

Menoufia University
Faculty of Electronic Engineering
Dept. of Electrical Communications Engineering

Adaptive Arrays for Mobile Radio Communications

B16978

A Thesis submitted for the degree of M.Sc.

By

Eng. Yasser Attia Albagory

Supervised By

Prof. Dr. Mohiy M. Hadhoud

Faculty of Computers & Information
Menoufia University

[M.M. Hadhoud]

Prof. Dr. Mostafa A. Nofal

Dept. of Electrical Communications Eng.
Faculty of Electronic Engineering
Menoufia University

Prof. Dr. Moawad I. Dessouky

Dept. of Electrical Communications Eng.
Faculty of Electronic Engineering
Menoufia University

[M.I. Dessouky]

[Mostafa Nofal]



2002

18/8/2002

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Acknowledgments

First and foremost, I am thankful to God, the most gracious most merciful for helping me finishing this work. It is a pleasure to acknowledge my supervisors that have profoundly influenced me with guidance and support. I do not know with whom I may begin, Professor Mohiy Hadhoud, Professor Moawad Ibraheim, and Professor Mostafa Nofal provided me with generous and continuous support for attendance at numerous technical meetings and discussions with grateful encouragement, they are really a great and excellent teamwork.

I am indebted to my father for teaching me the importance of hard work and perseverance and for instilling in me the confidence that I could succeed at whatever I chose to do.

I finally dedicate this work to the person who is usually beside me in all happy as well as hard times and continuously praying for the desire of my success.

ABSTRACT

An analysis to the high-altitude platforms communications system is done with the application of adaptive antenna arrays indicating the radio coverage parameters and the main factors that affect the system performance. Several coverage schemes are proposed based on switched-beam antennas for the macrocellular regions that need large area radio coverage with the expectation that the users may exist at any location within these regions. These schemes have shown a reduction in the power consumption, increase in user location accuracy and efficient utilization of the spectrum. Of these approaches, the beam splitting one sequentially splits wider coverage beams into narrower sub-beams, which when compared with the other possible schemes can be considered as a compromise between hardware requirements and processing complexity.

Regarding the positional instability of the platform and the resulting problems of handovers and location updating, a novel cellular structure is proposed that adopts ring-shaped cells instead of the traditional hexagonal cells configuration. This innovated structure can be achieved by adaptive antenna arrays at the platform. The array pattern constituting these cells is resulted from a scanning operation of multiple of beams, which is named as multi-beam scanning approach in which a number of azimuthally equispaced beams scan in the azimuth plane with constant elevation angle. Definitions of the beam scanning rate and beam visiting time are deduced. This new cellular structure improves the system performance, as it is capable of reducing the transmitted power, simplifies the location updating and handover algorithms and rates. The adaptation of the cell area to meet teletraffic changes from hour to hour is easier with this structure than utilizing the conventional hexagonal one.

LIST OF PUBLICATIONS

- [1] M. Hadhoud, M. Dessouky, M. Nofal, Y. **Albagory**, "Two-dimensional switched-beam smart antennas for stratospheric platform cellular communications", Proceeding of The IEEE International Conference on Software, Telecommunications, and Computer Network (SoftCOM 2001), Split – Dubrovnik, Croatia, Ancona – Bari, Italy, pp. 279-285, 9-14, October 2001.

- [2] M. Nofal, M. Dessouky, M. Hadhoud, Y. **Albagory**, "A novel cellular structure for the stratospheric platform mobile communications," Proceeding of The Nineteenth National Radio Science Conference (19th NRSC' 2002), Alexandria, Egypt, pp. 354-362, 19-21 March 2002.

*Also has been accepted for presentation and publication in the 6th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2002), Orlando, USA, July 14-18, 2002.

- [3] M. Nofal, M. Dessouky, M. Hadhoud, Y. **Albagory**, "Performance and feasibility of different switched-beam antennas for the stratospheric platform mobile communications covering newly developing regions," Proceeding of The Nineteenth National Radio Science Conference (19th NRSC' 2002), Alexandria, Egypt, pp. 133-140, 19-21 March 2002.

*Also has been accepted for presentation and publication in the 6th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2002), Orlando, USA, July 14-18, 2002.

- [4] M. Hadhoud, M. Dessouky, M. Nofal, Y. **Albagory**, " Smart Antennas for High Altitude Platforms Wireless Communications," has been accepted for presentation and publication in the Wireless 2002 Conference in Calgary, Alberta, Canada, July 8-10, 2002.

CONTENTS

LIST OF FIGURES	iv
LIST OF TABLES	vii
1 INTRODUCTION	
1.1 A Promising Future with High Altitude Platforms	1
1.2 Adaptive Antenna Arrays at the HAP Base Station	3
1.3 Thesis Plan	4
2 HIGH ALTITUDE PLATFORMS FOR MOBILE RADIO COMMUNICATIONS	
2.1 Introduction	6
2.2 Concept of Cellular Communications	7
2.3 First-Generation Cellular Systems	8
2.4 Second-Generation Cellular Systems	9
2.5 Third-Generation Systems	10
2.6 Mobile-Satellite Communications System	11
2.7 High Altitude Platforms (HAPs) Solution	12
2.8 HAP Evolution and Prototypes	15
2.8.1 Balloons	15
2.8.2 Airship HAPs	16
2.8.3 Aeroplane HAPs	18
2.8.4 Other HAP Configurations	20
2.9 HAP Communications Applications	21
2.9.1 Wireless Broadband Fixed Networks and Cellular Mobile Communications Applications	23
2.9.2 Rapid Communications System Deployment Applications	24
2.9.3 Military Communications	24
2.10 Advantages of HAP Communications	25
2.11 Some Critical Factors and Challenges	26
3 ADAPTIVE ARRAYS AND BEAMFORMING	
3.1 Introduction	30

3.2 Basics of Mobile Radio Propagation	30
3.2.1 Fading Channels	31
3.2.2 Doppler Spread	31
3.2.3 Delay Spread	32
3.3 Narrowband Signals	33
3.4 Adaptive Antenna System	34
3.5 Uniform Linear One-Dimensional Array	36
3.6 Direction-Of-Arrival Based Beamforming	38
3.6.1 Conventional Beamforming (Phased Arrays)	39
3.6.2 Interference Canceling with Null-Steering Beamformer	41
3.7 Optimal Beamformer	47
3.8 Adaptive Beamforming	49
3.8.1 Sample Matrix Inversion (SMI) Algorithm	49
3.8.2 Least Mean Square (LMS) Algorithm	50
3.9 Performance Improvement with Adaptive Arrays	56
4 PERFORMANCE OF HAP MOBILE COMMUNICATIONS WITH ANTENNA ARRAYS	
4.1 Introduction	60
4.2 Planar Arrays Steering Vector	61
4.3 Conventional Beamforming	67
4.3.1 Array Sensitivity and Power Pattern	68
4.3.2 Beamwidth	69
4.3.3 Array Size	71
4.4 Cell Geometry and Radio Coverage Parameters	73
4.4.1 Cell Boundary and Area	73
4.4.2 Cell Elevation Angles	77
4.4.3 Total Coverage Radius and Area	79
4.5 Power Distribution and Dynamics	81
4.5.1 Power Profile within a Cell	81
4.5.2 Carrier-to-Interference Ratio (<i>CIR</i>)	85
4.5.3 Frequency Reuse Pattern	87

5 SWITCHED-BEAM HAP TECHNIQUES FOR MACROCELLULAR NEWLY DEVELOPED REGIONS

5.1 Introduction	89
5.2 The Basic Switched-Beam System	90
5.3 Switched-Beam Techniques	92
5.3.1 Fixed Spot-Beam Antennas Technique	92
5.3.2 Variable Beam-Pattern Antenna Array Technique	93
5.3.3 Single Scanning Beam Technique	94
5.3.4 Beam Splitting Approach	95
5.4 Performance Measures and Comparison	97

6 A NOVEL CELLULAR STRUCTURE FOR HAP MOBILE COMMUNICATIONS

6.1 Introduction	101
6.2 Attitude Instability Effects on HAP Performance	102
6.2.1 Cell Boundary Motion due to Rotational Shift	102
6.2.2 Instability Initiated Handover	105
6.2.3 Location Updating	107
6.3 A Novel Coverage Solution	108
6.4 Scanning Multi-Beam Approach	109
6.4.1 Geometry of The Ring-Shaped Cell	110
6.4.2 The Proposed Multi-Beam Scanning Method	113
6.4.3 Beam Visiting Time and Scanning Rate	115
6.4.4 Number of Scanning Beams within a Ring Cell	118
6.5 Performance Improvement with Ring Cells	119
6.5.1 Power Consumption	119
6.5.2 Handover Algorithms and Rate	119
6.5.3 Location Updating Traffic	120
6.5.4 Teletraffic Balancing	120

7 CONCLUSION AND FUTURE WORK

REFERENCES

LIST OF FIGURES

Fig. 2.1	Wide area coverage for traditional mobile radio	7
Fig. 2.2	Cellular mobile radio with frequency reuse concept	8
Fig. 2.3	Wind speed profile with height. (Source: NASA)	17
Fig. 2.4	Basic airship HAP Configuration	17
Fig. 2.5	Helios AeroVironment's craft has a wingspan of 75 m and aims to operate up at 100000 feet under solar power	19
Fig. 2.6	HALO Proteus aircraft. (Courtesy of Angel Technologies Corp.)	20
Fig. 2.7	Predator, a military UAV (Courtesy of General Atomics Aeronautical Systems Inc.)	21
Fig. 2.8	HAP communications scenario	22
Fig. 3.1	Mobile radio environment and multipath signals	32
Fig. 3.2	Adaptive beamformer	35
Fig. 3.3	Array configurations: a) Linear, b) Circular, c) Two-dimensional, and d) Three-dimensional array	35
Fig. 3.4	Uniform one-dimensional array	37
Fig. 3.5	Array radiation pattern for different dimensions and inter-element separation	40
Fig. 3.6	Interference cancellation by an adaptive array	42
Fig. 3.7	Radiation pattern (array factor) for nulling an interference at 30°	43
Fig. 3.8	Receiving two signals utilizing the same frequency	44
Fig. 3.9	Array sensitivity patterns for two signals utilizing the same frequency	44
Fig. 3.10	The pattern of the array utilizing the weight vector in Eq. (3.37).....	48
Fig. 3.11	LMS Adaptive beamformer	51
Fig. 3.12	LMS beamformer for large interferers canceling	54
Fig. 3.13	Learning curve for the beamformer depicted in Fig. 3.12	55
Fig. 3.14	Power Pattern for the LMS beamformer depicted in Fig. 3.12	55
Fig. 4.1	Scattering Model for HAP base station	61
Fig. 4.2	Two-dimensional array of $M \times N$ elements and lies in the x-y plane	62

Fig. 4.3	Two-dimensional beamformer	63
Fig. 4.4	Normalized array factor for 10×10 array with the main lobe oriented toward the broadside direction	69
Fig. 4.5	Normalized array factor for 10×10 array with a main lobe oriented toward (θ_o, ϕ_o)	70
Fig. 4.6	BW_θ in degrees versus number of elements at different beam orientation angle θ_o	72
Fig. 4.7	BW_ϕ in degrees versus number of elements at different beam orientation angle θ_o	72
Fig. 4.8	Array area versus number of array elements at different carrier frequencies	73
Fig. 4.9	HAP cell footprint	74
Fig. 4.10	Cell central angle versus beam direction θ_o	75
Fig. 4.11	Cell minor axis versus beam direction θ_o at different array dimensions	76
Fig. 4.12	Cell major axis versus beam direction θ_o at different array dimensions	76
Fig. 4.13	Cell-area versus beam direction θ_o at different array dimensions	78
Fig. 4.14	Definition of cell elevation angles	78
Fig. 4.15	The upper elevation angle β in degrees versus θ_o at different array dimensions	80
Fig. 4.16	The lower elevation angle α in degrees versus θ_o at different array dimensions	80
Fig. 4.18	Total coverage radius in km versus θ_o at different array dimensions	82
Fig. 4.19	Total coverage area in square km versus θ_o at different array dimensions	82
Fig. 4.20	Power profile function for 10×10 array versus θ_o	85
Fig. 4.21	Power profile function for six contiguous cells versus beam orientation θ at $\phi = 0^\circ$	86
Fig. 4.22	Cellular system utilizing 61 beams to cover an area of 40 km diameter....	88

Fig. 5.1	General block diagram of switched-beam system	91
Fig. 5.2	The fixed spot-beam-pattern antennas switched-beam system	93
Fig. 5.3	Switched-beam antenna system based on beamformer and antenna array	94
Fig. 5.4	Switched-beam antenna system based on scanning antenna array	95
Fig. 5.5	Beam-splitting for user acquisition	96
Fig. 5.6	A user moving toward an area covered by higher layer coverage beam	97
Fig. 5.7	Flow chart of the beam splitting approach	98
Fig. 6.1	Attitude instabilities of the HAP and its effect on the coverage	103
Fig. 6.2	Rotation of HAP station and its effect on the radio coverage	104
Fig. 6.3	Effect of rotation by 10° of the HAP station on the cellular radio coverage	106
Fig. 6.4	The normalized number of handover users as a function of the rotation angle ($\Delta\phi$ in Deg.) for different cells (i.e. at different values of θ_0 in Deg.) formed by 10×10 array	108
Fig. 6.5	A Novel cellular structure for airborne HAP systems	109
Fig. 6.6	Geometry of the ring cell formed by scanning operation	111
Fig. 6.7	Ring width in km versus the number of elements at different ring directions	112
Fig. 6.8	Ring area in km^2 versus the number of elements at different ring directions.....	113
Fig. 6.9	The normalized radiation pattern of five beams formed by a single weight vector.	115
Fig. 6.10	The geometry of the scanning beam	117
Fig. 6.11	The ground angle (ϕ_g in Deg.) versus beam orientation (θ_0 in Deg.) at different number of array elements	117
Fig. 6.12	Different scenarios for teletraffic unbalance and the ways for rebalance utilizing adaptive antenna arrays with the ring-shaped cells mobile communications system	122

LIST OF TABLES

Table 2.1 Characteristics of some Mobile Satellite Services	13
Table 2.2 Comparison between Terrestrial, Satellite and HAP communications	14
Table 3.1 Typical delay, direction of arrival spread and Doppler spread	33
Table 5.1 Comparison between different switched-beam HAP techniques	100

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

The demand for mobile communications services is growing at an explosive rate with the anticipation to provide any one, anywhere, and at anytime with services at low cost, high quality, high data rates supporting multimedia, with little mobile handset. These demands will put the system operators and researchers in a challenge with the system resources in digging for solutions for increased capacity demands at an affordable cost. Mobile communications faced evolutionary path starting with first-generation analog systems, second-generation digital system, and recently the way to apply third-generation system. All the technology improvements aimed the above demands. The last decade has a great research activity on the application of antenna arrays at the base stations. This approach named *smart antenna technology* and has a great effect on the system performance. Many studies [1]–[6] indicate the feasibility of antenna arrays in mobile radio communications indicating the improvements in performance as it is capable of reducing the cochannel interference level, reducing the cluster size, tracking mobiles for handover reduction and others that will be discussed in detail later. But there are more needed requirements such as flexibility in system design, reconfiguration, adaptability for teletraffic demands and cost effective deployment, which form a great impact especially with the conventional terrestrial systems. Mobile satellite communications although covering large area, it offers a limited solution and suffers from several problems such as Doppler spread, complicated handover schemes, limited capacity, and extraordinary system cost.

1.1 A Promising Future with High Altitude Platforms

Recently, the idea of high altitude platforms (HAP) communications system [7] has a great interest especially for mobile and wireless data communications. Since 1992, un-manned aerial platforms have been proposed, where Steele [8] (Royal

Society meeting in London) proposed the use of stationary stratospheric platforms to handle teletraffic hotspots and peaks saying, "The Platforms will be tethered to the earth and located up to 30 km in height and placed between the aircraft flying lanes. Barely visible from earth they will be able to deliver many services. They will held on station by power conveyed to them via their tie-lines, and these lines will also house the fibers that convey the teletraffic with the network. Alternatively these platforms could be untethered, hovering, and therefore capable of being rapidly re-deployed. The hovering platforms will be able to track 'solitons of the teletraffic', rather than force the task on the terrestrial networks. For example, the platforms could handle the teletraffic from high-speed trains, highways, aircraft and ships. They can be rapidly deployed when disasters occur, for example, the rapid provision of communications to a city, which has been devastated by an earthquake" and latter the application of aerial platforms for cellular communications in [9].

The platforms consist of multi-layer skin airship having buoyant helium-filled cells, a station-keeping system, solar panels for daytime power supply, and regenerative fuel cells for nighttime. Station-keeping with the new technology of corona ion engines make these platforms to be practically available as well as global positioning system (GPS) for accurate positioning and ultra-thin fabric hulls for long duration buoyancy [10]. The HAPs are stationary therefore, no Doppler frequency shift results as in low-earth-orbit satellites. The HAP communications is basically a line-of-sight as it is used with higher elevation angles. Due to the lower altitudes (few kilometers to 70 km high), the path loss is low and is similar to that of conventional macrocells.

Worldwide regulatory approval for the use of stratospheric platforms was granted by the International Telecommunications Union in November 1997 and by the U.S. Federal Communications Commission earlier that year. Many current systems employ and designing to apply HAPs in mobile communications and wireless networks such as SkyStation International Inc.[11], which announced the starting to deploy its global