



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRONICS AND COMMUNICATIONS ENGINEERING DEPARTMENT
CAIRO - EGYPT

Enhancement of OFCDMA Systems Performance Using MIMO Techniques

A Thesis

Submitted in Partial Fulfillment of the Requirement for
the Doctor of Philosophy Degree in Electrical Engineering

Submitted By

Ahmed Hassan Ahmed Mansour

M.Sc. of Electrical Engineering
Electronics and Communications Engineering Department
Ain Shams University, 2011

Supervised By

Prof. Dr. Salwa Hussein El-Ramly

Electronics and Communications Engineering Department
Faculty of Engineering
Ain Shams University

Dr. Mona Zakria Saleh

Electronics and Communications Engineering Department
Faculty of Engineering
Ain Shams University



**AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRONICS AND COMMUNICATIONS ENGINEERING DEPARTMENT
CAIRO - EGYPT**

Examiners Committee

Name: Ahmed Hassan Ahmed Mansour

**Thesis: Enhancement of OFCDMA Systems Performance
Using MIMO Techniques**

Degree: Doctor of Philosophy in Electrical Engineering

Name, Title and Affiliation

Signature

1- Prof. Dr. Mona Riad EL-Ghoneimy

Electronics and Communications Engineering Department
Cairo University, Cairo, Egypt

2- Prof. Dr. Hadia Said EL-Hennawy

Electronics and Communications Engineering Department
Ain Shams University, Cairo, Egypt

3- Prof. Dr. Salwa Hussein El-Ramly

Electronics and Communications Engineering Department
Ain Shams University, Cairo, Egypt

Date: / /

Table of Contents

	Page
Acknowledgement	I
Table of contents	II
List of Figures	VII
List of Tables	XII
Lists of Abbreviations	XIV
Nomenclature	XVIII
Abstract	XXI
Chapter 1: Introduction	1
1.1 Introduction	1
1.1.1 FDMA	3
1.1.2 TDMA	4
1.1.3 CDMA	5
1.2 Thesis Objectives	9
1.3 Thesis Organization	10
Chapter 2: Beyond the Fourth Generation	13
2.1 Introduction	13
2.2 The 4 th generation system	15
2.3 Beyond the 4 th generation system (5G)	18
2.3.1 5G system services	19
2.3.2 5G system requirements	20
2.3.3 5G Radio Access Technology (RAT)	22
Chapter 3: Orthogonal Frequency Code Division Multiple Access (OFCDMA)	26
3.1 Introduction	26
3.2 Types of spreading schemes	27
3.2.1 Introduction	27
3.2.2 SC-DS-CDMA	28
3.2.3 MC-CDMA	33
3.2.4 MC-DS-CDMA	41
3.2.5 Two dimensional (2D) spreading (MC-DS-CDMA using T-F spreading)	45
3.2.6 Flexibility comparison	51

3.2.7 MC-DS-CDMA using 2D spreading advantages	53
3.3 Orthogonal Frequency Code Division Multiple Access (OFCDMA)	55
3.3.1 OFCDMA technique motivation	56
3.3.2 OFDM versus OFCDM	58
3.3.3 The OFCDMA system structure	62
3.3.3.1 The OFCDMA symbol definition	66
3.3.3.2 OFCDMA packet structure	68
3.3.3.3 Multi-Code transmission	69
3.4 Conclusions	72
Chapter 4: MIMO OFCDMA	74
4.1 Introduction	74
4.2 Types of MIMO techniques	74
4.3 MIMO multiplexing techniques receiver algorithms	80
4.3.1 ZF receiver algorithm	82
4.3.2 ZF-IC receiver algorithm	84
4.4 Simulation results	91
4.4.1 Simulation schemes	93
4.4.2 System configuration	96
4.4.3 Results and conclusion	100
4.5 Conclusions	101
Chapter 5: The Proposed System: STS-Aided-OFCDMA-IIC	102
5.1 MIMO spatial diversity technique using STS $n_t = 2$ and $n_r = 1$	102
5.1.1 Simulation results	111
5.1.1.1 Simulation schemes	112
5.1.1.2 System configuration	114
5.1.1.3 Results and conclusion	115
5.1.1.3.1 Single user STS system	117

simulations	
5.1.1.3.2 Single user STS system simulations for adaptive time domain spreading (N_T)	119
5.1.1.3.3 Multi-user STS system simulations for adaptive time domain spreading (N_T)	120
5.2 STS system with $n_t = 2$ and n_r receive antennas	123
5.2.1 Simulation results	126
5.2.1.1 Simulation schemes	126
5.2.1.2 System configuration	128
5.2.1.3 Results and conclusion	128
5.2.1.3.1 Single user STS $n_t = 2$ and variable n_r system simulation schemes and results	128
5.2.1.3.2 Multi- user STS $n_t = 2$ and variable n_r system simulation schemes and results	130
5.3 Data rate boosting using STS system with $n_t = 4$ and $n_r = 2$ receive antennas	131
5.3.1 STS system with $n_t = 4$ and $n_r = 2$	132
5.3.1.1 Simulation results	139
5.3.1.1.1 Simulation schemes	139
5.3.1.1.2 System configuration	141
5.3.1.1.3 Results and conclusion	141
5.3.1.1.3.1 Single user system	141
5.3.1.1.3.2 Multi- user STS $n_t = 4$ and variable N_T system simulation schemes and results	143
5.3.2 First model for OFCDMA system	145
5.3.3 The proposed STS-Aided-OFCDMA system	147
5.3.3.1 Simulation Results	149

5.3.3.1.1 Simulation schemes	150
5.3.3.1.2 System configuration	153
5.3.3.1.3 Results and conclusion	157
5.3.3.1.3.1 Single user system and constant N_F	157
5.3.3.1.3.2 Single user system and variable N_F	158
5.3.3.1.3.3 Multi-user system and variable N_F	170
5.3.4 The proposed STS-Aided-OFCDMA-IIC system	172
5.3.4.1 Simulation results and conclusion	183
5.4 Conclusions	194
Chapter 6: The Proposed System: Full Loaded STS-Aided-OFCDMA-IIC	198
6.1 The full loaded OFCDMA system	198
6.2 The STS system with $n_t = 8$ and $n_r = 4$	200
6.3 The proposed full loaded STS-Aided-OFCDMA system	202
6.4 The MIMO-OFCDMA system	227
6.5 Simulation results and conclusion	230
6.6 Conclusions	239
Chapter 7: The Proposed System: STS- Aided-OFCDMA Based on CC codes	241
7.1 The integration of STS with Complete Complementary (CC) codes in CDMA technologies	241
7.2 Why Complete Complementary CDMA technologies based on CC codes?	245
7.3 The proposed integration of STS and (CC) CDMA technologies	255
7.4 Simulation results and conclusion	257
7.5 Conclusions	262

Chapter 8: Conclusions and future work	263
8.1 Introduction	263
8.2 Thesis summary	264
8.3 Conclusions	266
8.4 Suggested future research	272

REFERENCES

List of Figures

	Page
Figure 1.1	3
Figure 1.2	4
Figure 1.3	6
Figure 2.1	15
Figure 2.2	17
Figure 2.3	17
Figure 2.4	19
Figure 2.5	21
Figure 2.6	23
Figure 2.7	24
Figure 3.1	
a) Transmitter	
b) power spectrum of transmitted signal	
c) Rake Receiver	29
Figure 3.2	30
Figure 3.3	31
Figure 3.4	32
Figure 3.5	34
Figure 3.6	
a) Transmitter	
b) power spectrum of transmitted signal	
c) Receiver	35
Figure 3.7	
a) Transmitter	
b) power spectrum of transmitted signal	38
Figure 3.8	40
example	
Figure 3.9	40
Figure 3.10	41
Figure 3.11	
a) transmitter	
b) power spectrum of its transmitted signal	
c) receiver.	43
Figure 3.12	44
Figure 3.13	

	for example shown in figure 4.12	45
Figure 3.14	MC-DS-CDMA using T-F spreading scheme transmitter	46
Figure 3.15	example of general MC-DS-CDMA using T-F spreading scheme	47
Figure 3.16	General MC-DS-CDMA using T-F spreading scheme example	50
Figure 3.17	Power spectrum and time-domain signal waveforms associated with MC DS-CDMA for the example shown in Figure 3.16	50
Figure 3.18	Data rate boosting using multi-code transmission	
	(a) SISO-OFDM system	
	(b) SISO-OFDM combined with 2D spreading (OFCDMA) system	60
	(c) OFCDMA system using multi-code transmission	
Figure 3.19	OFCDMA system	63
Figure 3.20	Detailed transmitter of OFCDMA system	65
Figure 3.21	Two-dimensional spreading in both time and frequency domains	67
Figure 3.22	OVSF tree	68
Figure 3.23	Three-dimensional packet structure of the OFCDMA	69
Figure 3.24	Full loaded OFCDMA system ($K = N = 8$) code assignment example	73
Figure 4.1	Classification of MIMO techniques	76
Figure 4.2	MIMO system model	81
Figure 4.3	V-BLAST transmitter simulation scheme with $n_t = 2$	93
Figure 4.4	V-BLAST receiver simulation scheme with $n_r = 2$	94
Figure 4.5	Intervals between samples and periods in discrete time and frequency domain [74].	98
Figure 4.6	V-BLAST (2×2) system simulation results for ZF and MMSE algorithms	101
Figure 5.1	Sections arrangement flow chart.	103
Figure 5.2	Transmit diversity using STS	105
	(a) Transmitter block diagram	
	(b) The transmitter of STS indicated by one block	
	(c) Receiver block diagram	
Figure 5.3	STS single user transmitter simulation model with $n_t = 2$	113

Figure 5.4	STS single user receiver simulation scheme with $n_r = 1$.	113
Figure 5.5	STS simulation scheme bit rate calculation	115
Figure 5.6	STS simulation results for single user transmission, $N_T=4$ and $N_F=1$	117
Figure 5.7	Single user STS (2×1) system simulation results for ZF and variable N_T	120
Figure 5.8	Full loaded STS multi-user transmitter simulation scheme with $n_t = 2$ and variable N_T .	121
Figure 5.9	Multi-user STS (2×1) system simulation results for ZF and variable time spreading factor	122
Figure 5.10	Single user STS system simulation scheme with general number of receive antennas n_r	127
Figure 5.11	Single user STS (2×2) and (2×4) systems simulation results	129
Figure 5.12	Full loaded multi-user STS (2×2) and (2×4) systems simulation results	131
Figure 5.13	Expansion of STS system for data rate boosting.	132
Figure 5.14	STS receiver with $n_r = 2$	134
Figure 5.15	Single user STS (4×2) transmitter simulation scheme	139
Figure 5.16	Single user STS (4×2) receiver simulation scheme	140
Figure 5.17	Single user STS (4×2) and (2×1) systems simulation results	142
Figure 5.18	STS multi-user transmitter simulation scheme with $n_t = 4$ and variable N_T .	143
Figure 5.19	Full loaded multi-user STS (4×2) system simulation results	145
Figure 5.20	OFCDMA system example	146
Figure 5.21	OFCDMA and STS spatial diversity merging	
	(a) The OFCDMA system	149
	(b) The STS-Aided-OFCDMA system	
Figure 5.22	STS-Aided-OFCDMA ($n_t = 4$) transmitter simulation scheme	150
Figure 5.23	STS-Aided-OFCDMA ($n_t = 4$) receiver simulation scheme	152
Figure 5.24	STS-Aided-OFCDMA (4×2), $N_F = 2$ system simulation results	157
Figure 5.25	Generic STS-Aided-OFCDMA (4×2) transmitter simulation scheme	161
Figure 5.26	Generic STS-Aided-OFCDMA ($n_t = 4$) receiver simulation scheme	164
Figure 5.27	Generic STS-Aided-OFCDMA (4×2) system simulation results	168
Figure 5.28	Effect of changing N_F for STS-Aided-OFCDMA (4×2) system simulation result	169

Figure 5.29	Multi-user Generic STS-Aided-OFCDMA transmitter simulation scheme	171
Figure 5.30	The proposed STS-Aided-OFCDMA-IIC transmitter	173
Figure 5.31	The proposed STS-Aided-OFCDMA-IIC receiver	176
Figure 5.32	The proposed generic STS-Aided-OFCDMA-IIC ($n_t = 4$) receiver simulation scheme	187
Figure 5.33	Generic STS-Aided-OFCDMA-IIC ($n_t = 4$) system simulation results	188
Figure 5.34	Effect of number of loops in IIC detection for STS-Aided-OFCDMA-IIC system (4Tx, 2Rx) receiver	190
Figure 5.35	BER performance of two loops iterative cancellation STS-Aided OFCDMA-IIC system (4Tx, 2Rx) with $N_F = 4,32$ compared with LSSTS-MC-DS-CDMA ($N_F = 4$) and MRRC system (1Tx, 6Rx).	192
Figure 5.36	The effect of frequency domain spreading factor N_F	193
Figure 6.1	The full loaded SISO-OFCDMA system	198
Figure 6.2	Chapter 6 sections arrangement flow chart	199
Figure 6.3	The STS system with $n_t = 8$ and $n_r = 4$	201
Figure 6.4	The final proposed full loaded STS-Aided-OFCDMA transmitter	204
	a. The transmitter architecture	
	b. STS system sub-block	
	c. The STS-Aided-OFCDMA symbol structure	
Figure 6.5	The full loaded STS-Aided-OFCDMA-IIC receiver	209
Figure 6.6	The MIMO-OFCDMA system	
	a. Transmitter	228
	b. Receiver	
Figure 6.7	The full loaded STS-Aided-OFCDMA transmitter	232
Figure 6.8	The full loaded STS-Aided-OFCDMA-IIC receiver	233
Figure 6.9	BER comparison of the proposed FL-STs-Aided-OFCDMA-IIC system with the systems studied in [66-67].	235
Figure 6.10	Effect of number of loops in IIC detection for the proposed FL- STS- Aided- OFCDMA-IIC system (8Tx, 4Rx) receiver	236
Figure 6.11	BER performance of four loops iterative cancellation FL- STS-Aided- OFCDMA-IIC system(8Tx, 4Rx) with $N_F = 32$ compared with MRRC system (1Tx, 8Rx).	238
Figure 6.12	The effect of frequency domain spreading factor N_F	239
Figure 7.1	The SISO generic multi-user downlink CDMA transmitter based on CC codes	242
Figure 7.2	The SISO generic multi-user downlink CDMA receiver based	

	on CC codes	244
Figure 7.3	The despreading operation for the packets sent from user 1 and user 2 at receiver (synchronous transmission is assumed)	249
Figure 7.4	The despreading operation for the packets sent from user 1 and user 2 at receiver (asynchronous transmission is assumed)	254
Figure 7.5	The STS system $n_t = 2$ based on CC codes	256
Figure 7.6	The STS based on CC codes transmitter (2 users uplink asynchronous transmission)	258
Figure 7.7	The STS based on CC codes receiver tuned to user 1 (2 users uplink asynchronous transmission)	259
Figure 7.8	The STS system based on CC codes simulation results	262

List of Tables

	Page
Table 2.1	Comparison of 2G and 3G systems
	14
Table 4.1	Major contributions for MIMO applications
	77
Table 4.2	ZF equalizer algorithm.
	84
Table 4.3	ZF-IC equalizer algorithm.
	90
Table 4.4	V-BLAST system configuration used for simulation scheme in Figure 4.3
	96
Table 5.1	STS system configuration used for simulation scheme in Figure 5.3
	116
Table 5.2	STS system configuration used for simulation scheme in Figure 5.3 in case of adaptive N_T
	119
Table 5.3	Full loaded multi-user STS system configuration used for simulation scheme in Figure 5.8
	123
Table 5.4	STS with variable number of receive antennas system configuration used for simulation scheme in Figure 5.10
	128
Table 5.5	Multi-user STS with variable number of receive antennas system configuration and variable N_T
	130
Table 5.6	Single user STS (4×2) system configuration
	141
Table 5.7	Multi-user STS (4×2) system configuration with variable N_T
	144

Table 5.8	Single user STS-Aided-OFCDMA (4×2) system configuration	153
Table 5.9	Single user-variable N_F STS-Aided OFCDMA (4×2) system configuration	158
Table 5.10	STS-Aided-OFCDMA system detection pseudo code.	179
Table 5.11	STS-Aided-OFCDMA-IIC system detection pseudo code.	180
Table 5.12	Complexity comparison of STS, the proposed STS-Aided-OFCDMA system with and without IIC.	182
Table 6.1	Full loaded-STS-Aided-OFCDMA system detection pseudo code	224
Table 6.2	Full loaded-STS-Aided-OFCDMA-IIC system detection pseudo code	225
Table 6.3	Full loaded STS-Aided-OFCDMA-IIC (8×4) system configuration	234
Table 7.1	the STS based on CC codes (2×1) system configuration	260

Abbreviations

3GPP	3 rd generation partnership project
3G	Third generation
4G	Fourth generation
5G	Fifth generation

A

ATM	Asynchronous transfer mode
AWGN	Additive white gaussian noise
ARQ	automatic repeat request

B

BS	Base station
BER	Bit error rate
BoD	Bandwidth on demand
BPSK	Binary phase shift keying
BLAST	Bell Labs' Layered Space-Time

C

CDMA	Code division multiple access
CC	Complete complementary
CSI-R	Channel State Information at the Receiver
CRC	Cyclic redundancy check
CPM	Continuous phase modulation
CP	Cyclic prefix
C-plane	Control plane

D

DFT	Discrete fourier transform
DSSS	Direct sequence spread spectrum
DSCH	Downlink shared channel
DAB	Digital audio broadcasting
DVB	Digital video broadcasting
DS-CDMA	Direct sequence-CDMA
DECT	Digital enhanced cordless telephone

E

EDGE	Enhanced data rate for GSM evolution
EU-DCH	Enhanced uplink-downlink channel
EUL	Enhanced uplink
EGC	Equal gain combining