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DESIGN AND PERFORMANCE EVALUATION OF A FULL RATE, FULL DIVERSITY SPACE-TIME-SPREADING CODE FOR AN ARBITRARY NUMBER OF Tx ANTENNAS

By

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SUMMARY

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Since the mid 1990's, the wireless communications industry has witnessed explosive growth. The worldwide cellular and personal communication subscriber base surpassed 600 million users by late 2001, and the number of individual subscribers surpassed 2 billion at the end of 2006 [1, 2]. In order to attract and accommodate these subscribers, modern communication systems, like the Third Generation (3G) and Fourth Generation (4G) cellular networks, will have to provide attractive new features such as increased data throughput rates, greater system capacity, and better speech quality. These modern communication systems promise to have advantages such as wireless access in ways that have never been possible before, providing, amongst others services such as live television (TV) broadcasting to Mobile Stations (MS)s, multi-megabit Internet access, communication using Voice over Internet Protocol (VoIP), unparalleled network capacity, seamless accessibility and many more.

With specific, but not exclusive reference to the cellular environment, there are numerous ways to increase the data throughput rate and system capacity. From an economical perspective, it would be more efficient to add equipment to the Base Station (BS) rather than the MSs. To achieve these improvements the motivation to utilise transmit diversity's capabilities have been identified as a key research issue in this study. Alamouti [3] proposed a transmit diversity technique using two transmit antennas and one receive antenna, providing the same diversity order than using one transmit antenna and two receive antennas. Since Alamouti's publication in 1998, many papers in the field of Space-Time (ST) coding have been published. Current research in the field of ST coding consists of finding methods to extend the number of transmit antennas to more than four, while still achieving full rate, as well as full diversity which is the main motivation for this study.

This study proposes a novel idea of breaching the limitations with ST coding theory by combining ST coding with Spread Spectrum (SS) modulation techniques in order to extend the number of transmit antennas to more than four and still achieve full rate as well as full diversity. An advantage of the proposed scheme, called Direct Sequence Space-Time Spreading (DSSTS) has over current Space-Time Spreading (STS) techniques is that it uses 50% less spreading codes. A performance evaluation platform for the DSSTS scheme was developed to simulate the performance of the scheme in a realistic mobile communication environment. A mobile communication channel that has the ability to simulate time-varying multipath fading was developed and used to evaluate the performance of the DSSTS scheme. From the simulation results obtained, it is evident that Walsh sequences that exhibit particularly good cross-correlation characteristics, cannot overcome the effect of the antenna self-noise in order to exploit the diversity gain by adding extra antennas, i.e. diversity extension. The research also showed that an optimal trade-off exists between antenna diversity and antenna created self-noise. Performance results of the DSSTS scheme in slow and fast fading channels for a different number of transmit antennas are also presented in this study. With the capacity analysis of the DSSTS scheme, it was shown that the addition of extra transmit antennas to the system indeed increased the system capacity.

A further addition to this study is the investigation into the assumption that the channel should be quasi-static over the frame length of the ST code. A Space Sequence Transmit Diversity (SSTD) technique is consequently proposed that allows the transmission of the Alamouti symbols during one time interval instead of two. This relieves the ST code from the assumption that the channel should be quasi-static, allowing it to be used in a more realistic multi-user environment. A performance evaluation platform for the SSTD scheme was developed and used to obtain simulation results in a multipath fading channel. It was also shown that the proposed SSTD scheme is successful in combating the effects of multipath fading for small Code Division Multiple Access (CDMA) user loads. However, as a rule of thumb, the square root of the spreading sequence length divided by two depicts the user load at which the SSTD scheme was not capable of overcoming the combined effects of Multi-User Interference (MUI) and multipath fading.

Keywords: 3G, 4G, transmit diversity, capacity, ST Block coding, full rate, full diversity, Spread Spectrum, SSTD, DSSTS, time varying multipath fading, cross-correlation, antenna self-noise, quasi-static, CDMA, MUI.

SAMEVATTING

ONTWERP EN WERKVERRIGTING EVALUERING VAN N VOL TEMPO, VOL DIVERSITEIT RUIMTE-TYD-SPREIDING KODE VIR N ARBITRERE AANTAL UITSAAI ANTENNAS

deur

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Sedert die middel 1990’s het die draadlose kommunikasie-industrie ’n reuse ontploffing in gebruikersgetalle beleef. Die wêreldwye getal sellulêre en persoonlike kommunikasie gebruikers het die 600 miljoen kerf bereik, en die getal het 2 biljoen bereik aan die einde van 2006 [1, 2]. Om al hierdie aantekenare te akkommodeer, sal moderne kommunikasiestelsels, soos die Derde-Generasie (3G) en Vierde-Generasie (4G) selfoonnetwerke, grootliks moet aanpas om hul datatempo te verhoog, groter stelsel kapasiteit hê, beter stemkwaliteit te verkry, ens. Hierdie moderne kommunikasiestelsels beloof om voordele soos draadlose toegang te verleen, wat nog nooit van tevore moontlik was nie, soos byvoorbeeld direkte televisie uitsendings na mobielestasies, multi-megagreep Internet-toegang, kommunikasie wat gebruik maak van stem-oor-internet-protokol (VoIP), altyd-aan Internet-toegang, en meer.

Met spesifieke, maar nie eksklusiewe verwysing na die sellulêre omgewing nie, is daar ’n verskeidenheid maniere om die datatempo, asook die stelselkapasiteit te verhoog. Uit ’n ekonomiese lewensvatbare oogpunt is dit meer effektief om toerusting by die basisstasie te plaas as by die mobielestasie. Om hierdie voordele te behaal, is uitsaai-diversiteit dus as ’n sleutel navorsingsveld in hierdie studie geïdentifiseer. Alamouti [3] het ’n uitsaai diversiteitskema voorgestel wat twee uitsaai-antennas en een ontvangs-antenna gebruik en dieselfde diversiteitsorde het as ‘n stelsel wat een uitsaai-antenna en twee ontvangs-antennas het. Sedert Alamouti se publikasie in 1998 is talle publikasies oor Ruimte-Tyd (RT) kodering gepubliseer. Hedendaagse navorsing op die terrein van RT-kodering wat metodes behels wat fokus op die uitbreiding van die aantal uitsaai-antennas na meer as vier, terwyl volle datatempo en volle diversiteit steeds bereik word, het gelei tot die hooftema van hierdie studie. Hierdie studie stel ’n skema voor wat die beperkings in RT-kodering oorbrug deur Sprei-Spektrum (SS) modulasie te kombineer met RT-kodering om die aantal uitsaai-antennas te vermeerder na meer as vier, terwyl volle datatempo, sowel as volle diversiteit, steeds gehaal word. ’n Voordeel wat die voorgestelde skema, naamlik Direkte Sekwensie Ruimte-Tyd Spreiding (DSRTS), oor konvensionele Ruimte-Tyd-Spreiding (RTS) het, is dan ook dat 50% minder spreisekwensies gebruik word. ’n Werkverrigting evaluasie-platform vir die DSRTS-skema is ontwikkel om die werkverrigting van die skema in ‘n werklike omgewing te simuleer. ’n Mobiele kommunikasiekanaal wat die vermoë het om tyd-variërende multipad-deinende kanaaltoestande te simuleer, is ontwikkel en gebruik om die DSRTS-skema se werkverrigting te evalueer. Uit die simulasieresultate was dit ooglopend dat die Walsh-sekwensies, wat besonder goeie infasige kruiskorrelasie-eienskappe besit, nie die effekte van die antenna-self-ruis kon oorkom ten einde die diversiteit wat deur die byvoeging van ekstra antennas verskaf word, te benut nie, d.i. diversiteits-uitbreiding. Uit die studie was dit ook duidelik dat daar ‘n optimale uitruiling bestaan tussen antenna-diversiteit en antenna-self-ruis. Werkverrigtings-resultate van die DSRTS-skema in stadig - sowel as vinnig - deinende kanale vir verskillende aantal uitsaai-antennas, word ook in hierdie studie voorgelê. Met die kapasiteitsanalise wat van die DSRTS skema gedoen is, is bewys dat die uitbreiding van uitsaai-antennas wel die stelselkapasiteit verhoog.

In ’n verdere uitbreiding op hierdie studie is ondersoek ingestel na die onrealistiese aanvaarding dat die kanaal quasi-stationêr oor die vensterperiode van die RT-kode is. ’n Ruimte-Sekwensie Uitsaai-Diversiteits (RSUD)-metode word voorgestel in hierdie studie wat die uitsaai van die Alamouti simbole oor een tydsinterval, in plaas van twee tydsintervalle laat geskied. Dus hoef die kanaal vir ‘n RT-kode nie meer quasi-stationer te wees nie en kan dit gebruik word in ’n meer realistiese multi-gebruiker omgewing. ’n Werkverrigtings-evaluasieplatform vir die RSUD is ontwikkel om simulasieresultate vir ’n deinende multipad kanaal te verkry. Die studie toon ook dat die voorgestelde RSUD-skema suksesvol is in die oorkoming van deinende multipad-kanaal effekte vir ’n klein Kode-Divisie-Veelvuldige-Toegang (KDVT) gebruikersbelading. As ‘n algemene reël kan die vierkantswortel van die sekwensielengte gedeel deur twee beskou word as die gebruikerslading waar die RSUD skema egter nie die gekombineerde effekte van die deinende kanaal en Multi-Gebruiker-Steuring (MGS) kan oorkom nie.

Sleutelwoorde: 3G, 4G, uitsaai diversity, kapasiteit, RT kodering, volle tempo, volle diversiteit, Sprei Spekrum, RSUD, DSRTS, tyd varieërende multipad deining, kruis-korrelasie, antenna self-ruis, quasi-staties, KDVT, MGS.

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TABLE OF CONTENTS

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

LIST OF FIGURES

CHAPTER SIX

CHAPTER SEVEN

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

LIST OF TABLES

LIST OF ABBREVIATIONS

1G	First Generation
1xEV-DO	Single Carrier Evolution Data Only/Optimised
1xEV-DV	Single Carrier Evolution Data and Voice
2G	Second Generation
3G	Third Generation
3GPP	3G Partnership Project
3GPP2	3G Partnership Project Two
8PSK	Eight-Phase Shift Keying
ABC	Analytic Bandlimited Complex
AWGN	Additive White Gaussian Noise
BCH	Bose-Chaudhuri-Hocquenghen
BER	Bit Error Rate
BLAST	Bell-Labs Layered Space-Time
BPSK	Binary Phase Shift Keying
BS	Base Station
CCDFs	Complementary Cumulative Distribution Functions
CDMA	Code Division Multiple Access
CD-ROM	Compact Disk Read Only Memory
CE	Constant Envelope
CE-LI-RU	Constant Envelope Linearly Interpolated
CSI	Channel State Information
CSS	Complex Spreading Sequence
dB	Decibels
DC	Direct Current
DS/SSMA	Direct Sequence Spread Spectrum multiple Access
DSB CE LI RU GCL	Double Sideband Constant Envelope Linearly Interpolated Root-of-Unity Filtered General Chirp Like
DSB	Double Sideband
DSPs	Digital Signal Processors
DS-SS	Direct Sequence Spread Spectrum
DSSTS	Direct Sequence Space-Time Spreading
ECSD	EDGE Circuit Switched Data
EDGE	Enhanced Data Rates for GSM Evolution

EGPRS	Enhanced GPRS
FDMA	Frequency Division Multiple Access
FER	Frame Error Rate
FFCS	Flat Fading Channel Simulator
FH-SS	Frequency Hopped Spread Spectrum
GAST	Generalised Algebraic ST
Gbps	Giga bits per second
GCL	General Chirp-like
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Services
GSM	Global System Mobile
HSCSD	High Speed Circuit Switched Data
HSDPA	High Speed Downlink Packet Access
IMT-2000	International Mobile Telephone 2000
IS-136	Interim Standard 136
IS-95	Interim Standard 95
IS-95B	Interim Standard 95B
ISI	Inter Symbol Interference
ITU	International Telecommunication Union
Kbps	Kilo bits per second
LCR	Level Crossing Rate
LOS	Line of sight
MAC	Medium Access Control
MAI	Multiple Access Interference
MAP	Maximum a-Posteriori
Mbps	Mega bits per second
MIMO	Multiple Input Multiple Out
ML	Maximal Length
ML	Maximum Likelihood
MPSK	M-ary Phase Shift Keying
MRRC	Maximal Ratio Receiver Combining
MS	Mobile Station
MUI	Multi-User Interference
NLOS	non-line of sight
OFDMA	Orthogonal Frequency Division Multiple Access

OOP	Object Orientated Programming
OVSF	Orthogonal Variable Spreading Factor
PAM	Pulse Amplitude Modulation
PCS	Personal Communications Systems
PDC	Pacific Digital Cellular
PDF	Probability Density Function
PG	Processing Gain
PN	Pseudo-Noise
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPH	Quadriphase
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RMS	Root Mean Square
RS	Reed-Solomon
SNR	Signal to Noise Ratio
SS	Spread Spectrum
SSB	Single Sideband
SSTD	Space-Sequence Transmit Diversity
ST	Space-Time
STS	Space-Time Spreading
STTC	Space-Time Trellis Coding
STTD-OTD	Space-Time Transmit Diversity- Orthogonal Transmit Diversity
TCM	Trellis Coded Modulation
TDMA	Time Division Multiple Access
TV	Television
UMTS	Universal Mobile Telecommunications Service
VA	Viterbi Algorithm
VoIP	Voice over Internet Protocol
WCDMA	Wideband CDMA
WLAN	Wireless Local Area Networks
WiMAX	Worldwide Interoperability for Microwave Access
ZC	Zadoff-Chu

LIST OF IMPORTANT SYMBOLS

a_n	n'th signal point in signal constellation ν
ν	Signal constellation
A	ST-transmission matrix
X	DSSTS design matrix
Γ	E_b/N_o
E_b	Energy per bit
E_s	Energy per symbol
N_o	Noise spectral density
μ	Cross-correlation between path h_1 and h_2
τ	Time shift
b_n	n'th bit in bitsteam *b(t)*
b(t)	Bitstream
g(t)	Spreading sequence
θ_c	Carrier phase
θ_i	i'th delay phase in the mulipath fading channel
f_c	Carrier frequency
T_s	Symbol period
T_c	Chip period
ς	Spreading sequence *g(t)* length
G	Spreading codes for STS in matrix form
S	Transmit symbols for STS in matrix form
B	Bits in matrix form for STS
υ	Noise variable in STS
β_i	i'th path amplitude in multipath fading
Ω	Data bits in a code word
p	Probability
L	Independent fading replicas/paths
χ	Total length of a block code word
n	Number of transmit antennas
m	Number of receive antennas
t	Time
r(t)	Received signal

$d(t)$	Channel output
$R_a(\tau)$	Periodic auto-correlation function
$R_c(\tau)$	Periodic cross-correlation function
$h(t)$	Complex channel path gain
η	AWGN
c	Transmitted ST symbols
l	ST code frame length
C	ST coding design matrix
x	Transmission matrix enties
A	Transmit signal constellation
q	Number of bits representing a symbol
M	Hadamard Matrix
N	Length of spreading sequence
R_c	Code rate
R_b	Bit rate
ϑ	Delay spread
BW_s	Signal bandwidth
BW_d	Doppler bandwidth
BW_c	Coherence bandwidth
B_{ss}	SS signal bandwidth
σ^2	Variance (power)
z	Amplitude
K	Rician factor
$u(t)$	Channel input signal
α	Channel Fading amplitude
ϕ	Channel phase
$d(t)$	Channel output
$\bar{\gamma}$	Matrix containing shifted symbols from DSSTS scheme
y	Number of ST-encoders in DSSTS scheme
ξ	Duration of a fade
ρ	RMS level (level crossings)
κ	Convolutional code constraint length
DM	ST decoder decision metric
PG	Processing gain

P_e Probability of error

$S_c(f)$ Doppler power spectrum

f_d Doppler frequency

$pdf(z)$ Probability density function of the amplitude z

f_{samp} Sampling frequency

$CLOS$ Line-of-Sight component added to the in-phase branch of the FFCS

C_{SCALE} FFCS output scaling factor

$\Phi_{MFC}(t)$ Multipath power delay profile

T_n DSSTS scheme's transmission matrix with n transmit antennas

Δ Despreaded DSSTS symbols