UNIVERSITI PUTRA MALAYSIA

CHANNEL MODELING AND DIRECTION-OF-ARRIVAL ESTIMATION IN MOBILE MUTIPLE-ANTENNA COMMUNICATION SYSTEMS

ARASTOO ROSTAMI RAVARI.

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By

ARASTOO ROSTAMI RAVARI

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

January 2006

DEDICATION

This Thesis is dedicated to

All I Love

Specially

My Mother's Sprite

and

My Father, Wife, Daughter and Son

and

My supervisor Professor Dr. Borhanuddin Mohd. Ali

for

his guidance, advice and endless supports

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman: Professor Borhanuddin Bin Mohd. Ali, PhD

Faculty: Engineering

Antennas that are able to adaptively direct the transmitted (and received) energy are of great interest in future wireless communication systems. The directivity implies reduced transmit power and interference, and also a potential for increased capacity. This thesis treats some modeling and estimation problems in mobile communication systems that employ multiple antennas, primarily at the base stations. With multiple antennas at the receive side, the spatial dimension is added, and processing is performed in both the temporal and spatial domains. The potential benefits are increased range, fading diversity and spatially selective transmission. Specifically, the problems dealt in this thesis are mainly related to the uplink transmission from mobile to the base station. Two main topics are studied, channel modeling and estimation of channel parameters.

This thesis first describes the modeling of the reflected power distribution due to the scatterers close to the mobile stations, in terms of the received signal azimuth at the base station with multiple-antenna. As a more realistic channel modeling, a

multipath fading deterministic channel model is proposed to generate properly correlated faded waveforms with appropriate power distribution through azimuth spread of received signal. The purpose of the proposed channel model is to model fading received signal waveforms with Laplacian distribution of power through received signal azimuth spread.

This thesis is divided into two parts; in the first part multipath fading by local scattering are used to derive a channel model including the spatial dimension for non frequency-selective fading. This means that the mobile is not modeled as a point source but as a cluster of a large number of independent scatterers with small time delay spread to take into account angular spreading of the signal. Properly correlated fading waveforms are obtained by taking into account the angular spread of the scattered signals from a particular distribution of scatterers. By appropriate scaling of the array response vector (ARV) based on non-equal locations for various received signal components as a function of distance from the transmitter, the reflected power from a given scatterer is no longer constant but varies as a function of the distance from the transmitter. Our proposed channel model is able to produce fading signal waveform which agrees with the results of reflected angular power dispersions measured in the field, e.g. Laplacian distribution of power in azimuth. It is also shown that the channel response can be modeled as a complex Gaussian vector.

Although the channel will be frequency selective in the case of multipath propagation with considerable time spread, this can be modeled as having more than

one cluster of scatterers. By employing Walsh-Hadamard codewords an extension to wideband multipath fading model is achieved.

It is shown that the statistical properties of proposed model such as signal waveform's correlation, autocorrelation and crosscorrelation between generated paths, are in good agreement with the theory in space and time domain. The model can be applied to evaluate smart antenna systems and beamforming algorithms in the uplink by generating uncorrelated multipaths Rayleigh fading waveforms with certain spatio-temporal correlation and spatial coordinates relative to base stations to simulate received signals from mobiles and interferers. Bit-error-rate (BER) performance analysis of uniform linear array antenna (ULA) based on correlation matrix is also presented as an application of our proposed model for multiple-antenna evaluations. Our simulated results show 5% improvement than other published related works.

One problem when modeling frequency selective fading is that each cluster has to be assigned spatial parameters. Since the joint spatial and temporal characteristics are unknown, non-parametric channel estimation approaches are required in this case in order to estimate the channel parameter, which is the subject of the second part.

The second part of the thesis deals with channel parameter estimation of distributed scattering sources. Because of local scattering around the transmitter the signal waveforms appears spatially distributed at the receiver. The characterization of the spatial channel, in particular mean direction of arrival and spatial spread, is of prime interest for system optimization and performance prediction. Low-complexity

spectral-based estimators are used for the estimation of direction and spatial spread of the distributed source by employing the proposed channel model for simulation. Estimated parameters from recent measurements ([PMF00]) are compared with estimated parameters from model generated waveforms as well as theoretical distribution of received signal's angular spread. Good agreement between them is observed which shows the correctness of our proposed channel model for simulating spatio-temporally correlated received signal at an antenna array. The estimated parameter error improved by 5% over the other published related works.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMODELAN SALURAN DAN PENGANGGARAN ARAH KETIBAAN DALAM SISTEM KOMUNIKASI BERGERAK ANTENA BERBILANG

Oleh

ARASTOO ROSTAMI RAVARI

Januari 2005

Pengerusi: **Profesor Borhanuddin Bin Mohd Ali, PhD**

Fakulti: **Kejuruteraan**

Antena yang mampu untuk menghala tenaga dihantar (dan diterima) secara mudahsuai adalah merupakan tarikan besar pada sistem komunikasi wayerles akan datang. Penghalaan menandakan kuasa penghantaran dan gangguan yang lebih kecil, dan potensi untuk penambahan kapasiti. Tesis ini mengolahkan beberapa masalah pemodelan dan penganggaran dalam sistem komunikasi bergerak yang menggunakan antena berbilang, terutamanya di stesyen tapak. Dengan antena berbilang pada bahagian penerimaan, dimensi ruangan adalah ditambahkan, dan pemerosesan dibuat dalam kedua dua domain masa dan ruangan. Potensi manafaat adalah peningkatan julat, kepelbagaian pemudaran, dan penghantaran pilihan ruangan. Secara khususnya, masalah yang diolahkan di dalam tesis ini adalah terutamanya berkaitan dengan penghantaran ke atas dari stesyen bergerak ke stesyen tapak. Dua topik utama adalah dikaji, pemodelan saluran dan penganggaran parameter saluran.

Tesis ini mula mulannya memerihalkan pemodelan kepada taburan kuasa terpantul disebabkan oleh penyelerak berhampiran dengan stesyen bergerak, dalam bentuk azimuth isyarat yang diterima di stesyen tapak dengan antenna berbilang. Untuk pemodelan saluran yang lebih realistik, suatu model saluran pudaran deterministik adalah dicadangkan untuk menjanakan bentukgelombang pudar yang benar benar berhubungkait dengan taburan kuasa bersesuaian melalui penyebaran azimuth isyarat yang diterima.

Tesis ini dibahagikan kepada dua bahagian; dalam bahagian pertama pemudaran laluan berbilang oleh penyelerakan lokal adalah digunakan untuk menerbitkan suatu model saluran temasuk dimensi ruangan untuk pemudaran frekuensi-pilihan. Ini bermaksud bahawa stesyen mobil ini tidak dimodelkan sebagai sumber titik tetapi sebagai suatu gugusan kepada suatu bilangan penyelerak bebas yang banyak, dengan penyebaran lengah yang kecil untuk mengambil kira penyebaran sudut isyarat tersebut. Gelombang pemudaran berhubungkait sempurna adalah diterima dengan mengambil kira penyebaran sudut isyarat terselerak dari suatu taburan penyelerak tertentu. Dengan penskalaan vektor sambutan tatasusunan (ARV) yang sesuai berdasarkan kepada lokasi tak sama beberapa komponen isyarat yang diterima sebagai fungsi kepada jarak dari pemancar, kuasa terpantul dari suatu penyelerak adalah tidak lagi malar malah berubah sebagai fungsi kepada jarak dari pemancar. Model saluran cadangan kami ini mampu untuk mengeluarkan gelombang isyarat pudaran yang bersetuju dengan hasil keputusan penyebaran kuasa sudut pantulan yang diukur di medan, cth, taburan Laplacian kuasa pada azimuth. Adalah ditunjukkan juga bahawa sambutan saluran boleh dimodelkan sebagai vektor Gaussian komplex.

Walaupun saluran ini akan menjadi frekuensi pilihan dalam kes perambatan berbilang laluan dengan penyebaran masa yang banyak, ia boleh dimodelkan sebagai mempunyai lebih dari satu gugusan penyelerak. Dengan menggunakan kod perkataan Walsh-Hadamard satu tambahan model pudaran berbilang jalurluas adalah dicapai.

Adalah ditunjukkan bahawa sifat model yang dicadangkan seperti hubungkait gelombang isyarat, hubungkait sendiri, dan hubungkait bersilang di antara laluan yang dijanakan, adalah bersetuju dengan baik dengan teori domain ruangan dan masa. Model ini boleh diaplikasikan untuk menilaikan sistem antena pintar dan algoritma pembentukalur pada pautan ke atas dengan menjanakan gelombang pudaran Rayleigh berbilanglaluan dengan suatu hubungkait ruangan-masa dan koordinat ruangan relatif kepada stesyen tapak untuk menyimulasi isyarat terimaan dari stesyen bergerak dan pengganggu.

Satu masalah apabila memodelkan pemudaran frekuensi pilihan adalah setiap gugusan hendaklan diberikan parameter ruangan. Oleh kerana ciri ruangan dan masa bersama adalah tidak diketahui, pendekatan penganggaran saluran tak parametrik adalah diperlukan dalam kes ini untuk menganggarkan parameter saluran, ia itu tajuk bahagian kedua ini.

Bahagian kedua tesis ini membincangkan penganggaran parameter saluran kepada sumber penyelerak tertabur. Oleh kerana penyelerkakan lokal sekitar pemancar, gelombang isyarat nampak tertabur secara ruangan pada penerima. Pencirian

saluran ruangan, terutamanya arah ketibaan min dan penyebaran ruangan, adalah menjadi minat utama untuk pengoptimuman sistem dan ramalan prestasi. Penganggar berasaskan spektrum yang tak berapa rumit adalah digunakan untuk penganggar arah dan penyebaran ruangan sumber tertabur dengan menggunakan model saluran yang dicandangkan untuk simulasi. Parameter anggaran dari pengukuran terkini adalah dibandingkan dengan parameter anggaran dari gelombang janaan model dan juga taburan teoretikal penyebaran sudut isyarat terimaan. Persetujuan yang baik di antara mereka adalah diperhatikan yang menunjukkan ketepatan model saluran cadangan kami untuk mensimulasiisyarat terimaan berhubungkait secara ruang-masa pada tatasusuan antena. Ralat parameter anggaran menjadi 5% lebih baik dari hasilkerja lain yang berkaitan yang telah diterbitkan.

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I certify that an Examination Committee met on 12 of January 2006 to conduct the final examination of Arastoo Rostami-Ravari on his Doctor of Philosophy thesis entitled "Channel Modeling and Direction-of-Arrival Estimation in Mobile Multiple-Antenna Communication Systems" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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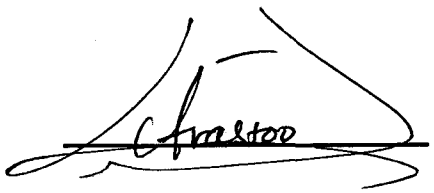
DECLARATION

I hereby declare that the thesis based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



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5.5 RMSE of $\hat{\theta}_0$ for different number of antennas array elements (sensors) M. Gaussian azimuth spread ($\widetilde{\theta}$) with parameters $\theta_0 = 0^\circ$, $\sigma_\theta = 5^\circ$ (i.e. $p(\theta;\theta_0,\sigma_\theta)$ is the Gaussian PDF $\aleph(\theta_0,\sigma_\theta^2)$), N=64 scatterers, 10 dB SNR 155

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5.7 Estimated PDFs. Gaussian spread, $\theta_0 = 0^\circ$, $\sigma_\theta = 5^\circ$, 16 sensors, theoretical covariance matrix with S/σ^2 = 10 dB 157

LIST OF ABBREVIATIONS

3G	Third Generation
AOA	Angle-of-arrival
ARV	Array Response Vector
AS	Azimuth Spread (or Angle Spread)
BER	Bit-error-rate
BPSK	Binary Phase-Shift Keying
CBF	Conventional Beamformer
CLT	Central Limit Theorem
CM	Centre of Mass
CRLB	Cram´er-Rao Lower Bound
DISPARE	Dispersed Signal Parametric Estimation
DOA	Direction-of-arrival
DSPE	Distributed Signal Parameter Estimator
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile communication
LOS	Line-of-sight
LTV	Linear Time-variant Filter
MMSE	Minimum Mean Square Error
MUSIC	Multiple Signal Classification
MVDR	Minimum Variance Distortionless Response
PAS	Power Azimuth Spectrum
PDF	Probability Density Function