Capacity of Multiple-Input Multiple-Output Wireless Communication Systems Operating in the HF Band

by

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B E (Computer Systems Engineering)

Thesis submitted for the degree of

Doctor of Philosophy

in

School of Electrical and Electronic Engineering,
Faculty of Engineering,
Computer and Mathematical Sciences

The University of Adelaide, Australia

2010

Typeset in LaTeX 2ε
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Contents

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Abstract

Spatial multiplexing is a wireless communication technique that employs MIMO (multiple-input multiple-output) antenna arrays and spatial signal processing to effectively establish multiple parallel spatial data pipes within the same frequency band. The number of parallel spatial data pipes that can be supported is dependent on a number of factors, one of the most significant of these being multipath richness. In general, a channel that is rich in multipath will be capable of supporting a large number of parallel spatial data pipes, leading to high capacities.

The HF (high frequency) band is subject to significant multipath caused by multiple refractions and reflections between the ionospheric layers and the earth's surface, making it a possible candidate for MIMO techniques. In this thesis, the capacity offered by spatial multiplexing in the HF band is investigated. To the best of our knowledge, no such investigation has previously been conducted. The approach taken involves collection of multi-channel HF sounder data from which antenna and propagating mode correlation measurements are made. The antenna and mode correlation measurements are used to generate stochastic channel matrices, from which estimates of MIMO capacity can be calculated.

The key contributions presented include estimation of HF MIMO capacity from ionograms, development of a multi-channel receiver for HF radio research, development of a model for the HF MIMO channel matrix, and development and application of a technique for estimating HF MIMO capacity from multi-channel receiver data. The results obtained from the investigation indicate that spatial multiplexing offers a significant increase in capacity compared with single channel communication technqiues, and should therefore be seriously considered for future HF radio systems. A major application that stands to benefit from HF MIMO technology is ship based communications.

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Declaration

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Acknowledgements

First and foremost I would like to thank my supervisor Cheng Chew Lim for providing me with the opportunity to undertake this research, and for the considerable effort he has put in during the lengthy process of reviewing and editing this thesis.

Secondly I would like to thank Angus Massie of DSTO who came up with the idea for this project, and provided valuable technical supervision.

Design and implementation of the Multi-Channel Receiver system was a challenging task which involved contributions from several individuals. Kevin Zacher created the layouts and schematics for the ADC and MCR boards. Kiet To designed the DDC chip. Darren Dicera wrote firmware and embedded software for the controller FPGA. Matthew Goss assisted with the layout of the DDC chip, performed systems engineering tasks, and wrote the Console software. Matthew Trinkle assisted with integration and testing of the MCR system during the final stages of the project.

Collection of radio data could not have been possible without the assistance of Warren Marwood, Angus Massie, and the ISRD of DSTO who provided access to the receive antenna array and RF front-end infrastructure. The ISRD also provided ionosonde data logs required to perform initial HF MIMO capacity calculations.

Financial assistance was provided to this project by Ebor Computing and the Australian Research Council through the Linkage-Projects grant LP0219662. Additional funding was also provided by the IEEE AP & MTT Chapter through the Young RF Engineer Project Award 2004, which enabled me to visit an overseas conference and the headquarters of Airgo Networks in Palo Alto.

My friends made things a lot of fun along the way, in particular Tony Sarros who I thank for introducing me to a wealth of new terminology, stealing my LaTeX templates, and that near death

experience, Brian Ng and Bobby Yau who provided crazy times involving tiny table tennis, tuna and sandwich toasters, and Hong Gunn and Troy Townsend who helped me fine-tune my XBlast skills on a daily basis.

Lastly I would like to thank Mum for the love and support she provided along the way, particularly during 2005 when my scholarship had run out.

Nigel Brine

List of Figures

List of Tables

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List of Acronyms

3GPP . . . . . 3rd Generation Partnership Project

ADC . . . . . analog-to-digital converter

AGC . . . . . automatic gain control

AM . . . . . amplitude modulation

AWGN . . . . . additive white Gaussian noise

BER . . . . . bit error rate

BLAST . . . . . Bell Laboratories layered space-time

BPF . . . . . band pass filters

CCDF . . . . . complementary cumulative distribution function

CIC . . . . . cascade integrate comb

codec . . . . . coder decoder

CORDIC . . . . . co-ordinate rotation digital computer

COTS . . . . . commercial off-the-shelf

CSI . . . . . channel state information

DDC . . . . . digital down converter

demux . . . . . demultiplexer

DFT . . . . . discrete Fourier transform

DSTO . . . . . Defence Science and Technology Organisation

FDTD . . . . . finite difference time domain

FFT . . . . . fast Fourier transform

FIFO . . . . . first-in first-out

FIR . . . . . finite impulse response

FMCW . . . . . frequency modulated continous wave

FPGA . . . . . field programmable gate array

GPS . . . . . global positioning system

HF . . . . . high frequency

I/O . . . . . input/output

IEEE . . . . . Institute of Electrical and Electronics Engineers

IF . . . . . intermediate frequency

iid . . . . . independent identically distributed

LAN . . . . . local area network

LCM . . . . . lowest common multiple

LLISP . . . . . Low Latitude Ionospheric Sounding Project

LO . . . . . local oscillator

LOS . . . . . line-of-sight

MCR . . . . . multi-channel receiver

MIMO . . . . . multiple-input multiple-output

MISO . . . . . multiple-input single-output

MTBF . . . . . mean time between failures

MTTR . . . . . mean time to recovery

MUF ..... maximum usable frequency

OFDM ..... orthogonal frequency division multiplexing

PDF ..... probability density function

PLL ..... phase locked loop

PPS ..... pulses per second

PRBS ..... pseudo-random binary sequence

PSD ..... power spectral density

QAM ..... quadrature amplitude modulation

Rx ..... receiver

SFDR ..... spur free dynamic range

SIMO ..... single-input multiple-output

SISO ..... single-input single-output

SNR ..... signal-to-noise ratio

SRAM ..... static random access memory

TCP/IP ..... transmission control protocol/internet protocol

Tx ..... transmitter

UTC ..... co-ordinated universal time

UTRA ..... Universal Terrestrial Radio Access

V-BLAST ..... vertical BLAST

WiSE ..... Wireless Systems Engineering

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