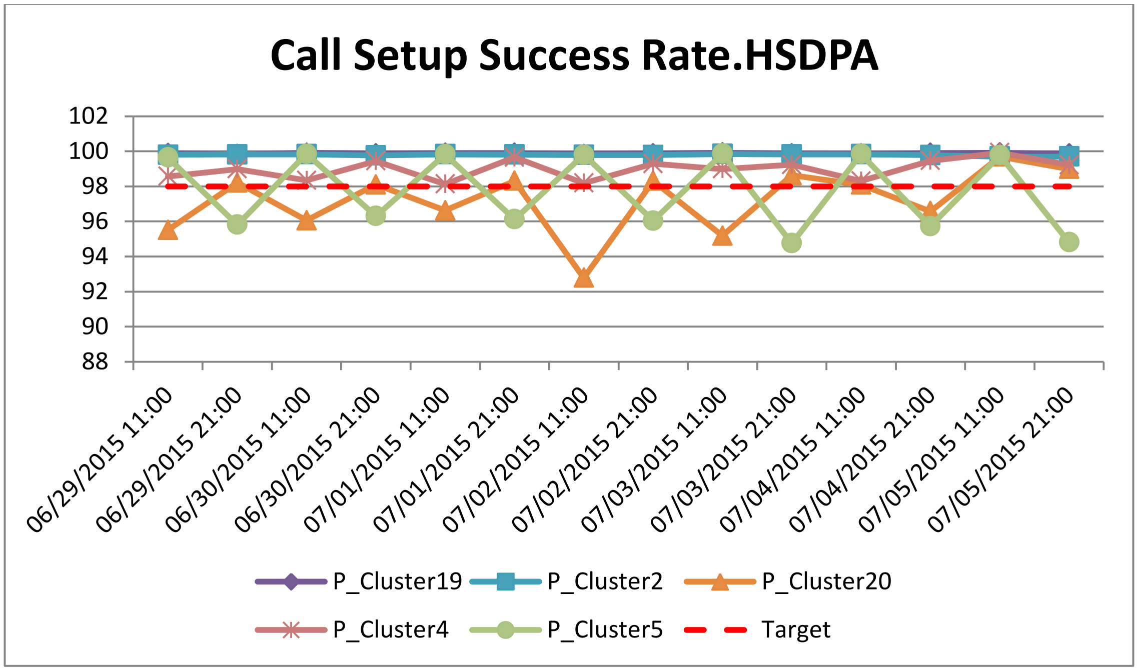


Figure 3.3 Call Set up Success Rate High-Speed Downlink Packet Access Performance

III. Call Drop Rate (CDR)

Call Drop Rate Adaptive Multi-Rate (CDR-AMR) is UMTS voice call retainability performance KPI parameter. The target KPI set by Ethiotelecom for this parameter is to be less than or equal to 0.6. However Cluster 15, 16, 17, and 18 are performing below the target KPI.

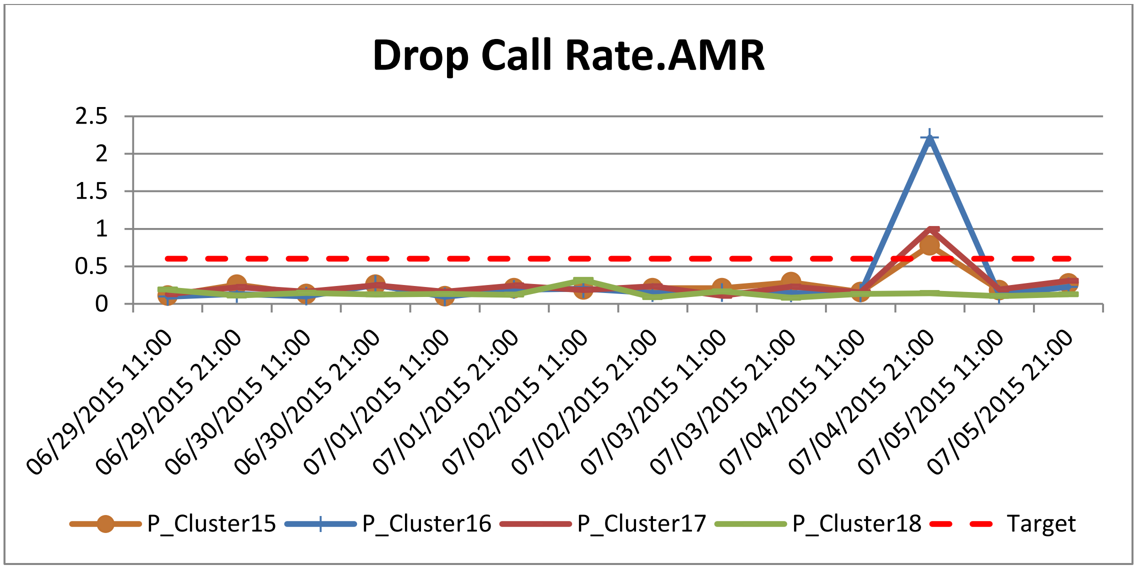


Figure 3.4 Call Drop Rate Adaptive Multi-Rate Performance

IV. 3G to 2G HO Success Rate

It is one of the KPIs to analyze and evaluate WCDMA–GSM mobility performance of the network in terms of Outgoing Handover Success Rate. The target KPI set by Ethiotelecom is needed to be 98 and above, however Cluster 2, 4, 5, 19 and 20 are performing below the target KPI due to 2G resource unavailability.

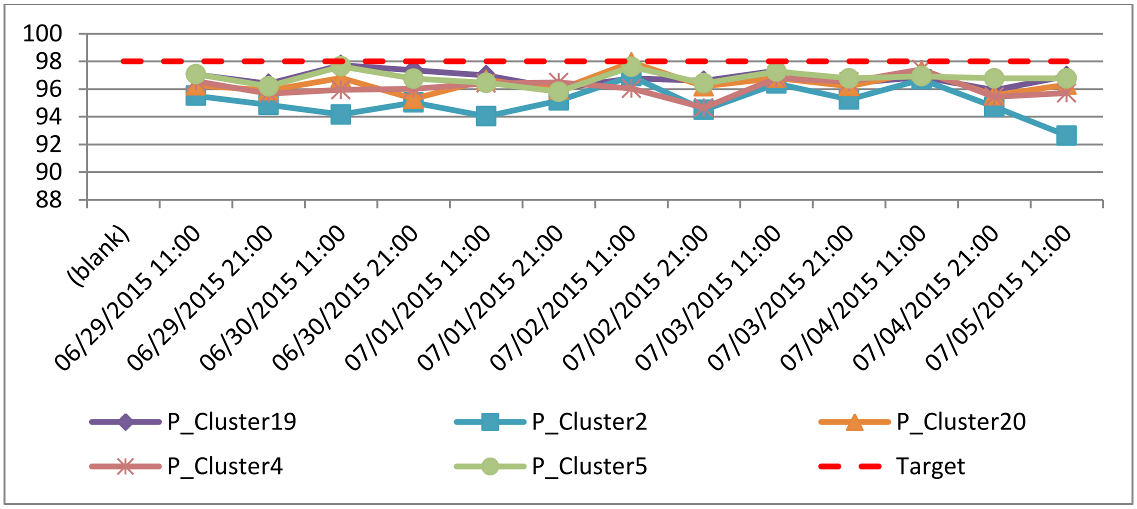


Figure 3.5 WCDMA–GSM Mobility Performance

Observations

Using the drive test data and Operation Support System (OSS) network output a root cause analysis is done to figure out the cause of performance limitation of the KPI parameters defined by Ethiotelecom which are listed hereunder. Accordingly a two stage solution is proposed and implemented by Ethiotelecom to optimize the network i.e. the first stage is adjusting the physical and logical parameters (Antenna Electrical and Mechanical tilt, Azimuth, Antenna height, Neighbor definition, etc.) of the radio network which is supposed to optimize coverage, Soft handover gain, interference reduction, signal overshooting and traffic issues. If the first stage does not work out, in the second stage a new site is proposed and deployed to optimize the network which significantly increase the network optimization cost.

- ✓ The accessibility performance drop on the different clusters on the above charts is due to Down Link Channel Element (DL CE) resource congestion on sites, from the drive test the following symptoms are observed i.e. received E_C/N_O of the pilot channel is less than -16dB, received RSCP of the pilot channel is high enough to maintain the connection, DL Received Signal Strength Indicator (RSSI) is very high and finally the connection drops.
- ✓ Call drop rate on Clusters 16 & 17 is due to RF reason, from the drive test it is found that the UE receives “Radio Resource Control (RRC) connection setup“ message and starts the transmission. However, the UE does not send out “RRC connection setup complete” message to the UTRAN.
- ✓ The mobility performance drop is mainly due to target 2G cell resource unavailability, one of the major symptoms observed: in the measurement report, which is sent from the UE after getting the “measurement control” from the UTRAN, the target cell is not in the active set.
- ✓ Poor coverage due to Received Signal Code Power (RSCP) coverage less than -90dBm and geographical issues and poor E_C/N_O related with pilot pollution in this phenomenon the User Equipment (UE) cannot firmly camp on a cell at one location because of receiving many pilot channels with similar quality (signal strength) hence the UE at one location frequently change its active set cells i.e. active set update rate is very high.

3.5 Conclusion

Though Ethiotelecom has recently deployed a telecom expansion project throughout Addis Ababa, the recent result of drive test and network performance analysis result shows that the current radio network has encountered the following major technical performance problems:

- ✓ Low CSSR and Location Update Success Rate are caused by SDCCH congestion
- ✓ Current sites distribution do not match with the real traffic distribution in which some sites have poor coverage due to RSCP coverage less than -90dBm
- ✓ High call drop rate on some cells due to traffic channel drop rate
- ✓ The mobility performance drop is mainly due to target 2G cell resource unavailability

Moreover the overall performance of the network is limited regarding capacity, coverage and quality of service, having examined these problems a smart antenna based base station system is proposed as an alternative solution to enhance the overall network performance in which its performance is investigated in the coming chapters.

Chapter 4: Performance of Smart Antenna Systems for Mobile Communication

4.1 Introduction

There is an ever increasing demand on mobile wireless operators to provide voice and high speed data services. At the same time, operators want to support more users per base station to reduce overall network cost and make the services affordable to subscribers. As a result, wireless systems that enable higher data rates and higher capabilities are pressing need. Unfortunately because the available broadcast spectrum is limited, attempts to increase traffic within a fixed bandwidth create more interference in the system and degrade the signal quality. While using the existing antennas at the base station, the transmission and reception of each users signal becomes a source of interference to other users located in the same cell, making the overall system interference limited.

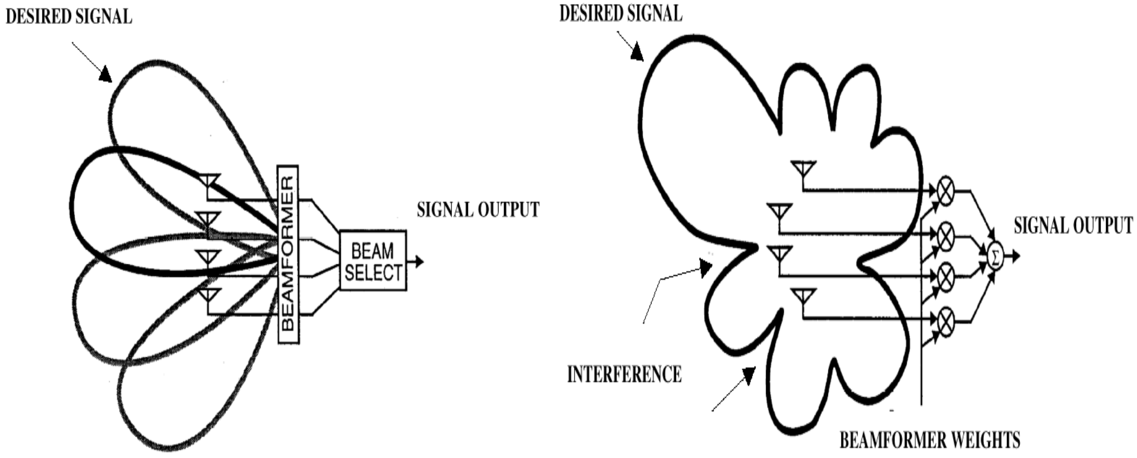
Wireless communication systems are evolving from the second generation systems to the third and fourth generation systems, which will provide high data rate multimedia services as video transmission. New value added services such as the position location (PL) services for emerging calls, the fraud detection, intelligent transportation systems, and so forth are also coming in to reality.

These concerns have led to propose the deployment of smart antenna systems throughout major cellular networks. Smart Antennas are arrays of antenna elements that change their antenna pattern dynamically to adjust to the noise, interference in the channel and mitigate multipath fading effects on the signal of interest.

Smart antenna systems are customarily categorized as either switched beam or adaptive array systems. That is, for the adaptive array, the beam pattern changes as the desired user and the interference move, and for the switched beam type, the beam is steered or different beams are selected as the desired user moves.

Switched beam antenna systems form multiple fixed beams with heightened sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams, and switch from one beam to another as demand changes throughout the sector. Instead of shaping the directional antenna pattern with the metallic properties and physical design of a single element (like a sectorized antenna), switched beam systems combine the outputs of multiple antennas in such a way as to form finely sectorized (directional) beams with more spatial selectivity than it can be achieved with conventional, single element approaches.

Adaptive antenna array systems is an array of multiple antenna elements with the received signals weighted and combined to maximize the desired signal to interference and noise (SINR) ratio. This means that the main beam is put in the direction of the desired signal while nulls are in the direction of the interference.



(A) Phased array

(B) Adaptive Array

Figure 4.1: (A) Phased Array and (B) Adaptive Array Smart Antennas [16].

4.2 System Elements of a Smart Antenna

4.2.1 Smart Antenna Receiver

Smart antenna reception part consists of four units. In addition to the antenna itself it contains a radio unit, a beam forming unit and a signal processing unit

Fig. 4.2 shows schematically the elements of the reception part of a smart antenna. The antenna array contains M elements. The M signals are being combined into one signal, which is the input to the rest of the receiver (channel decoding, etc.). The array will often have a relatively low number of elements in order to avoid unnecessarily high complexity in the signal processing.

The radio unit consists of down–conversion chains and (complex) analog-to-digital converters (A/D).There must be M down-conversion chains, one for each of the array elements.

The signal processing unit will, based on the received signal, calculate the complex weights $w_{1,}w_2, \dots w_M$ with which the received signal from each of the array elements is multiplied. These weights will decide the antenna pattern in the uplink direction. The weights can be optimized from two main types of criteria: maximization of received signal from the desired user (e.g. switched beam or phased array) or maximization of the SIR by suppressing the signal from interference sources (adaptive array).

The method for calculating the weights will differ depending on the type of optimization criterion. When switched beam (SB) is used, the receiver will test all the pre-defined weight vectors (corresponding to the beam set) and choose the one giving the strongest received signal level. If the Adaptive array approach is used, which consists of directing a maximum gain beam towards the strongest signal component, the direction-of-arrival (DOA) is first estimated and then the weights are calculated. When the beam forming is done digitally (after A/D), the beam forming and signal processing units can normally be integrated in the same unit (Digital Signal Processor, DSP).

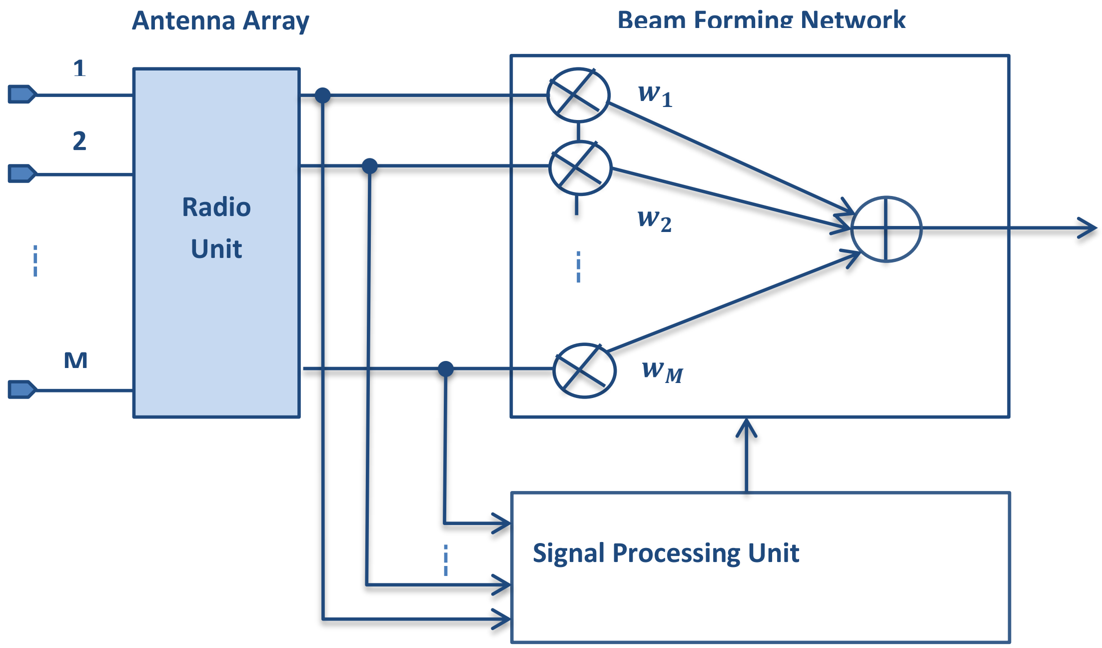


Figure 4.2: Reception Part of a Smart Antenna

4.2.2 Smart Antenna Transmitter

The transmission part of the smart antenna is schematically very similar to the reception part. The signal is split into *M* branches, which are weighted by the complex weights $w_{1,}w_2, \dots w_M$ in the beam forming unit. The weights, which decide the radiation pattern in the downlink direction, are calculated as before by the signal processing unit. The radio unit consists of D/A converters and the up converter chains. In practice, some components, such as the antennas themselves and the DSP will of course be the same as on reception.

The principal difference between uplink and downlink is that no knowledge of the spatial channel response is available on downlink. In a time division duplex (TDD) system the mobile station and base station use the same carrier frequency only separated in time. In this case the weights calculated on uplink will be optimal on downlink. If frequency division duplex (FDD) is used, the uplink and downlink are separated in frequency. In this case the optimal weights will generally not be the same because of the channel response dependency on frequency.

Thus optimum beam forming (i.e., AA) on downlink is difficult and the technique most frequently suggested is the geometrical approach of estimating the direction-of-arrival (DOA). The assumption is directional reciprocity, i.e., the direction from which the signal arrived on the uplink is the direction in which the signal should be transmitted to reach the user on downlink. The strategy used by the base station is to estimate the DOA of the direction (or directions) from which the main part of the user signal is received. This direction is used on downlink by choosing the weights $w_{1,}w_2,\dots w_M$ so that the radiation pattern is a lobe or lobes directed towards the desired user.

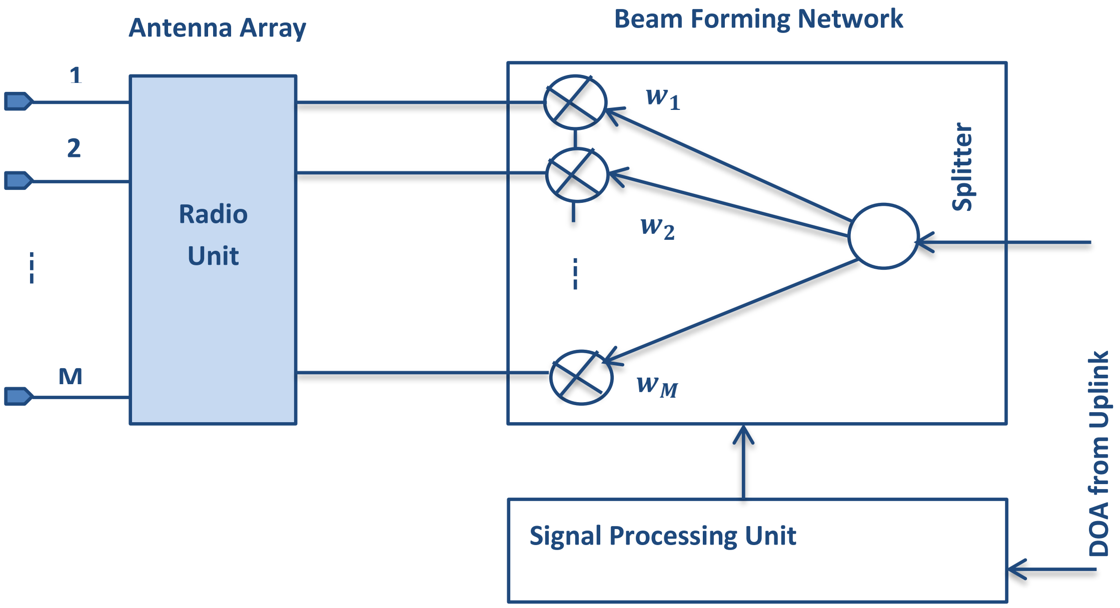


Figure 4.3: Transmission Part of a Smart Antenna

4.2.3 Fundamentals of Antenna Arrays

An antenna array has spatially separated sensors whose output is fed into a weighting network or a beam forming network. The antenna array can be implemented as a transmitting or a receiving array. There are many assumptions made in analyzing an antenna array, they are as follows:

- All signals incident on the receiving antenna array are composed of finite number of plane waves. These plane waves result from the direct as well as the multipath components.

- The transmitter and the objects that cause multi paths are in the far-field of the antenna array.
- The sensors are placed closely so that the amplitudes of the signals received at any two elements of the antenna array do not differ significantly.
- Each sensor is assumed to have the same radiation pattern and the same orientation.
- The mutual coupling between the antenna elements is assumed to be negligible.

An antenna array can be arranged in any arbitrary fashion, but the most preferred geometries are linear and circular geometries. Linear geometry is simpler to implement than the circular geometry, but the disadvantage is the symmetry (ambiguity) of the radiation pattern about the axis along the end fire, which is not the case in circular array. Linear array with uniformly spaced sensors is the most commonly used structure.

The array as shown in Fig. 4.4 has a reference element at the origin and the coordinates of the *m*th antenna element are marked as$(x_m y_m z_m)$. The signal as it travels across the array undergoes a phase shift. The phase shift between the signal received at the reference element and the signal received at the element *m* is given by

$$\Delta\gamma_m = \gamma_m(t) - \gamma_1(t) = -\beta\cos\varphi\sin\varphi - \beta y_m\sin\varphi\sin\theta - \beta z_m\cos\theta \ldots.(4.1)$$

Where $\beta = \frac{2\pi}{\lambda}$ is the propagation constant in free space

The reference plane is assumed to lie on $z = 0$. Since the distance between the transmitting and receiving antenna is larger than the distance between the heights of the receiving and transmitting antenna, a wave reaching the antenna array can be assumed to come along the horizon or with.$\theta = 90^0$ Therefore, the direction-of arrival (DOA) of each plane wave is described using only azimuth coordinate φ.

Since any variation in the array element height z_m does not affect the phase difference between the reference element and element *m*. Therefore, we may consider only *x* and *y* offsets from the reference element. Consider a transmitted narrowband signal in complex envelope representation

$$u_m(t) = A_m(t)e^{j\gamma_m(t)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots(4.2)$$

Where $A_m(t)$ is the magnitude and $\gamma_m(t)$ is the phase of the signal. The vector containing these signals is called the data or the illumination factor

$$u(t) = [u_1(t)u_2(t) \ldots \ldots u_M\ ] \ldots \ldots \ldots .(4.3)$$

A complex quantity $a_m(\varphi) = A_m$ is defined as the ratio between the signal received at the antenna element *m* and the signal received at the reference element when a plane wave is incident on the array and it is given by

$$a_m(\varphi) = e^{-j\beta(x_m \cos\varphi + y_{m} \sin\varphi)} \ldots \ldots (4.4)$$

If a single plane wave is incident on the antenna array, then

$$u_m(t) = u_1(t)a_m(\varphi) \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots . . (4.5)$$

The response of an antenna array to a traveling single plane wave coming at an angle *φ* is defined as the steering vector

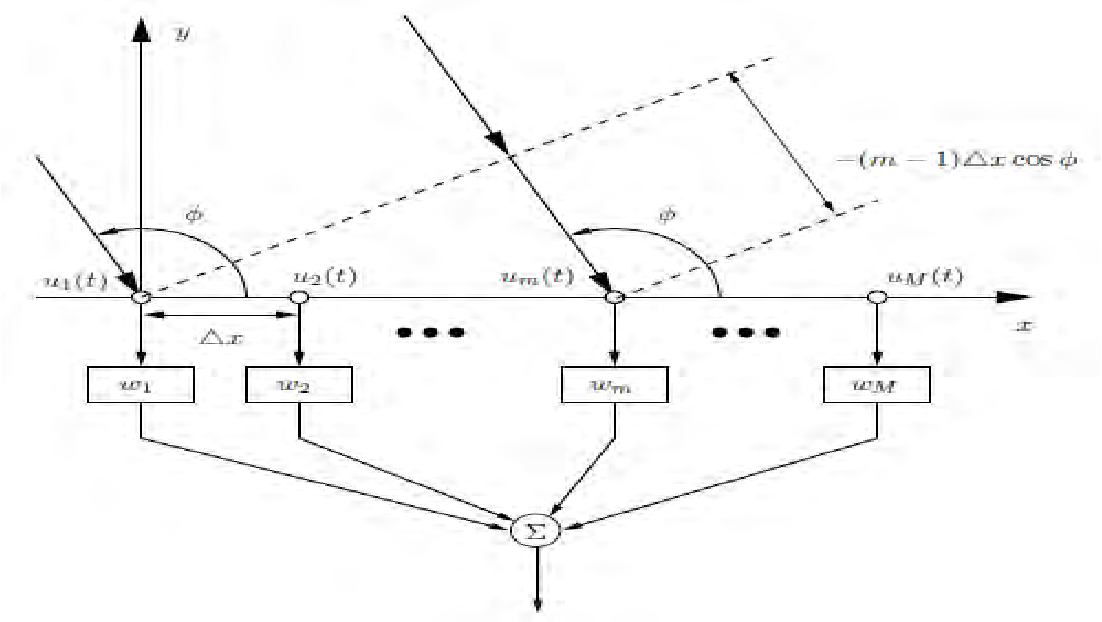


Figure 4.4: Illustration of the Coordinates of an Antenna Array [16]

$$a(\emptyset) = \begin{bmatrix} 1 \\ a_2(\emptyset) \\ \cdots \\ a_M(\emptyset) \end{bmatrix} = \begin{bmatrix} 1 \\ e^{-j\beta(x_2 \cos\emptyset + y_2 \sin\emptyset)} \\ \cdots \\ e^{-j\beta(x_M \cos\emptyset + y_M \sin\emptyset)} \end{bmatrix} \dots\dots\dots\dots\dots\dots(4.6)$$

The collection of the steering vectors for all angles for a given frequency is known as the array manifold. The array manifold must be carefully measured to calibrate the array for direction finding experiments. For narrowband adaptive beam forming, each array element output is multiplied by a complex weight $wi*$ modifying the phase and amplitude relation between the branches, and summed to give

$$v(t) = u_1(t) \sum_{m=1}^{M} w_m^* e^{-j\beta(x_2 \cos\emptyset + y_m \sin\emptyset)} \dots\dots\dots\dots\dots\dots\dots\dots\dots(4.7)$$

$$= [w_1^* w_2^* \dots . w_M^*] \begin{bmatrix} 1 \\ e^{-j\beta(x_2 \cos\emptyset + y_2 \sin\emptyset)} \\ \cdots \\ e^{-j\beta(x_M \cos\emptyset + y_M \sin\emptyset)} \end{bmatrix} u_1(t) = w^H u(t) \dots\dots(4.8)$$

The response of the array (uniform linear array of isotropic elements) with the weighting network is called the array factor and it"s defined as

$$AF(\emptyset) = \frac{v(\emptyset)}{max[v(\emptyset)]} = w^H a(\emptyset) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(4.9)$$

The weighting network in an antenna array can be fixed or varying. In an adaptive array, the weights are adapted by minimizing certain criterion to maximize the signal-to-interference plus noise ratio (SINR) at the output of the array.

4.3 Basics of DOA Estimation

Since most RF antennas amplifiers, mixers, filters and ADC technologies have reached a mature state, accurate estimation of the angle of arrival of signals impinging an array of antennas becomes the most important parameter regarding the performance of an adaptive array. Assuming a linear and isotropic transmission medium, multiple impinging wave fronts can be modeled as the superposition of these wave fronts impinging on the array. Signals received by individual antenna elements, are down converted to base band signal then they are digitized and fed into a digital signal processing (DSP) chip where the DOA estimation algorithm is executed. Once DOA is estimated then forming beam towards the desired users PL using a beam forming algorithm will be done.

A simple and widely adopted technique for DOA estimation is the MUltiple SIgnal Classification (MUSIC) algorithm, which exploits the Eigen structure properties of the array correlation matrix.

The method assumes that the noise at different antenna elements is uncorrelated. In general, the incident signals can be correlated, although the MUSIC algorithm becomes ineffective when this correlation becomes too high. When $n_{tx}(< N)$ directions must be estimated, the space spanned by the eigenvectors of Rxx can be partitioned in two orthogonal subspaces: the signal Subspace Vs and the noise subspace Vn. The signal subspace is generated by the eigenvectors associated to the n_{tx} largest eigenvalues of Rxx, while the noise subspace is spanned by the eigenvectors associated to the $V - n_{tx}$ smallest eigenvalues of Rxx. The n_{tx} DOAs are estimated by evaluating the maxima of the MUSIC pseudo spectrum:

$$\tilde{S}_{MUSIC}\,(\varphi) = \frac{1}{a^{H}(\varphi)V_n V_n^{H} a(\varphi)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (4.10)$$

Where $a(\varphi)$ is usually redefined, in the DOA estimation terminology, as scanning vector. When $\tilde{S}_{MUSIC}$ (φ) has a local maximum, its denominator has a local minimum and so this method estimates the direction of arrival by searching the most orthogonal scanning vectors $a(\varphi)$ to the noise subspace.

4.4 Beam Forming

Beam forming is the method used to create the radiation pattern of the antenna arrays by adding constructively the phase of the signals in the direction of desired targets and nulling the pattern of undesired targets. In Beam forming, both the amplitude and phase of each antenna elements are controlled. Combined amplitude and phase control can be used to adjust side lobe levels and steer nulls better than can be achieved by phase control alone. Beam forming in a smart antenna array makes use of a number of individual antennas and associated signal processors to create a desired transmission radiation patter. The major benefits to using a smart, active antenna system come from a reduction in overall system power, reduction in communication interference, increase in system capacity and increase in power efficiency.

Beam forming techniques can be subdivided in two main groups: fixed beam forming and adaptive beam forming. In the first case the interference is mitigated but not suppressed and the system can be usually realized at a reasonable cost. Adaptive antennas, instead, require the adoption of complex signal processing algorithms in order to steer the main lobe towards the desired direction and to suppress the undesired sources. This second approach leads to optimal performance, but is more expensive and needs considerable implementation efforts.

4.4.1 Switched Beam Forming

Switched beam antenna systems form multiple fixed beams with heightened sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams and switch from one beam to another as the mobile moves throughout the sector. Instead of shaping the directional antenna pattern with the metallic properties and physical design of a single element, switched beam systems combine the outputs of multiple antennas in such a way as to form finely directional beams with more spatial selectivity than can be achieved with conventional, single-element approaches.

Fixed beam forming does not perform the amplitude weighting of the received signals and can be realized adopting either an analog approach (e.g. switched beam, delay and sum) or a digital approach (e.g. beam-space beam forming).

Beam-space is a fixed beam forming technique that adopts a digital approach. Rather than directly weighting the signals incoming on the array elements, the antenna outputs can be first processed in order to produce a set of orthogonal multiple beams

Assuming the use of N elements with inter element spacing *p1*, the generic component of the array weight vector has the form:

$$e^{-j\frac{2\pi}{\lambda}\rho_1 k \sin \varphi k'}, \quad k = 0, \ldots., N-1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.11)$$

Where the set of directions is selected according to:

$$\sin \varphi k' = \frac{k'\lambda}{N\rho 1}, \qquad k = 0, \ldots., N-1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.12)$$

Substituting the above two equations, one obtains a generic Discrete Fourier Transform (DFT) element:

$$W_{K'K} = e^{-j2\pi\frac{k'k}{N}}, \qquad k' = 0, \ldots..N-1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.13)$$

The DFT outputs x = DFT*N*[x] correspond to *N* orthogonal directions that can be further processed (selected and weighted in phase) to provide the final desired output.

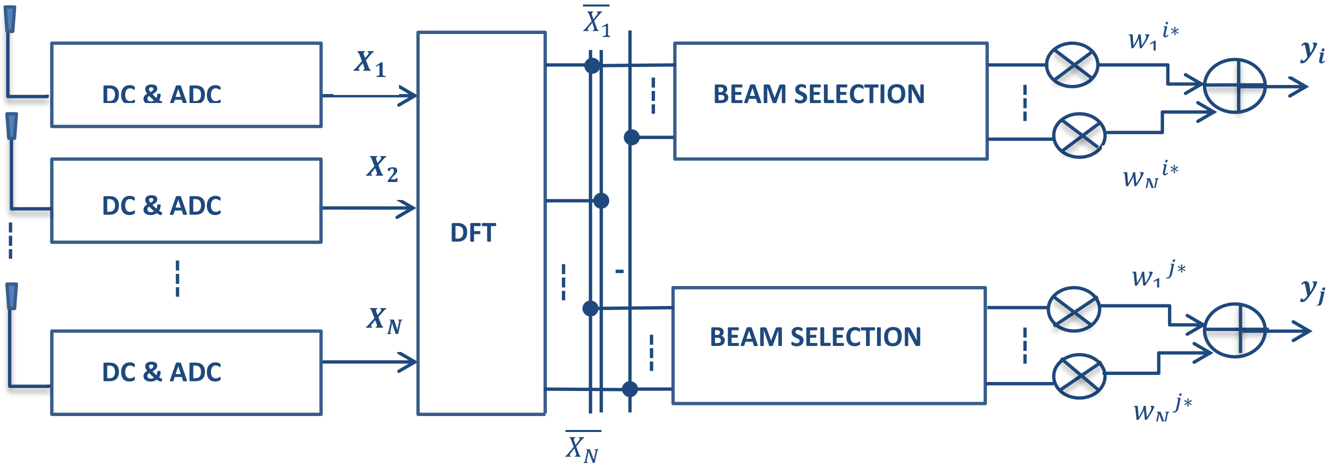


Figure 4.5: Beam-Space Beam Forming

4.4.2 Adaptive Beam Forming

Adaptive Beam forming is a technique in which array of antennas is used to achieve maximum reception in a specified direction while forming nulls in the directions of the interfering signal. The weights are computed and adaptively updated in real time based on signal samples. The adaptive process permits narrower beams in look direction and reduced output in other directions, which results in significant improvement in Signal to Interference Noise Ratio.

The core of smart antenna is the selection of smart algorithms in adaptive array. These algorithms use different criterion to adapt the system for better performance and steer the beam towards signal of Interest. An algorithm with less complexity, low computation costs, good convergence rates usually preferred. There are three main criteria for adaptive beam former design: maximal signal-to-interference-plus-noise ratio (MSINR), minimal mean-squared error (MMSE), and minimal least-squares error (MLSE).

There are different techniques for different applications among this, Constant modulus algorithm (CMA) kind of blind algorithms that does not require synchronization and least mean square (LMS) kind of non-blind algorithms which require a training sequence of known symbols to train the adaptive weights are presented for adaptive beam forming. These algorithms are embedded in smart antenna which calculates optimum weight vector that minimizes the total received power except the power coming from desired direction. The efficiency of CMA and LMS algorithms is compared on the basis of gain versus angle and mean square error (MSE) for mobile communication. Simulation results [11]-[13] reveal that both algorithms have high resolution for beam formation. However CMA has good performance to minimize MSE as compared to LMS. Therefore, CMA is found more efficient algorithm to implement in the mobile communication environment to enhance service quality and capacity.

Consider a smart antenna system with *Ne* elements equally spaced (*d*) and user‟s signal arrives from desired angle Φ_0. Adaptive beam forming scheme that is CMA and LMS is used to control weights adaptively to optimize signal to noise ratio (SNR) of the desired signal in look direction Φ_0. CMA is a kind of blind algorithm which doesn‟t require training signals for its guidance therefore a lot of energy is conserved whereas LMS is a non-blind algorithm requires training signals, known in advance by the receiver, to train the adaptive weights for convergence.

The array factor for elements (*Ne*) equally spaced (*d*) linear array is given by

$$AF(\Phi) = \sum_{n=0}^{N-1} A_n . e^{\left(jn\left(\frac{2\pi d}{\lambda} \cos\Phi + \alpha\right)\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4.14)$$

Where α is the inter element phase shift and is described as:

$$\alpha = \frac{-2\pi d}{\lambda_0} \cos\Phi_0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.15)$$

And Φ_0 is the desired direction of the beam

1. Constant Modulus Algorithm

CMA is a blind algorithm, based on the idea to reduce systems overhead and maintain gain on the signal while minimizing the total output energy. As a result number of bits for transmitting information is increased that leads to enhance capacity. This algorithm seeks for a signal with a constant magnitude i.e. modulus within the received data vector and is only applicable for modulation scheme which uses symbol of equal power includes phase and frequency modulated signals. The received data vector consists of desired signal plus interference and noise. Therefore, it can identify only one signal usually; this is the signal with greatest power.

Consider a signal of magnitude α within the received data vector *X.* The output of smart antenna array is given by

$$y = w^H X \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.16)$$

The function $f(w)$ with parameters *p* and *q* is given by [4].

$$f(w) = E|\,|y\,|^p - |\alpha\,|^p|^q \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.17)$$

Putting the value of *y* in the above equation, then we have

$$f(w) = E\|w^H X\,|^{\,p} - |\alpha\,|^{\,p}\,|^{\,q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4.18)$$

To minimize the function $f(w)$ for the development of CMA algorithm and setting α=1, *p* =1 and *q* =2, is calculated as:

$$f(w) = E\|w^H X\,|^{\,1} - |1\,|^{\,1}\,|^{\,2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4.19)$$

$$f(w) = E\|\;y\,|\;\; - 1\,|^{\,2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(4.20)$$

Differentiate equation (4.20) w.r.t. *w;* we get the performance cost function as

$$\nabla f = 2\frac{\partial f}{\partial w^*} = 2|y\,| - 1\,X\frac{y}{|y\,|} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots(4.21)$$

The weight update equation for this case becomes

$$w_{n+1} = w_n - 2\mu\left(y - \frac{y}{|y\,|}\right)X_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4.22)$$

Where μ represents the rate of adaptation, controlled by the processing gain of the antenna array. If a large value of μ is taken then convergence becomes faster but makes the array system unstable/noisy. Conversely if a small value is taken then convergence becomes slow that is also not desirable. Therefore, value of μ is taken in between that satisfy the following conditions for good convergence and to avoid instability.

$$0 \le \mu \le \frac{2}{\lambda_{max}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.23)$$

Where λ_{max} is the largest Eigen value of autocorrelation matrix of received data vector *X*

2. Least Mean Square Algorithm

LMS is non-blind algorithm which requires a training sequence of known symbols $d\,(n)$, to train the adaptive weights. It uses the estimate of the gradient vector from the available data. This algorithm makes successive corrections to the weight vector in the direction of the negative of the gradient vector which finally concludes to minimum MSE. This successive correction to the weight vector is the point at which optimum value W_0 is obtained that relies on autocorrelation matrix R and cross correlation matrix p of the filter [4].

$$y(n) = w^T(n-1)u(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.24)$$

$$e(n) = d(n) - y(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.25)$$

$$w(n) = w(n-1) + \mu e(n)u^*(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.26)$$

$$\xi = E[e^2(n)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.27)$$

$$\xi = E\left[\left(d^2(n)\right)\right] - 2w^Tp + w^TRw \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.28)$$

Where $y(n)$ is the filter output, $u(n)$is the input signal, $e(n)$ is the error signal between filter output and desired signal $d(n)$ at step n. $d(n)$ is the training sequence of known symbols (also called a pilot signal), is required to train the adaptive weights. Enough training sequence of known symbols must be available to ensure convergence but it is important to realize that training signal represents wasted of resources in terms of energy and time. The weight $w(n)$ is the update function for the LMS algorithm, where μ is the rate of adaptation, controlled by the processing gain of the antenna array. The convergence conditions imposed on step size μ is given by:

$$0 \leq \mu \leq \frac{1}{\lambda_{max}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.29)$$

Where λ_{max} is the largest Eigen value of autocorrelation matrix R. The rate of adaptation (μ) must select within bounded conditions as defined in (4.29) to ensure better convergence.

ξ is the performance cost function describing quadratic function of filter tap-weight vector w in terms of MSE. R is the autocorrelation matrix of filter input and is given by

$$R = E[u(n)u^T(n)] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (4.30)$$

And p is the cross correlation matrix between input and desired signal and is defined by

$$p = E[u(n)d(n)] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (4.31)$$

Solving equation (4.28) for optimum solution, we have:

$$w_0 = pR^{-1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (4.32)$$

w_0 is the optimum value of the weight vector $\mathrm{w(n)}$ after successive corrections

4.5 Simulations and Results

1. CM Algorithm Simulation

An adaptive array is simulated in MATLAB using Constant Modulus Algorithm (CMA). The simulation is done with a relatively low system noise, which is Gaussian noise with $\boldsymbol{\sigma = 0.1}$. The interference signals are Gaussian white noise, zero mean with $\boldsymbol{\sigma = 1}$. The extra system noise to all antennas is white noise with zero mean and $\boldsymbol{\sigma = 0.1}$. The received signals are MSK signals with an oversampling of 4 and amplitude of 1 in the simulations. The signals of the interferers arrive at an angle of –10 and –40 degrees. The signal to be received arrives at an angle of 10 degrees. Figure 4.6 shows the amplitude response of the adaptive array, where both interferers are rejected. The advantage of the CM algorithm is the fact that it only needs the instantaneous amplitude of the array output |y (n)| and therefore no synchronization is required. Due to this property, the CM algorithm is relative simple to implement. Figure 4.7 shows Phase and Magnitude of the Desired Signal (blue dash line) and CMA Output (solid red line) and the error between the desired signal and array output (blue solid line).

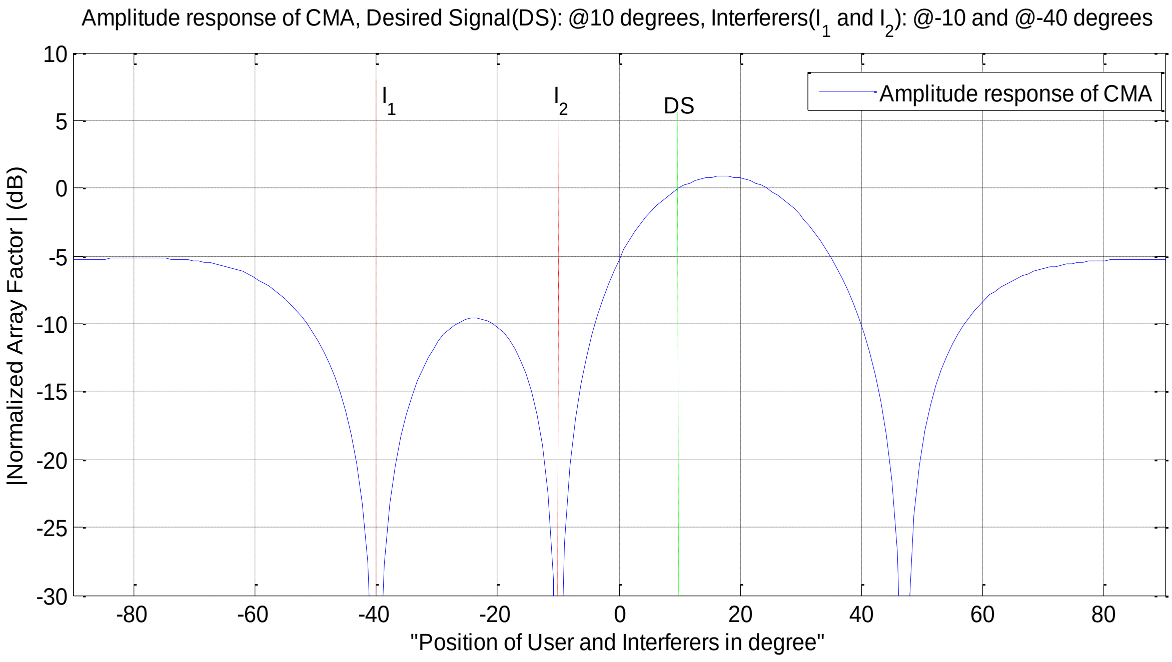


Figure 4.6: Amplitude Response after Beam Forming Using CMA

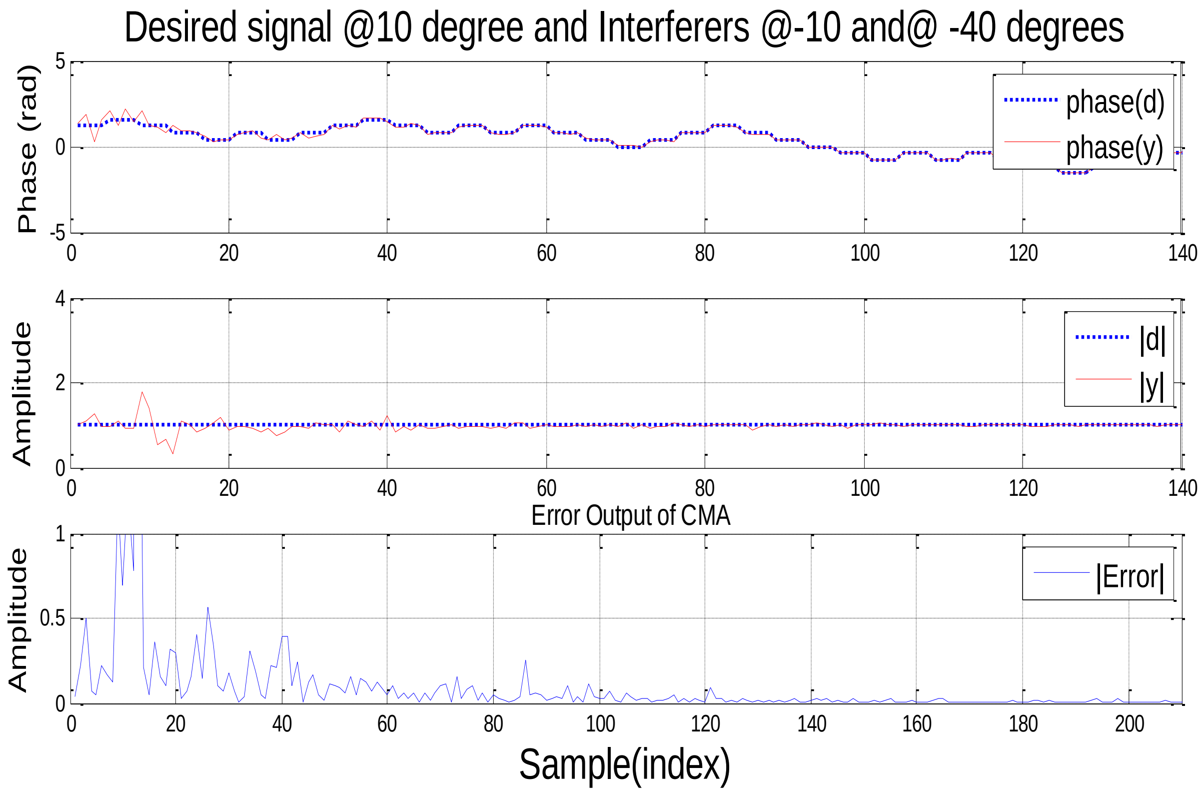


Figure 4.7: CM Algorithm (Phase, Magnitude and Error of the Desired Signal and CMA Output) for an Adaptive Array with 4 Antennas and 2 Interferers

2. LMS Algorithm Simulation

An adaptive array is simulated in MATLAB by using the LMS algorithm. When an array of 4 antennas is used with a separation of λ/2 (λ is wavelength), there is a maximum of 3 nulls that can eliminate the interferer. The interference signals are Gaussian white noise, zero mean with $\boldsymbol{\sigma} = \mathbf{1}$. The extra system noise to all antennas is white noise with zero mean and $\boldsymbol{\sigma} = \mathbf{0.1}$. The minimum error is a result of the extra „system" noise that is added to all antennas. The received signals are MSK signals with an oversampling of 4 and have amplitude of 1 in the simulations. The signals of the interferers arrive at an angle of 0 and –40 degrees. The signal to be received arrives at an angle of 25 degrees.

The true array output y (t) is converging to the desired signal d (t) as it can be seen in Fig 4.9. The LMS algorithm require that the reference vector d (n) is synchronized with the array output y (n). After 40 samples the signal is at its minimum due to the system noise. The LMS cannot filter the system noise, as it is not correlated for all four antennas. The resulting array vector has an amplitude response as shown in Figure 4.8. The interferers are cancelled by placing nulls in the direction of the interferers. The received signal arrives at an angle of 25 degrees. Figure 4.9 shows Phase and Magnitude of the Desired Signal (blue dash line) and LMS Output (solid red line) and the error between the desired signal and array output (blue solid line).

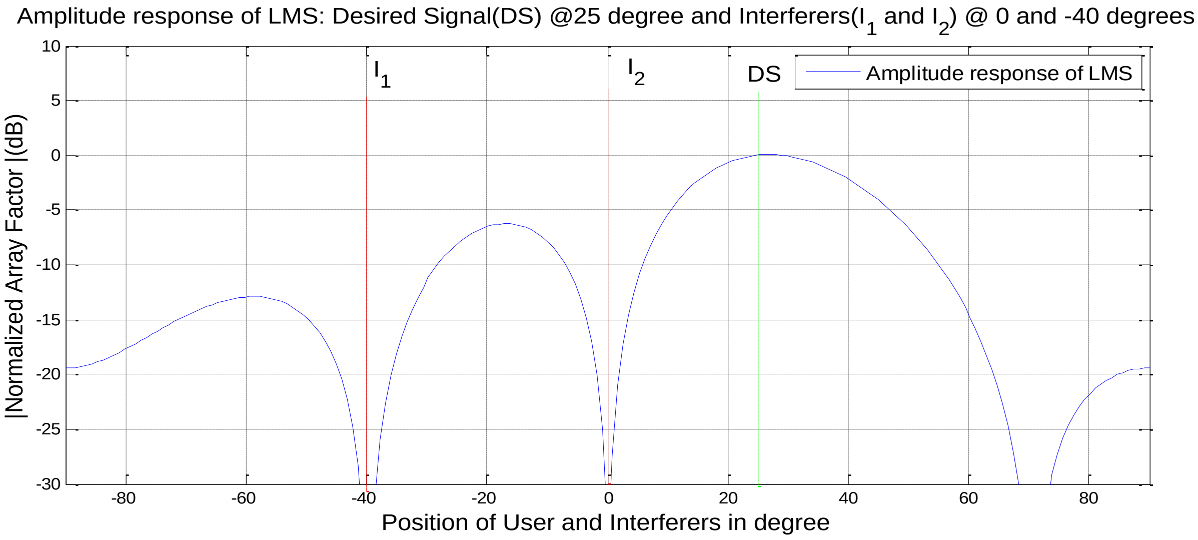


Figure 4.8: Amplitude Response after Beam Forming using LMS Algorithm

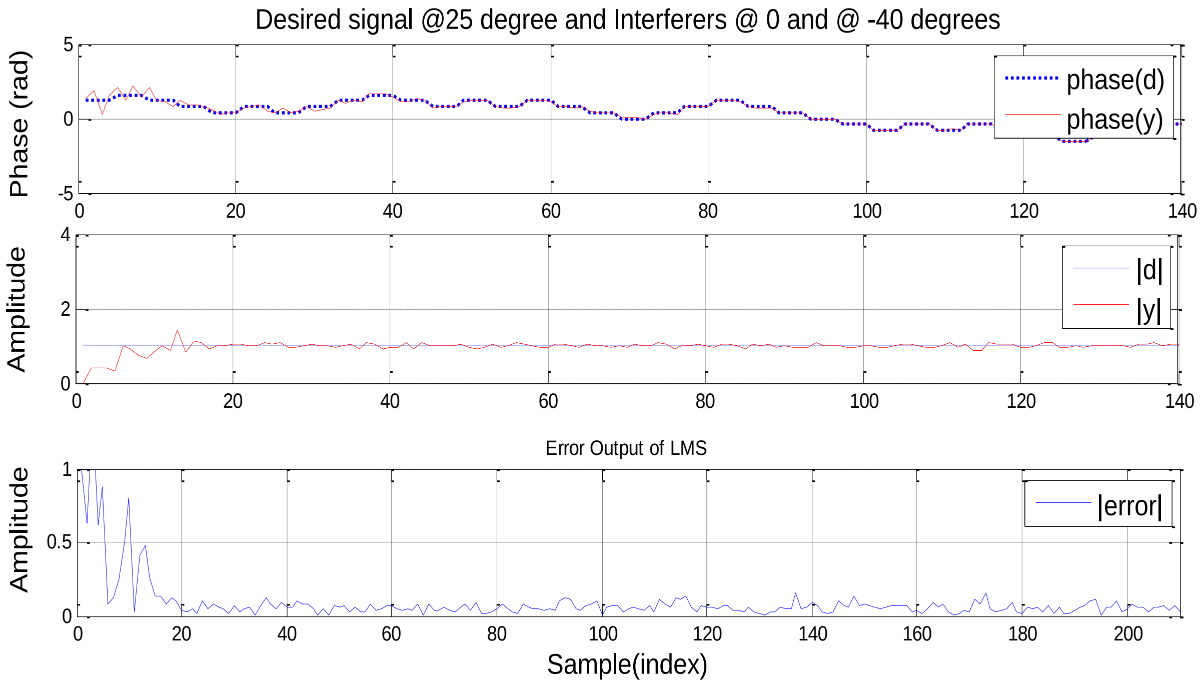


Figure 4.9: LMS Algorithm (Phase, Magnitude and Error of the desired signal and LMS output) for an Adaptive Array with 4 Antennas and 2 Interferers

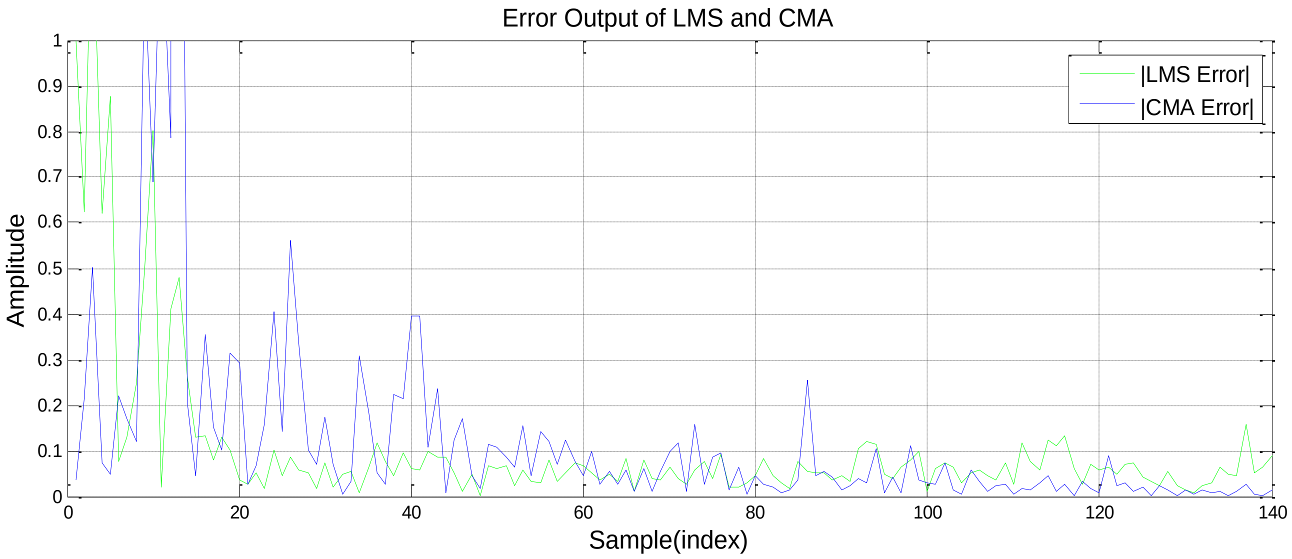


Figure 4.10 Error Output Comparison of LMS and CMA

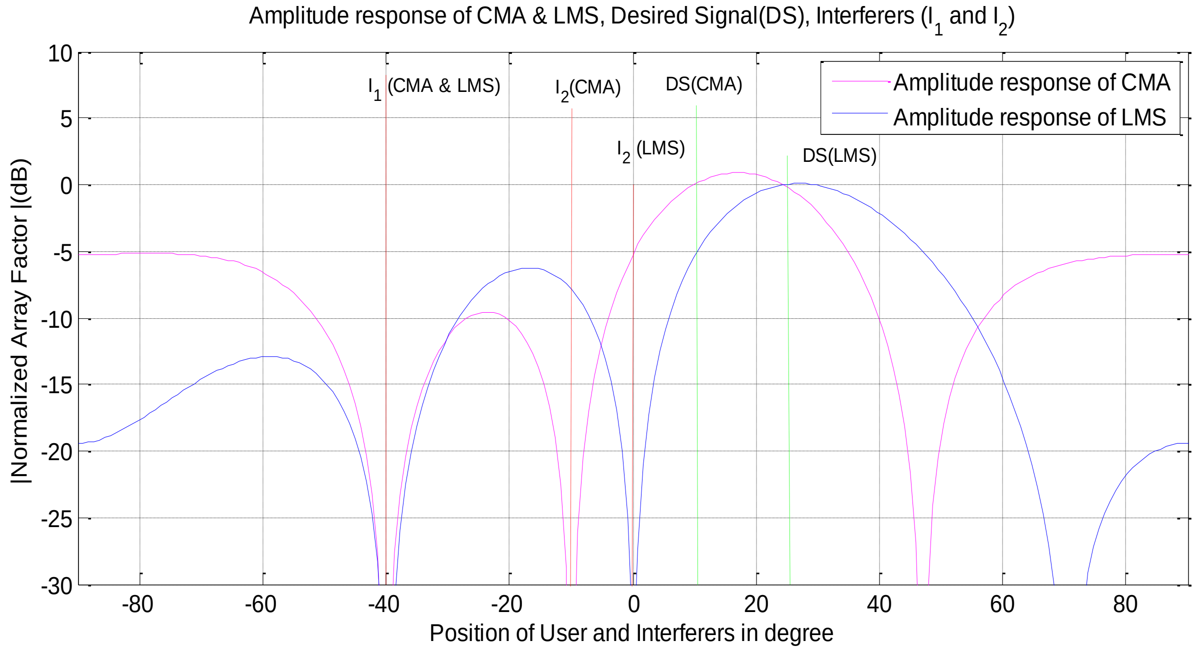


Figure 4.11 Amplitude Response Comparisons of LMS and CMA

3. Results and Discussions

There are different adaptive beam forming techniques for different applications among this, Constant Modulus Algorithm (CMA) kind of blind algorithms that does not require synchronization and Least Mean Square (LMS) kind of non-blind algorithms which require a training sequence of known symbols to train the adaptive weights are presented and simulated in this thesis work from the two different categories of adaptive beam forming techniques. These two algorithms are selected for further analysis in view of the aim of this thesis work and because of their better performance for mobile communication application than other adaptive algorithms [11]-[13].

Simulation is carried out for both algorithms with 4 antenna array elements and 2 Gaussian Interferers of zero mean with $\boldsymbol{\sigma = 1}$ and extra system noise with zero mean and $\boldsymbol{\sigma = 0.1}$ to all antennas. The received signals are MSK signals with an oversampling of 4 and amplitude of 1. The amplitude response after beam forming using CMA is simulated in Fig. 4.6 for a user located at 10° and Interferers located at -10° and -40° and in Fig. 4.8 the amplitude response after beam forming using LMS is simulated for a user located at 25° and Interferers located at 0°

and-40°, In the simulation the green line corresponds to the location of the desired Signal (DS) and the red lines correspond to the interferers (I_1 and I_2).

As can be seen from the simulation results in Fig. 4.6 and Fig 4.8, both algorithms can produce and steer strong main beam in the direction of the desired signal and place nulls to the directions of undesired interferers, considerably improve the SINR, that leads to optimum system performance.

However, it is ascertained from the simulation results as it can be seen in Fig. 4.10 and Fig.4.11 that LMS has better response towards the interference and it has faster convergence rate but this increase in convergence rate is obtained at the cost of increased computational complexity while the performance of CMA is better in forming much stronger main beam in the direction of the intended user, it also has less computational complexity while it maintain significant interference rejection capability. The performance of CMA is better to minimize MSE for different number of elements using performance cost function of the algorithm that minimized the average power in the error signal as compared to LMS algorithm which shows some deficiency to minimize MSE taking same number of iteration and elements.

Therefore, Constant Modulus Algorithm (CMA) which has the following features is a better option to implement at the base station of mobile communication systems: form a better radiation pattern, can reduce system overhead as it doesn‟t require pilot signal, less computational complexity which implies less cost and ease of implementation, avoid interference and optimize capacity.

Chapter 5: Business Case Analysis of Conventional Antennas and Smart Antenna Based Base Stations

5.1 Introduction

3G networks and services are launched all over the world. The basic investments on equipment have already been done according to preliminary traffic forecasts. However, if the mobile data traffic acquires “internet-like” proportions, network capacity shortage will become a reality in densely populated areas, such as city centers and business parks. In that case smart antennas may be the solution. Based on this assumption the financial aspects of the deployment of smart antenna systems in the 3G UMTS networks have been evaluated.

Furthermore, enabling new and better services in a cost effective manner is a main goal for mobile operators. In order to achieve this goal by the introduction of 3G technologies, e.g. UMTS the posed problems such as network capacity shortage must be solved by the operators. Adding more base station sites is not the most efficient means of solving the capacity shortage, coverage and QoS (Quality of Service) problems. Traditional cell splitting with more sites could also reduce the throughput per site due to complex management of co-channel interference. Smart antenna systems (SAS) may be the answer as the primary advantages of using smart antennas in wireless networks is to increase the number of voice calls and the amount of data throughput, to avoid interference and to ease network management.

5.2 Range-Coverage Extension

The coverage area is simply the area in which communication between a mobile and the base station is possible. Range extension is a means of increasing coverage area. Smart antennas employ collection of individual elements in the form of an array, so, they give rise to narrow beam with increased gain when compared to conventional antennas using the same power. The array gain is the average increase in signal power at the receiver due to a combination of the signals received at all antenna elements. The gain provided by adaptive antenna array is proved to provide an extension in a communication range that depends on the number of array elements. The goal of smart antenna is to receive in the uplink as much power as possible from the desired mobile station. In the downlink as much power as possible has to be transmitted into the direction of the desired mobile station.

During using smart (adaptive) antenna array of M elements the signal amplitude increases (M) times because the desired signal received at each antenna element is phase-shifted due to weight coefficient, and then the signal components from each element are positively combined.

The gain provided by smart antennas can extend the range of a cell to cover a larger area and more users than would be possible with sector antennas. The interference-rejection capability of the smart antenna system provides significantly more coverage than sectorized antennas as it can direct its beam in the direction of the user of interest.

Power Exponent Radio Wave Propagation Model

In planning cell coverage area the goal is to estimate the electric field strength of the transmitted signal at the receiver end (perimeter of coverage area). Friis transmission equation relates the power received to the power transmitted between two antennas separated by distance large enough for each antenna to be in the far field region of the other. This equation is given as,

$$\frac{P_r}{P_t} = (\frac{\lambda}{4\pi d})^2 G_t G_r \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(5.1)}$$

The power exponent model is also used to predict the power transfer between a transmitter and a receiver in different environments.

The received power (P_r) at distance (d) from the transmitting antenna can be expressed with respect to the power measured at a certain standard reference distance (do), i.e. the reference power $P_r(d_0)$

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^{\gamma} \quad \text{for } d > \ d_0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..\dots..\text{(5.2)}$$

The signal loss (L_p) at distance (d) from the transmitting antenna can be expressed as [6]:

$$L_p(d) = L_p(d_0)\left(\frac{d_1}{d_0}\right)^{\gamma} \quad \text{for } d > \ d_0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots (5.3)$$

Power exponent model is used to derive the approximate relationship of coverage area to antenna gain (G). The array gain (G) is the average increase in signal power at the receiver due to combination of the signals received at all antenna elements. It is proportional to the number of antennas. For an array of M antenna elements, the resultant beam gain is:

$$(Array\ Gain\ )_{dB} = G = 10\log M \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.4)$$

If for a single antenna the highest permissible attenuation level (path losses) is achieved at the distance (d_1) from the base station, then after application of smart (adaptive) antenna array the same attenuation is achieved at the distance (d_2), where

$$L_p(d_2) = L_p(d_1) + G \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5.5)$$

$$L_p(d_0) + 10\log(\frac{d_2}{d_0})^{\gamma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.6)$$

$$= L_p(d_0) + 10\log(\frac{d_1}{d_0})^{\gamma} + G \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.7)$$

$$G = \ 10\log(\frac{d_2}{d_0})^{\gamma} - \ 10\log(\frac{d_1}{d_0})^{\gamma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.8)$$

$$G = \ 10\log(\frac{d_2}{d_0}.\frac{d_0}{d_1})^{\gamma} = \ \log(\frac{d_2}{d_1})^{10\gamma} \ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots...(5.9)$$

From the logarithm definition and assuming that the value of γ is equal to 4 for urban environment, it can be written as [6]:

$$10^{G} = (\frac{d_2}{d_1})^{40} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots.(5.10)$$

$$10^{\frac{G}{40}} = \left(\frac{d_2}{d_1}\right) = \rho \ = Range\ Extension\ Factor \ldots\ldots\ldots....(5.11)$$

$$\log\rho = 0.25\log M = \log M^{0.25} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5.12)$$

The additional gain results in extending the range (area) of the cell.

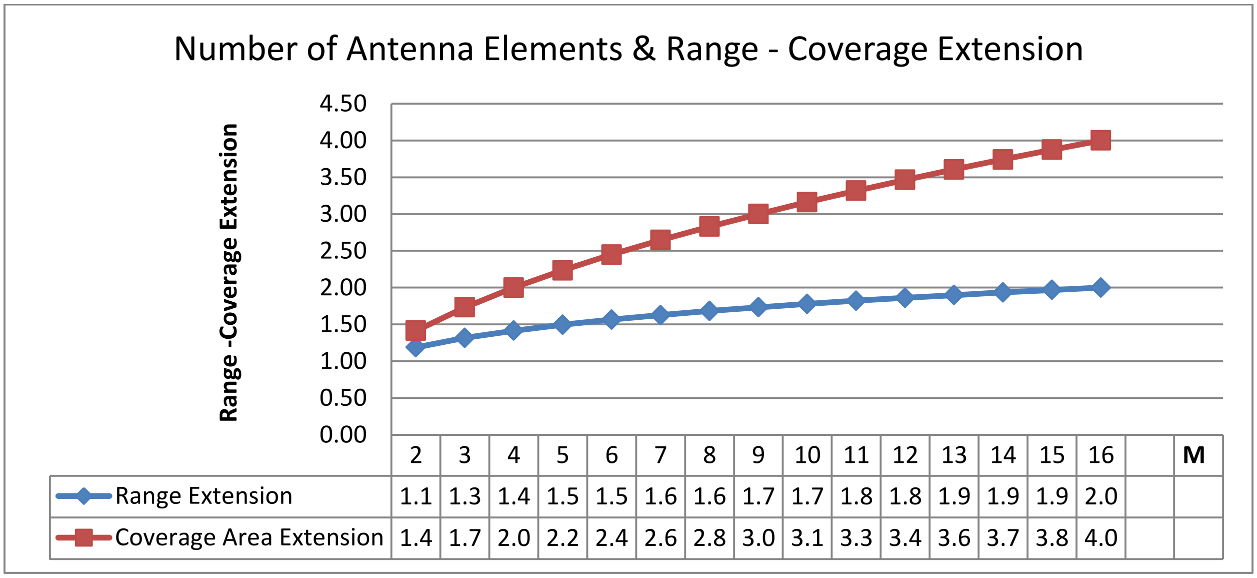
$$\rho = \left(\frac{d_2}{d_1}\right) = M^{0.25} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.13)$$

$$A_2 \;=\; A_{sma} \;= \pi(d_2)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots (5.14)$$

$$A_1 \;=\; A_{3sec} \;= \left(\frac{1}{3}\right)\pi(d_1)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5.15)$$

$$\left(\frac{A_2}{A_1}\right) = 3\left(\sqrt{M}\,\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5.16)$$

Range extension is suited to rural areas, where the user density is low and it is desirable to cover as much area with as few base stations as possible. As it can be seen in Fig. 5.1 the mobile communication range and coverage increases as the number of antenna elements increase.



	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		**M**
Range Extension	1.1	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	1.9	2.0		
Coverage Area Extension	1.4	1.7	2.0	2.2	2.4	2.6	2.8	3.0	3.1	3.3	3.4	3.6	3.7	3.8	4.0		

Figure 5.1: Range-Coverage Extension Factor against the Number of Smart Antenna Elements

5.3 Base Station Reduction

The additional coverage of a base station means that an operator can achieve a substantial reduction in infrastructure costs, due to the reduction in required base stations. Assuming that the base stations are distributed uniformly in a considered area (A), then to increase the cell radius from (d_1) (the area of a single cell is (A_1)) to (d_2) (the cell area is now (A_2), the necessary base stations decrease according to the reduction factor (g) which is given by [6]:

$$g = \frac{\frac{A}{A_2}}{\frac{A}{A_1}} = \frac{A_1}{A_2} = \frac{3\pi.(d_1)^2}{\pi.(d_2)^2} = 3(\frac{1}{\rho})^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.17)$$

$$\rho = M^{0.25} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5.18)$$

$$g = 3M^{-0.5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.19)$$

Since smart antenna is more directive than sector antennas, it can provide an additional gain so it can extend the range of a cell to cover an area that is larger by ($3\sqrt{M}$) than would be possible with sector antennas. Using smart antenna arrays reduces the number of base station required for a mobile system by amount of$(3/\sqrt{M})$. Using antenna arrays with M elements, for mobile communication systems will help in producing better quality beam patterns in terms of directivity and coverage. As it can be seen in Fig.5.2 the required number of base stations decreases as the number of antenna elements increase.

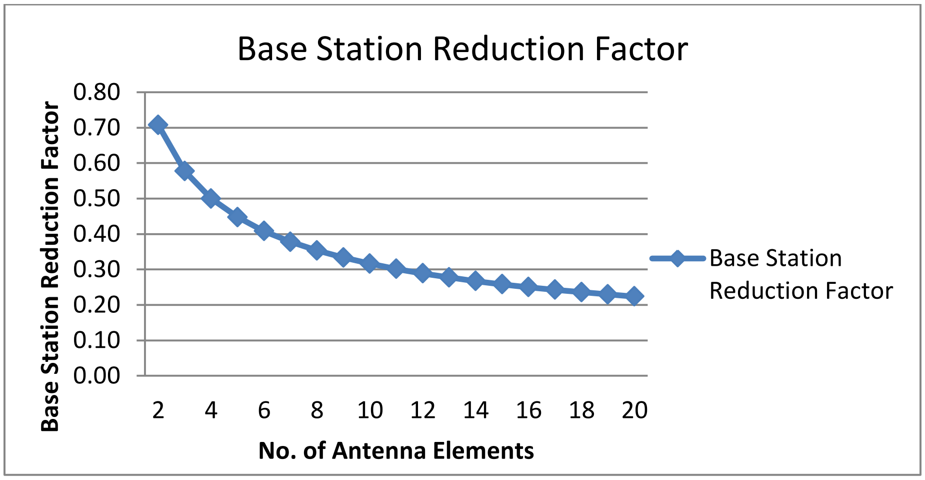


Figure 5.2. Number of Array Elements vs. Base Station Reduction Factor

5.4 Capacity Increase

The capacity of wireless communication system is a measure of users in a given area a system can support. Recently the need for providing high quality wireless access and the great demand on high speed wireless links has increased dramatically. Smart Antenna can enhance capacity of a wireless link through a combination of diversity gain, array gain and interference suppression. Increased capacity translates to high data rates for a given number of users or more users for a given data rate per users.

In general increasing capacity can be achieved by interference reduction by using narrow directional beam towards mobile phone this will reduce cochannel interference, another strategy is based on forming nulls in receiving antenna pattern in the interfering direction.

5.1.1 Uplink Capacity

As a basis for the analysis of the effect of uplink capacity, the following formula for the received bit energy per power spectral density of the thermal noise plus interference is given by:

$$\frac{E_b}{I_0} = MG\frac{S}{FN_{th}\,W + \alpha(1+\beta)(N-1)S} \dots\dots\dots\dots\dots\dots\dots..(5.20)$$

Where:

- E_b : $bit\ energy$
- I_0 :$power\ spectral\ density\ of\ thermal\ noise\ pluse\ interferance$
- F:$BS\ noise\ figure$
- N_{th} :$power\ spectral\ density\ of\ the\ thermal\ noise$
- S:$received\ signal\ strength\ per\ antenna$
- G:$processing\ gain$

- $\alpha: voice\ activity\ factor$
- $\beta: intercell\ interferance\ factor$
- $N: number\ of\ users\ in\ the\ cell$
- $W: system\ bandwidth$
- $M: number\ of\ antennas$

Using equation (5.20) the capacity of the cell can be expresses as [6]:

$$N = N_{pole} - \frac{FN_{th}W}{\alpha(1+\beta)S} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5.21)$$

Where N_{pole} is the pole capacity defined by:

$$N_{pole} = \frac{MG}{\alpha d(1+\beta)} + 1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (5.22)$$

Where d is the required E_b/I_0 note that the pole capacity is proportional to the number of antennas. The pole capacity is the theoretical maximum capacity if the mobiles have infinite transmits power available, i.e. the capacity in the limit where coverage is no longer a concern and interference alone limits capacity. The required received signal energy per antenna may be expressed as [6]:

$$S = \frac{FN_{th}W}{N_{pole}\alpha(1+\beta)(1-\frac{N}{N_{pole}})} \dots\dots\dots\dots\dots\dots\dots\dots\dots (5.23)$$

Assuming that the user terminals have a limited power, P_t and assuming path loss with a path loss exponent of γ, the cell radius, R' can be expressed as:

$$R' = r_0 (\frac{P_t}{S})^{\frac{1}{\gamma}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots... (5.24)$$

Where r_0 is a constant. Given the area A, of the cell is proportional to the cell radius squared and using equations (5.23) and (5.24) the next equation can be derived:

$$A^{\frac{-\gamma}{2}} = k \frac{1}{N_{pole}-N} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (5.25)$$

Where k is a constant. If N_{pole} is approximated as being proportional to M and assuming a nominal pole capacity of 1 when M=1 and absorbing the constant k into a normalized coverage area, equation (5.26) can be written as:

$$A^{\frac{-\gamma}{2}} = \frac{1}{M - N} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5.26)$$

The uplink normalized capacity, N can be expressed as a function of the normalized coverage area, the number of antennas at the BS, and the path loss exponent:

$$N = M - A^{\frac{\gamma}{2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (5.27)$$

With constant fractional loading and with the assumption that the pole capacity is proportional to the number of antennas:

Constant load capacity gain = M

5.1.2 Downlink Capacity

It is assumed that average SINR for the user terminal can be expresses as [6]:

$$SINR_{avg} = \frac{P_{delivered,avg}}{N_{thermal} + P_{base}(1 - \eta_{avg})(1 + \beta_{avg})\rho_{avg}} \dots\dots. (5.28)$$

Where:

- $P_{delivered,avg}$: $average\ power\ delivered\ to\ the\ user\ terminal$
- $N_{thermal}$: $thermal\ noise\ power$
- P_{base}: $total\ power\ transmitted\ by\ the\ BS$
- η_{avg}: $average\ othogonality\ factor$
- β_{avg}: $average\ inter\ to\ intra\ cell\ interferance\ ratio$
- ρ_{avg}: $average\ path\ loss\ for\ interferance$

The average delivered power to the user terminal can further modeled as:

$$P_{delivered,avg} = k\frac{P_{base}}{MN}M^2R^{-\gamma} = K\frac{P_{base}}{N}M\,R^{-\gamma} \ldots\ldots\ldots (5.29)$$

The total available BS power is divided among the N users and the M antennas, multiplied it with the coherent power combining gain which is potentially M^2 and multiplied it with the path loss factor $R^{-\gamma}$, R being the cell radius and γ being the path loss exponent. The constant k is for normalization. The average path loss for the interference, ρ_{avg}, which we can model as:

$$\rho_{avg} = \rho_0(\frac{R}{R_0})^{-\gamma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.30)$$

And

$$SINR_{avg} = \frac{K{R_0}^{-\gamma}P_{base}MR^{-\gamma}/N}{R^{-\gamma}N_{thermal} + P_{base}(1-\eta_{avg})(1+\beta_{avg})\rho_0 R^{-\gamma}} \ldots\ldots (5.31)$$

Using the above equation the following observations can be made:
If the number of BS antennas increased by a factor of M, keep the total BS power constant, and keep the cell radius constant, then the number of users can be increased by a factor of M. (By assuming perfect downlink beam-forming. In reality the factor of M is somewhat reduced due to imperfect downlink beam-forming.) When the number of user per BS is increased the radius of the cells can"t increase. That would lower the S/I ratio at the user terminals.

However, if the number of BS antennas increased by a factor of M, keep the total BS power constant, and keep the number of users constant, then the cell radius can be increased by at least a factor of $M^{\frac{1}{\gamma}}$. If the number of antennas increased by a factor of M and increase the total power of the BS by a factor of M (i.e. keep the same power amplifiers), then it can simultaneously increase the number of users by a factor of M and increase the radius of the cells by a factor of $M^{\frac{1}{\gamma}}$.

5.5 Cost Analysis

The cost of network directly depends on coverage and capacity requirements. Large coverage area requires more base stations and network elements which influences the network cost, moreover it depends on the environment type as well, denser area requires more stations as well which increases the cost of network. Another factor that affects the network cost is the traffic demand requirements. Higher traffic demand requires more capacity from network which raises the network cost as well. As a consequence, network cost depends on network dimensioning results. The network cost also dependent on the type of technology. The network cost is different for the different technology in this thesis the UMTS case is considered.

In general the Radio Access Network (RAN) dimensioning starts with link budget calculation, which provides the maximum allowed path loss thereby the maximum cell range is estimated depending on the propagation environment characteristics. Further the cell capacity is estimated taking into account the peak traffic and the loading factor which is also output of the capacity estimation process and is computed iteratively. Finally, the equipment requirements in terms of BS and RNC are derived.

The 3G network of Ethiotelecom is deployed with three-sectored sites only, each sector covering a hexagonal-shaped cell. The cell range is set to 0.34Km average cell radius in dense urban environments in the initial phase of the UMTS network deployment. It is further assumed that traffic density will be uniformly distributed over the coverage area, which is 70.45 km^2, which is the area covered by the UMTS sites in dense urban environment in Addis Ababa. The number of Node-Bs is then calculated in order to jointly satisfy the coverage profile and the traffic profile.

Based on the combination of the coverage and capacity scale estimation result, the number of sites is as follow: from the coverage point of view, the number of base station required is 705, but from the capacity point of view, the number of base station required is 692. So, to meet ET"s coverage, capacity and quality requirements, the final number of UMTS BS is 725 including 3 Indoor Base Stations (IBS) for indoor coverage in Addis Ababa.

The 3G network coverage and capacity for the three different Morphology scenarios in Addis Ababa is as follow: Dense Urban Area (70.45 km^2) continuous coverage with 541,632 users, Urban Area (170.36 km^2) continuous coverage with 604,800 users and Sub Urban Area (539.12 km^2) continuous coverage with 356,160 users using 725 UMTS BS. Accordingly with a simplified cost model the capital expenditures (CAPEX) and operational expenditures (OPEX) for 3G network in Addis Ababa is presented hereunder.

Equipment Costs		
Equipment	Cost (USD)	Capacity(Mbps)
UMTS RNC	1,500,000	2150
UMTS Macro Node-B, one sector	10000	14.4
UMTS Macro Node-B, additional sector	9000	14.4
UMTS Macro Node-B, additional carrier	9000	14.4

Installation & Build Out Costs	
	Cost(USD)
UMTS Macro Node-B site installation	4000
UMTS Macro Node-B site build out	6000

Running Costs			
	Cost (USD)	Capacity	Variable Annual Costs
Site lease, UMTS Node-B Macro	1500	U111	2000
Leased Line, E1	400	2 Mbps	500
Leased Line, E3	1000	45 Mbps	1500

Table 5.1 Equipment Costs, Installation & Build out Costs and Running Costs of a single UMTS

CAPEX and OPEX

The focus has been on the potential cost saving in terms of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) that potentially could be achieved by the deployment of smart antenna systems in the medium size UMTS network i.e. dense urban network. Despite the technological supremacy of one solution compared to the other, the cost aspect will be the driving force when it comes to the business implementation.

CAPEX and OPEX as function of both the smart antenna system capacity gain and the cost increase of smart antenna equipment relative to conventional antennas cost for baseline traffic profiles (Co) in Table 5.2 and ten times Co for a smart antenna capacity increase of 2.5 [16] have been evaluated. The base line traffic profile (Co) is what has been assumed in the model with the peak traffic demand per user corresponding to the UMTS Forum forecast and the values are extracted from various sources including equipment vendors (Huawei and ZTE), reviewed literature, marketing reports and network operator report (Ethiotelecom).

Traffic Forecast		
Worst Case Busy Hour	**Uplink**	**Downlink**
Average per subscriber	198.4 Kbytes	454.9 Kbytes
Business subscribers	361.4 Kbytes	808.7 Kbytes
Consumer subscribers	106.4 Kbytes	255.1 Kbytes

Table 5.2 Traffic Forecast

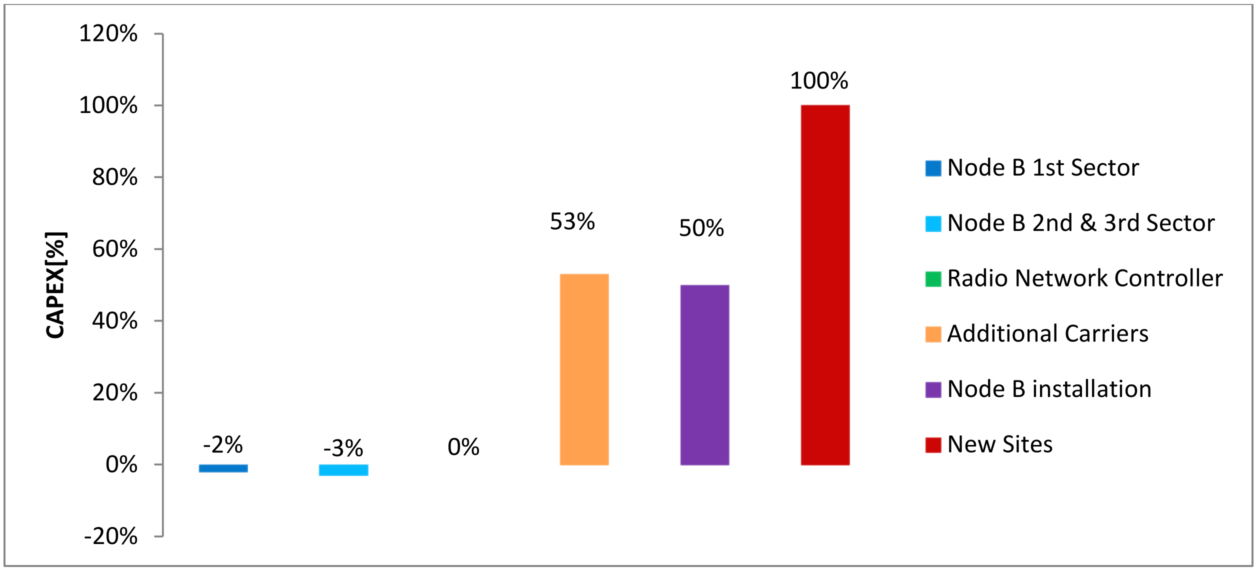
SAS should be deployed mainly in areas with high concentration of users that is highly dense Urban Areas or Business Parks where users are expected to generate a large amount of data traffic.

10Co Traffic Scenario **Smart Antenna Systems Capacity Increase by factor 2.5**			
Node B Cost Increase	100%	60%	0%
CAPEX saving	10%	24%	45%
OPEX saving	13%	22%	34%

As can be seen if the Smart Antenna System (SAS) equipment cost would be the same as CAS system the overall relative cost saving will be as high as 40% on the other hand if the SAS cost is doubled (100% cost increase) there will be still a cost saving of around 10%, which may be a considerable amount of financial resources, that could be used in other profitable investments related to the UMTS services.

The other consideration is internal cost distribution over the systems" life span, for a system equipped with smart antennas that is 1.8 times more expensive than the system with conventional sector antennas. It was obtained that in the case of Conventional sector Antenna Systems (CAS) the initial investment will provide capacity through coverage so the systems are over dimensioned with only one carrier deployed. However, already after five years in order to meet the increasing traffic demand new investment must be done, which are reached by adding new carriers. This would apparently solve the problem but in practice new ones will be added since additional carriers may introduce further interference and cause coverage and capacity shortages. Further, more RNCs must be deployed in order to take care of the increasing data traffic.

After some years from the start no more spectrum will be available so new sites must be deployed and with that extra costs expected. The need of new sites will also impact negatively the overall interference scenario and the overall planning will become a hard task. Additional carriers must be added as well as new sites must be acquired again worsening the whole situation. The OPEX will also increase since new sites must be acquired. The costs for leased lines remain almost unchanged and are subject only to discount rates. In other hand, for smart antennas the CAPEX was concentrated to the initial investment. The costs due to RNC are the same as in the CAS case since the same traffic scenario has been assumed. However, after some years new investments must be done since the traffic demand is not fulfilled, and a new carrier must be deployed. However, no more sites are acquired in this case and both CAPEX and OPEX costs due to build outs are avoided.



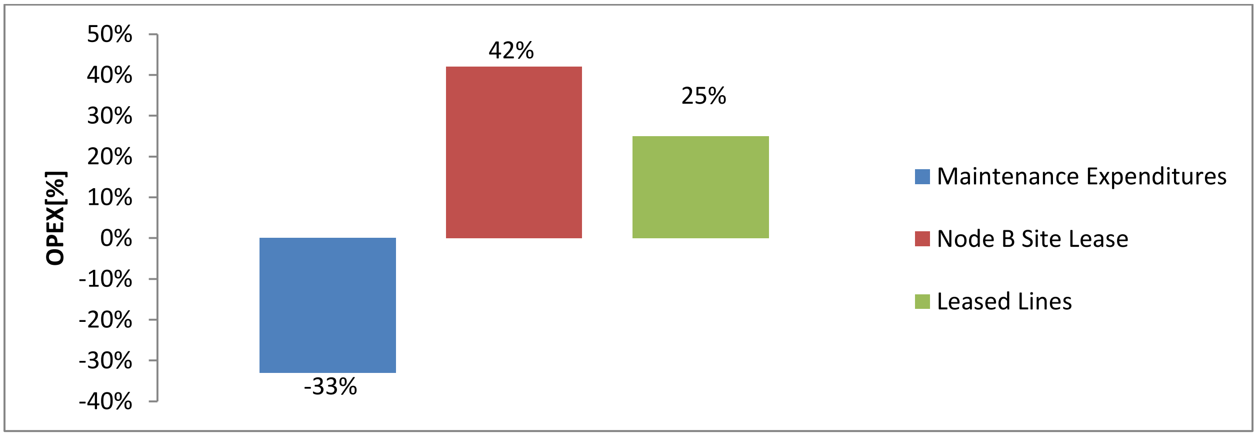


Fig.5.3: CAPEX and OPEX Reduction Obtained By the Deployment of Smart Antenna Systems Relative to Conventional Antenna Systems

A discounted cash flow model is used in the cost analysis where investment and operation costs of Table 5.1 are considered using the traffic profile of Table 5.2 and a smart antenna system capacity gain of 2.5. The following assumption are considered: the mobile penetration is assumed to increase every year with a saturation level at about 90% of the population, the population is assumed to increase with 0.35% each year and it is also assumed that 21% of all the inhabitants populate the urban environments, and a traffic rate increase of 6 % yearly for a period of five years.

Using the above cost model and assumptions for the same traffic scenario in both cases i.e. case of Conventional sector Antenna Systems (CAS) and Smart Antenna System (SAS) the following estimated result is drawn, as it can be seen in the Fig.5.3 the equipment cost is higher for the SAS deployment compared to CAS. The maintenance expenditure is also higher (33%) for that system since it is directly proportional to the equipment costs. The cost due to RNC is the same (0%) since the same traffic demand must be met in both deployment scenarios. So the main cost savings come through the fewer site acquisitions, which will impact on the build out costs (no new sites are needed so a 100% of costs of new sites are saved), Node B installation costs (50%), leased lines (25%) and site lease (42%). It is clear that the cost saving in terms of CAPEX and OPEX is directly proportional to the average year traffic and the system capacity gain provided by a smart antenna technology though it is inversely proportional to the equipment cost increase.

In order to find such “simple” relationship CAPEX and OPEX calculation were repeated for different equipment cost increase for ten traffic profiles, which are multiples of the basic traffic profile Co and different smart antenna system capacity gains. It displays the cost savings in percent as function of the average traffic demand taken over the period of interest divided by the cost factor of the smart antenna equipment. Results for two different systems are provided; the one improves the capacity performance of NBs by a factor 2.5, which could be achieved by an array of switched beams in urban environments and the second by a factor 5 that could be obtained with more sophisticated smart antenna system [16]. The cost saving is calculated relative to the same traffic scenario for different values of the equipment cost increase.

Let us denote the minimum cost saving by K and a fitting equation could be expressed as follows [21]:

$$K \leq ln\left(\alpha \times ln\left(\frac{\lambda}{c}\right) + \beta\right) \ldots\ldots\ldots\ldots\ldots(5.32)$$

The constants α and β in equation (5.31) depend on the capacity gain provided by the smart antenna system. The average traffic demand ($\lambda > 0$) taken over the period of interest divided by the cost factor of the smart antenna equipment($c \geq 1$). The positive K means that there is a decrease of capital and operational expenditures; on the other hand negative K indicates additional expenditure costs. Now let us say there is a target cost investment saving (and related operational) of 10% and then solving equation (5.32)and obtain:

$$\frac{\lambda}{c} \geq e^{(e^k-\beta)/\,\alpha} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5.33)$$

Substituting the numerical values and obtain that in order to achieve the 10% saving target, the maximum cost factor for the same traffic demand may be higher for the system providing higher capacity gain, which was expected as illustrated by equations below,

$$C_5 \leq \frac{\lambda}{3} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5.34)$$

$$C_{2.5} \leq \frac{\lambda}{3.76} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5.35)$$

For instance if the average traffic demand equals 5Mbps/km^2 then in order to achieve a 10% CAPEX plus OPEX reduction the smart antenna equipment cost should not exceed the 66% increase for the system providing 5 times the capacity of CAS and should not exceed 33% if it provides a factor 2.5 capacity gain. Conversely, if the equipment cost is known the minimum average traffic demand required in order to meet the cost target may be estimated. It is also clear that for the same "average traffic-to-cost" ratio doubling the system capacity gain from 2.5 to 5 may provide additional 10 % in CAPEX plus OPEX reduction.

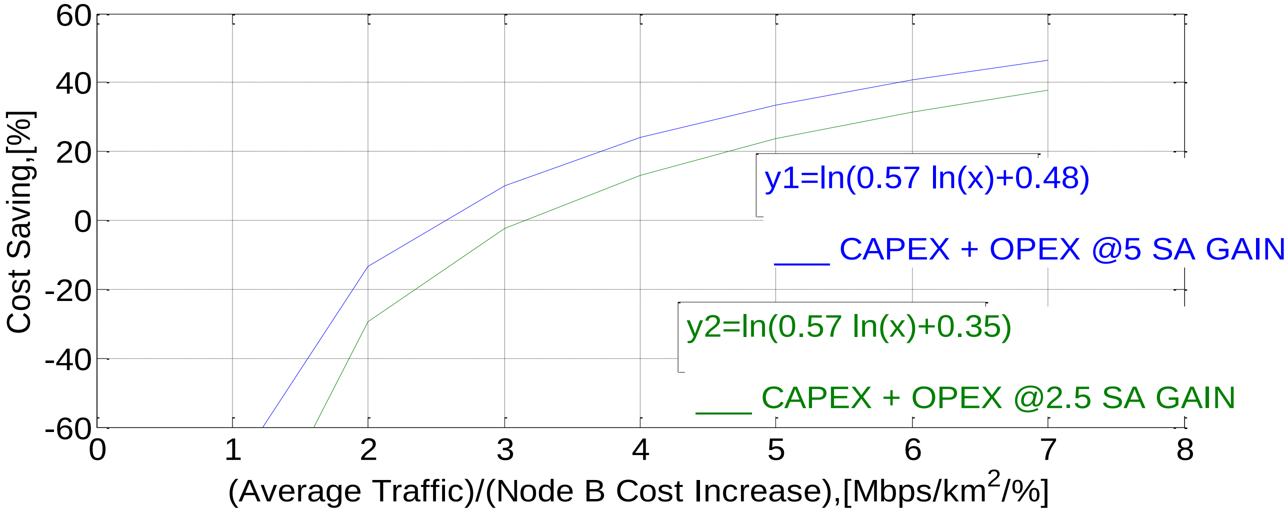


Fig.5.4: Cost Saving in Percent as Function of the Average Traffic Load Divided by the Relative BS Cost Increase

Therefore, a more efficient and flexible network infrastructure could be built with the help of smart antennas, though with the condition that sufficient amount of data traffic is generated by the UMTS users. Therefore sufficient network capacity must be available through higher capacity gain. However this capacity is most likely to be needed only in highly dense urban environments but even more in technical parks and business centers where large amount of business users have their work place. Hence, the deployment of smart antenna systems for the 3G UMTS networks in dense urban environments has a potential CAPEX and OPEX savings provided by such a system compared to more conventional antenna systems. It shows that a cost savings of the order of 10% to 25% are feasible if the cost increase of the smart antenna equipment is of the order of 100% to 50% of the conventional antennas equipment costs, respectively.

Chapter 6: Conclusion and Recommendation for Future Work

6.1 Conclusion

The performance of 3G network of Ethiotelecom in Addis Ababa has been evaluated and the major challenges which incur the overall performance degradation is investigated and identified in the first section of this thesis work. Though Ethiotelecom has recently deployed a telecom expansion project throughout Addis Ababa, the recent result of drive test and network performance analysis result shows that the current radio network has encountered major technical performance problems regarding coverage, capacity and overall quality of service due to the following major reasons: Poor RSCP, Current sites distribution do not match with the real traffic distribution, Poor CSSR and mobility performance drop in which most of the problems encountered in dense urban areas of Addis Ababa.

A Smart antenna based Base Station which can enhance network performance, is proposed as an alternative solution, in which its performance is evaluated through adaptive array type using CMA and LMS algorithms which are a blind and non-blind algorithm types respectively that shows strong narrow beam of smart antenna can be steered towards the desired direction and capable of placing nulls towards the interferer, CMA is found more efficient algorithm as compared to LMS and it is a better option to implement at base station of mobile communication systems to suppress the undesired sources and leads to optimal performance.

The financial aspects of the deployment of smart antenna systems in the 3G UMTS networks have been evaluated in the last section of this thesis work and it is shown that the smart antenna gain compared to a single element antenna can be increased by an amount equal to the number of array elements. Because smart antenna is more directive than sector antennas, it can provide an additional gain, so it can extend the range of a cell to cover an area that is larger by $(3\sqrt{M})$ and reduces the number of base station required for a mobile system by amount of $\left(3/\sqrt{M}\right)$ than would be possible with sector antennas accordingly in rural and sparsely populated areas the base stations can be placed further apart, potentially leading to a more cost-efficient deployment and it is shown that for M number of antenna arrays the number of users can be increased by a factor of M.

The deployment of smart antenna systems for the 3G UMTS networks in areas with high concentration of users, that is dense Urban Areas or Business Parks where users are expected to generate a large amount of data traffic a potential CAPEX and OPEX savings is provided by such system compared to more conventional antenna systems. It shows that a cost savings of the order of 10% to 25% are feasible if the cost increase of the smart antenna equipment is of the order of 100% to 50% of the conventional antennas equipment costs, respectively. Accordingly a more efficient and flexible network infrastructure could be built with the help of smart antennas, though with the condition that sufficient amount of data traffic is generated by the UMTS users in dense urban areas.

6.2 Recommendation for Future Work

In this thesis work the performance of the conventional antennas and smart antenna systems is investigated and a cost analysis is done as well for 3G network deployment scenario. While there are still some issues that require further research for further improvement. Accordingly here are list of recommendations to the possible extensions of the works of this thesis research:

- ✓ A network planning concept with SA is not considered in this thesis work thus the work can be extended further by developing a site specific network planning tool.
- ✓ To allow those advantages of SA and achieve the benefits more rapidly this thesis work can be further extended for the possibility of using the existing organizational structures of mobile radio network.
- ✓ In this thesis work a beam forming processing approach is addressed while Considerable improvements in the radio network performance with SA may be achieved by combining different spatial-domain processing techniques like beam-forming, spatial diversity, Sectorization with temporal-domain processing, and other diversity techniques. This thesis can be further extended in investigating the Correct and feasible combination which can provide more improvements in system performance than implementation of very complex and sophisticated SA algorithms.
- ✓ One can extend this thesis work, for the possibility of smart antenna at handheld system for further performance enhancement of cellular systems.

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