DESIGN OF MULTIBEAM ANTENNA FOR WIRELESS LOCAL AREA NETWORK APPLICATIONS

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ABSTRACT

The current trend in most access point in conventional wireless local area network (WLAN) is to use omnidirectional antennas, which radiates and receives power equally in all directions. This attribute however gives result of lower power efficiency and decrease network performance due to co-channel interference that arrived from undesired directions. One of the proposed solutions to overcome these constraints is to use multibeam antenna on WLAN access points. Multibeam antennas are antenna arrays that make use of beamforming networks to produce multiple independent beams that directed to different directions. In this project, multibeam antenna comprises of linear antenna array and beamforming network is presented. It was designed at 2.4 GHz to suit the application of WLAN at 802.11b/g. Butler Matrix 4 x 4 is chosen as a beamforming network which was designed to provide four different progressive phase shifts, -45°, +135°, -135°, +45° that coupled to antenna array. It is made up from four 90° hybrid coupler, two 0 dB crossover and two -45° phase shifter. Each component is designed and simulated using Agilent ADS software and fabricated on FR4 board. This network is then combined with a linear antenna arrays with the aim to produce four independent beams at four different directions. Three types of antenna array that having different kind of radiation patterns have been implemented which are square patch antenna, 4 x 2 planar antenna array and dipole antenna. The obtained result shows that 4 beams are generated by each design where square patch antenna array produce Half Power Beamwidth, HPBW for each beams about 30° and manage to cover 120° of coverage area, 4 x 2 antenna array has HPBW about 7° and cover 30° while dipole antenna produce two kind of beams, broader and narrower beams. Finally, it can be concluded that the objectives of this project are achieved.

ABSTRAK

Hala tuju kebanyakan titik akses pada Rangkaian Kawasan Tempatan Wayarles (WLAN) masa kini masih menggunakan antena halaan-omni, di mana ia menyebarkan dan menerima kuasa daripada semua arah. Keadaan ini bagaimanapun telah menyebabkan kecekapan kuasa menjadi rendah, malah menyebabkan penurunan prestasi rangkaian yang disebabkan oleh gangguan saluran utama daripada arah yang tidak dikehendaki. Salah satu jalan penyelesaian kepada kelemahan ini ialah dengan menggunakan antena pelbagai sinaran pada titik akses WLAN. Antena pelbagai sinaran adalah tatasusun antena yang menggunakan jaringan pembentuk alur untuk menghasilkan beberapa sinaran yang menghala pada arah yang berlainan. Dalam projek ini, antena pelbagai sinaran yang diperbuat daripada tatasusun antena dan jaringan pembentuk alur dibentangkan. Ia direka pada frekuensi 2.4 GHz untuk applikasi WLAN pada 802.11b/g. 4 x 4 Butler Matrix dipilih sebagai jaringan pembentuk alur dan direka untuk menghasilkan empat nilai anjakan fasa progesif yang berbeza iaitu -45°, +135°, -135°, +45° yang digandingkan dengan tatasusun antena. It diperbuat daripada empat komponen gandingan hibrid 90°, dua komponen garis silang 0 dB dan dua penganjak fasa -45°. Setiap komponen direkabentuk dan disimulasi menggunakan perisian Agilent ADS and difabrikasi ke atas papan FR4. Jaringan ini kemudiannya dicantumkan bersama antena bertatasusun lurus dengan matlamat untuk menghasilkan empat sinaran yang berasingan. Tiga jenis antena yang mempunyai corak radiasi berbeza telah digunakan iaitu antenna tampalan segi empat sama, 4 x 2 tatasusun antena dan antena dua-kutub. Keputusan yang diperolehi menunjukkan empat sinaran telah dihasilkan, yang mana antena tampalan segi empat sama menghasilkan HPBW selebar 30° dan kawasan liputan seluas 120°, 4 x 2 tatasusun antenna mempunyai HPBW selebar 7° dan kawasan liputan seluas 30° dan antena dua-kutub menghasilkan dua jenis sinaran yang berbeza, sempit dan lebar. Akhirnya, dapatlah disimpulkan bahawa objektif projek telah dicapai.

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LIST OF ABBREVIATIONS

2D	-	Two dimensional
3D	-	Three dimensional
3G	-	Third Generation
AF	-	Array Factor
AP	-	Access Point
BER	-	Bit Error Rate
BPSK	-	Binary Phase Shift Keying
CCK	-	Complementary Code Keying
CIR	-	Carrier to Interference Ratio
CPW	-	Co-planar waveguide
DBPSK	-	Differential Binary Phase Shift Keying
DQPSK	-	Differential Quadrature Phase Shift Keying
DSSS	-	Direct Sequence Spread Spectrum
FCC	-	Federal Communications Commission
FR4	-	Fire Retardant Type 4
FHSS	-	Frequency Hoping Spread Spectrum
GFSK	-	Gaussian Frequency Shift Keying
HPBW	-	Half-power beamwidth
IEEE	-	Institution of Electrical and Electronic Engineer
IF	-	Intermediate Frequency
ISM	-	Industrial, Scientific, Medical
LAN	-	Local Area Network
LOS	-	Line of Sight
NLOS	-	Non line of sight
OFDM	-	Orthogonal Frequency Division Multiplexing

QPSK	-	Quadrature Phase Shift Keying
QAM	-	Quadrature Amplitude Modulation
RF	-	Radio Frequency
SDMA	-	Spatial Division Multiple Access
SINR	-	Signal to Interference and Noise Ratio
SIR	-	Signal to Interference Ratio
SLL	-	Side lobe level
SNR	-	Signal to Noise Ratio
UV	-	Ultra Violet
VoWi-Fi	-	Voice over Wide Fidelity
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

dB	-	decibel
$1R$	-	First beam on the right side of polar plot
$1L$	-	First beam on the left side of polar plot
$2R$	-	Second beam on the right side of polar plot
$2L$	-	Second beam on the left side of polar plot
W	-	Width of rectangular patch antenna
L	-	Length of rectangular patch antenna
ε_r	-	Dielectric constant
h	-	Substrate height
λ_g	-	Guided wavelength
(r,θ,φ)	-	Spherical coordinate system
E	-	Electric
H	-	Magnetic
$P(\theta)_n$	-	Normalized radiated power pattern
$P(\theta)$	-	θ component of the radiated power as a function of angles θ
$P(\theta)_{max}$	-	The radiated power maximum value
E_θ	-	E field existing θ direction
E_φ	-	E field existing φ direction
f_u	-	Upper cutoff frequency
f_l	-	Lower cutoff frequency
N	-	Number of elements
d	-	distance between antenna elements
θ	-	phase
β	-	phase difference between antenna elements
k	-	wave number

λ_0	-	wavelength in free space
l	-	transmission line length
Z_o	-	characteristic impedance
w	-	transmission line width
ε_{eff}	-	effective dielectric constant
c	-	velocity of light in free space
f_r	-	operating frequency
$tan\ \delta$	-	dissipation factor
L_{eff}	-	Effective length
ΔL	-	length extension
$BW\%$	-	bandwidth in percentage

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CHAPTER 1

INTRODUCTION

This dissertation proposes the development of multibeam antenna that can be implemented for WLAN application. In this first chapter, the background of the project is discussed providing the problem statement, objective, scope of the study and project contribution.

1.1 Project Background

In recent years, wireless networking has become a key solution to various data communication needs. Wireless LANs are fast, flexible and cheap compared to conventional wired LANs and they are still improving [1]. While in wireless communications two most important restricting factors are interference and multipath fading [2]. Multipath is a condition which arises when transmitted signal undergoes reflection from various obstacles in the propagation environment which cause the multiple signals arrive from different directions [3]. The result is degradation in signal quality when they are combined at the receiver due to the phase mismatch. Co-channel interference is the interference between signals that operate at the same frequency.

Smart antenna is one of the most promising technologies that will enable higher capacity in wireless networks by effectively reducing multipath and co-channel interference [4]-[6]. This achieved by focusing the radiation only in the desired direction and adjusting itself to change traffic conditions or signal environment. The early smart antenna systems were designed for use in military applications to suppress interfering or jamming signals from the enemy [3]. Since interference suppression was a feature in this system, this technology was borrowed to apply to personal wireless communications where interference was limiting the number of users that a network could handle [3].

It has been studies [7] and tested [8], [9], that applying simple smart antenna systems and algorithm to WLAN, would improve the performance worthily [1]. Taking into account that IEEE 802.11a WLAN the bit rate rises with an increase in the Signal to Interference and Noise Ratio (SINR), developing a smart antenna solution for WLAN application becomes more valuable [1]. Multiple beam antenna array, a part of smart antenna system is known to be able to provide capacity enhancement by means of interference reduction though spatial filtering [9]. It provides a considerable increase in network capacity when compared to traditional antenna systems or sector based systems [9].

The current trend in most access point in conventional WLAN is to use omnidirectional antennas, which radiates and receives power equally in all directions [10]. The implementation of this antenna is simple but it forms some limitations on the performance of the network. As the direction is not specific, only small percentage of the overall energy is reaching to the desired user which resulting the lower power efficiency. It also suffers of co-channel interference as signals that operate at the same frequency from undesired directions also capable to reach the antenna. Due to the limited spectrum allocation in WLAN, co-channel interference will become an issue which is the major problem of omnidirectional antenna broadcast [11].

One of the proposed solutions to overcome these constraints is to use multibeam antenna on WLAN access points, AP [12]. Multibeam antennas are antenna array that make use of beamforming network to produce multiple independent beams that directed to different directions. By offering independent beams or channels, AP will switch between these channels to select the channel that has the highest received power. This feature assist the antenna system to maximize the power received in the desired directions.

The implementation of multibeam antenna is not new. In fact, it has been implemented in Cellular Radio Systems in a few years back. It has been reported in [6] that by having a multiple beam, the selected beam can reduce the interference, increase the system carrier to interference level and then offer an opportunity for the greater capacity by tighter frequency reuse. The increase in frequency reuse permits a 75% increase in the number of RF channels at the site and doubling the overall number of the subscriber capacity [6].

As the implementation of multibeam antenna gives a tremendous result in cellular communications, people interested to apply multiple beam antennas for WLAN communications. So far, most studies had done on the simulation to observe the performance in WLAN [1], [9], [12]-[15]. For example in [12], it has been proved that the multibeam antenna is capable to reduce the value of Bit Error Rate (BER). Compare to omni directional antenna application, the simulation results show that utilizing switch-beam antenna in AP the BER performance improve about 2 dB in light-of-sight (LOS) case, and 6 dB in non-light-of –sight (NLOS) case.

With the motivation gained from the simulation that has been done in literature [1], [9], [12]-[15], this project aims to produce physical implementation of multibeam antenna so that the actual performance of multibeam antenna in WLAN could be observed in future.

1.2 Problem Statement

By applying omnidirectional antenna on the WLAN AP, it is suffering from a number of disadvantages which can be summarized as follows:

I. Lower power efficiency
II. Capacity Limitation due to contribution of co-channel interference

These disadvantages can be overcome by using multibeam antenna on the WLAN access point. This project will only focus on the development of the antenna itself to meet the satisfied performance that can be used in WLAN system. Thus far, a few studies has been done on the multibeam antenna, but most of them were discussing more about beamforming network [16]-[23] which are in terms of bandwidth and compactness while put less concentration on constructing the multibeam antenna itself. The main task here is to design a multibeam antenna system by integrating an antenna array with beamforming network so that the overall performance of the multibeam antenna in terms of radiation pattern could be observed.

1.3 Objective

The main objectives of this study can be divided into two goals;

I. To design an antenna system that capable to produce multiple beam of the radiation pattern
II. To simulate and fabricate that antenna system design so that its performance can be observed

This project is aim for WLAN application at 2.4GHz

1.4 Scope of Study

The first part of this study is to understand the concept of multibeam antenna. The needed of multibeam antenna on WLAN, the function of the multibeam antenna and implementation of the antenna system are studied.

In the second part of the study, the multibeam antenna is designed and simulated. At this stage, the fundamental of antenna parameters, microstrip antenna characteristics and the theory about multibeam antenna has been covered. After that, the antenna array and Butler Matrix are designed and simulated.

The third part is the fabrication and measurement of the design. At this stage, related equipment such as UV Light Equipment, Network Analyzer, Spectrum Analyzer, Signal Generator, etc. are expected to be familiarized and well handled.

The last part of the study is the analysis part. It is expected that during the study, the measured result and the theoretical should be compared and observed.

1.5 Project Contribution

The application of smart antenna is not limited to the WLAN network only, but also can be implemented in most communication network. As provided in Chapter 2, Section 2.4, most studies have been done on the improvement of beamforming network [16]-[23] rather than constructing the multibeam antenna itself. This dissertation will give a basic idea about the integration between antenna array and beamforming network and the performance of multibeam antenna using 3 different types of antenna (directional antenna, omnidirectional antenna, and broader beamwidth antenna) are observed. Previous works only show the result of using omnidirectional antenna [24] and broader beamwidth antenna [25]-[27] which constructed and discussed independently. The multibeam antenna produced by this project could be integrated later with RF switch and controller part that constructed by other parties so that a complete switched beam antenna system could be constructed. Multibeam antenna also can be implemented in the case of Spatial Division Multiple Access (SDMA) by injecting different signal to each input ports [28], [29].

1.6 Organization of Thesis

The thesis is divided into five chapters. The first chapter is Introduction, which provides information regarding the project background, objectives, scope of project, project contribution and the layout of the thesis.

The second chapter is Literature Review. In this chapter, the concept of smart antennas, antenna theory, beamforming network and related previous works are thoroughly explained.

The third chapter is Methodology, in which the methods employed in this project will be explained. The design procedures and simulation results for this project will be presented in detail. The simulation results and subsequent analysis will be discussed. Prototype fabrication and measurement setup are also presented.

Results and analysis of the fabrication and measurement are presented in Chapter 4. The comparison between simulations, fabrication results, measurement results, and computation result will be explained in this chapter.

The last chapter is Conclusion and Future Work. This chapter will conclude the findings of the project and provide recommendations for future work.