UNIVERSITI PUTRA MALAYSIA

DESIGN AND ANALYSIS OF PHASED ARRAY ANTENNA BEAM STEERING FOR SATELLITE TRACKING

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of Requirement for the Degree of Master of Science

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DEDICATION

To my beloved parents who have guided me with endless patience

my brothers and sister for their presence in my life.

Thank you.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairperson: **Nor Kamariah Noordin, M.Sc.**

Faculty: **Engineering**

Nowadays achievements on mobile satellite system (MSS) communication give a great concern for research in global wireless communication fields. This has prompted the development of several Non Geostationary Earth Orbit (Non-GEO) satellite systems that promises worldwide connectivity for real-time communications. The mobility of Non-GEO satellite systems require a high directivity satellite tracking technique and a reliable inter satellite handover algorithm to ensure that connectivity between two end users are not interrupted as a result of satellite movement.

In this thesis, phased array antenna has been proposed to obtain high directivity beam for satellite tracking. In order to do this, the phased array antenna mathematical model has been developed. This mathematical model has demonstrated that a narrow beam with high directivity could be generated. By changing the phase of the exciting currents in each element of antenna array, the radiation pattern could be varied through space. Thus, the generation of multiple and steerable beams also could be depicted by varying the phase shift of phase shifter with appropriate spacing between each elements

to be sufficiently large. It is also shown here that the generated radiation beamwidth can be controlled by varying the number of antenna elements. It was found that the beamwidth reduces exponentially with the increment of the number of antenna elements.

A new algorithm called Soft Dual Beam (SDB) algorithm has been developed to provide a solution to handle the inter satellite handover process. SDB is derived from a number of various Non-GEO satellite orbital parameters such as satellite orbital period, satellite visibility period and inter satellite period. A high directivity beam from phased array antenna will be generated and steered to link up with incoming ascending satellite at one end when the connected outgoing descending satellite exceeded the defined critical elevation angle at the other end. The SDB algorithm helps to lower the inter satellite handover delay by accurately tracking the position of the satellite with the same signal level before the handover. Simulations have been done to measure the performance of the SDB algorithm.

It is concluded that the proposed SDB algorithm provides low delay in handover between satellites process. Thus, the possibility of communication connection dropping during handover will be significantly low. This is due to the algorithm which uses elevation angle in initiating inter satellite handover, instead of measuring signal link level to the satellites. With the introduction of SDB algorithm, the quality of service (QoS) for the next generation MSS communication system is expected to be improved.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANTENA TATASUSUNAN FASA ALUR KEMUDIAN UNTUK JEJAKAN SATELIT

Oleh

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Pencapaian sistem komunikasi satelit bergerak (MSS) masa kini telah memberi banyak tumpuan bagi penyelidikan dalam bidang komunikasi wayarles sedunia. Ini telah merangsangkan pembangunan pada beberapa sistem satelit Bukan Orbit Geopegun Bumi (Non-GEO) yang menjanjikan perhubungan ke seluruh dunia bagi komunikasi masa nyata. Pergerakan sistem satelit Non-GEO memerlukan teknik jejakan satelit yang berketerarahan tinggi dan satu algoritma pengambilalihan antara satelit yang konsisten bagi memastikan perhubungan antara dua pengguna akhir tidak diganggu akibat daripada pergerakan satelit itu.

Dalam tesis ini, antena tatasusunan fasa telah dicadangkan bagi memperoleh alur berketerarahan tinggi untuk jejakan satelit. Untuk tujuan ini, model matematik untuk antena tatasusunan fasa telah dibangunkan. Model matematik ini telah menunjukkan satu alur halus berketerarahan tinggi dapat dijanakan. Dengan menukarkan fasa arus teruja dalam setiap unsur antena tatasusunan, corak alur dapat diubah menerusi ruang. Oleh itu, penjanaan alur yang berbilang dan berkebolehkemudian juga dapat ditunjukkan dengan

mengubah fasa pada penganjak fasa dengan peruntukan ruang antara setiap unsur yang cukup luas. Ini juga menunjukkan lebar jalur sinaran yang dijanakan dapat dikawal dengan mengubah bilangan unsur antena. Didapati bahawa lebar jalur menyusut secara exponen dengan tokokan bilangan unsur antena.

Satu algoritma baru yang dikenali sebagai algoritma Dwi Alur Halus (SDB) telah dibangunkan untuk memberi satu penyelesaian bagi mengendalikan proses pengambilalihan antara satelit. Algoritma SDB diterbit daripada pelbagai orbit satelit Non-GEO parameter seperti tempoh orbit satelit, tempoh kebolehlihatan satelit dan tempoh antara satelit. Satu alur berketerarahan tinggi dari antena tatasusunan fasa akan dijanakan dan dikemudikan bagi menyambungkan kedatangan satelit yang menaik pada satu hujung apabila sambungan keluaran satelit yang menurun pada satu hujung yang lain melebihi sudut dongakan takrifan yang kritikal. Algoritma SDB membantu mengurangkan masa kelengahan pengambilalihan antara satelit dengan kejituan jejak kedudukan satelit pada aras isyarat yang sama sebelum pengambilalihan. Simulasi telah dijalankan untuk mengukur prestasi algoritma SDB.

Ini dapat disimpulkan bahawa algoritma SDB yang telah dicadangkan memberi masa kelengahan yang rendah dalam proses pangambilalihan antara satelit. Dengan itu, kebarangkalian rangkaian komunikasi tercicir semasa pengambilalihan akan menjadi rendah. Ini disebabkan algoritma yang mengunakan sudut dongakan dalam memulakan pengambilalihan antara satelit, sebagai mengganti bagi mengukur paras isyarat sambungan pada satelit. Dengan pengenalan algoritma SDB, kualiti perkhidmatan untuk sistem komunikasi MSS pada generasi akan datang dijangka dapat dipertingkatkan.

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LIST OF ABBREVIATIONS

BS	-	Base Station
BW	-	Beamwidth
CDMA	-	Code Division Multiple Access
CPW	-	Coplanar Waveguide
DBS	-	Direct Broadcast Satellite
ES	-	Earth Station
FHRP	-	Footprint Handover Reroute Protocol
FR	-	Footprint Rerouting
GEO	-	Geostationary Earth Orbit
GSLD	-	Gain Switched Laser Diode
HTS	-	High Temperature Superconductor
IL	-	Insertion Loss
IF	-	Intermediate Frequency
IMT-2000	-	International Mobile Telecommunications year 2000
ISL	-	Inter Satellite Link
LEO	-	Low Earth Orbit
LF	-	Loop Filter
MAHO	-	Mobile-Assisted Handoff
MCHO	-	Mobile-Controlled Handoff
MEMS	-	Microelectromechanical System
MEO	-	Medium Earth Orbit

MIC	-	Microwave Integrated Circuit
MMIC	-	Monolithic Microwave Integrated Circuit
MSS	-	Mobile Satellite System
MT	-	Mobile Terminal
NCHO	-	Network-Controlled Handoff
Non-GEO	-	Non-Geostationary Earth Orbit
OEPLL	-	Optoelectronic Phase Locked Loop
PCS	-	Personal Communication System
PLL	-	Phase Locked Loop
PSK	-	Phase Shift Keying
PSTN	-	Public Switched Telephone Network
QoS	-	Quality of Service
SDB	-	Soft Dual Beams
SLR	-	Spacing Distance over Wavelength Ratio
TTD	-	True Time Delay
VCO	-	Voltage-Controlled Oscillator
YBCO	-	Yttrium Barium Copper Oxide

LIST OF NOTATIONS

h_G	-	Altitude of GEO Satellite
h_N	-	Altitude of Non-GEO Satellite
α	-	Angular Phase Shift
J_{SO}	-	Current Amplitude
J_S	-	Current Density
G	-	Directive Gain
ω	-	Earth Angular Rotation Speed
E	-	Electric Field
ε_o	-	Electric Permittivity
ψ	-	Elevation Angle
R_E	-	Equatorial Radius of the Earth
η_O	-	Free Space Wave Impedance
R_G	-	GEO Satellite Orbit Radius
v_G	-	GEO Satellite Speed
$T_{satellite}$	-	Inter Satellite Period
H	-	Magnetic Field
μ_o	-	Magnetic Permeability
v_N	-	Non-GEO Satellite Speed
T_N	-	Non-GEO Satellite Orbital Period

R_N	-	Non-GEO Satellite Orbit Radius
S_o	-	Orbit Length
v_p	-	Phase Velocity
$P_{isotrope}$	-	Power Density of Isotrope
$P_{semi\text{-}isotrope}$	-	Power Density of Semi-Isotrope
β	-	Propagation Constant
T_{visit}	-	Satellite Visibility Period
d	-	Spacing Between Antenna Elements
c	-	Speed of Light
λ	-	Wavelength

CHAPTER I

INTRODUCTION

The commercial proliferations of cellular voice and limited data service have created a great demand for mobile communications and computing. Current voice, fax, email, and paging services will give way to data transfer, video conferencing, image transfer, and video delivery. Achieving such an advanced level of tetherless mobile multimedia service requires the development of a wireless network that can provide not only the integrated services, but also dynamic relocation of mobile terminals. As a result, next generation mobile communication systems are currently being researched worldwide (Akyildiz, 1999).

Mobile Satellite Communication Systems Overview

Nowadays private companies are striving to provide truly seamless global communications to the public, making today's personal communication systems (PCS) a proving ground for new technologies. Recent years have witnessed the introduction of a large number of mobile satellite systems (MSS). The integration of MSS with terrestrial cellular networks will pave the way for future next generation mobile communication systems. Several satellite orbital constellations have been proposed for MSS (Re, 1999). Currently, there are more than 333 communication satellites in orbit at an altitude ranging from 780 km to 36,000 km away from earth (Boeke, 1999). Depending on the distance between the satellite and the earth, these systems are grouped into Low Earth

Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO) systems. The LEO satellite systems use orbits with altitudes in the range of 1000 km above the earth's surface. This is followed by MEO satellite systems, with their orbit altitudes between 2000 km and 10,000 km, and then by GEO satellite systems, with the orbit at 36,000 km above the earth's surface (Bialkowski, 1999).

GEO satellites are fixed with respect to a terrestrial observer and they are on an equatorial circular orbit at about 36,000 km of altitude. Theoretically, only three GEO satellites are required to serve all the Earth coverage (Re, 1995). GEO satellite systems allow full earth coverage below 70 degrees latitude with as few as three satellites. However, the GEO satellites may cause a significant transmission delay with more than 250 ms due to their high altitude. Therefore it could be a problem especially when there is a concatenation of networks. Some of these delay problems associated with satellite transmissions are avoided by going to wireline fiber and LEO or MEO communication satellites (Pattan, 2000). This has prompted the development of several Non-Geostationary Earth Orbit (Non-GEO) satellite systems which consists of LEO and MEO that promise worldwide connectivity and real-time voice communications.

Since LEO and MEO satellites are usually defined for those with altitude between 500 and 10,000 km above the Earth's surface, these low altitude satellites systems are seen as a means of providing truly global ubiquitous hand-held low delay real time communication systems with only low power requirements, and ensure the earth coverage with smaller cells, so achieving a higher traffic capacity. This global approach has sparked the development of several new communication satellite systems, which abandoned the traditional use of GEO in favour of LEO and MEO satellite systems (Uzunalioğlu, 1997; Pratt, 1999).

The Non-GEO satellites are not stationary with respect to a fixed point on the Earth with a constant speed where the satellite ground-track speed is far greater than the earth rotation speed and the user speed (Gariz, 1994). In contrast to terrestrial mobile cellular systems, when the mobile network is based on Non-Geo satellites, these satellites behave like moving base stations with respect to land users. The satellite footprints (or cells) therefore move through the user space and the period of visibility for an individual satellite is typically only a few minutes. These satellite cells move at such a high speed that the movement of the mobile terminal (MT) can usually be neglected (Carter, 1995; Ruiz, 1998).

Global coverage at any time is possible if a certain number orbits and satellites are used (Uzunalioğlu, 1997). Besides that, inter satellite links (ISL) make it possible to route a connection through the satellite network without using any terrestrial resources. As an example, the Iridium system uses 6 polar orbits with 11 satellites in each orbit (Pratt, 1999). Construction of these satellite constellations for global wireless communication has begun with the launch of a number of Motorola's Iridium satellites in 1997, and the building of a number of Qualcomm's Globalstar satellites launched in 1998. These early constellations, and their competitors, aim to provide low bandwidth satellite telephony world wide, including paging, faxing and high speed modem services. Future satellite constellations have been proposed for high bandwidth wireless data transmission such as Teledesic satellites (Wood, 1998).