OFDM SYSTEM BASED ON FRAMELET TRANSFORM AND RADON MAPPING WITH FPGA IMPLEMENTATION

by

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LIST OF ABBREVIATIONS

1D	One Dimensional
2D	Two Dimensional
3GPP	Third Generation Partnership Project
4G	4^{th} Generation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CP	Cyclic Prefix
CR	Column-Row
DAB	Digital Audio Broadcasting
dB	Decibel
DC	Direct Current (average level of the signal it's mean, or expected value)
DFE	Decision Feedback Equalizer
DFT	Discrete Fourier Transform
DRT	Discrete Radon Transform
DSP	Digital Signal Processing
DVB	Digital Video Broadcasting
DVB-H	Digital Video Broadcasting for Handheld
Eb/No	Energy per bit to Noise power spectral density ratio
ETSI	European Telecommunication Standards Institute
FDRT	Fast Discrete Radon Transform
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
FPGA	Field Programmable Gate Array

FRAT	Finite Radon Transforms
FT	Framelet Transform
HDL	Hardware Description Language
IC	Integrated Circuit
ICI	Inter-Carrier Interference
IDE	Integrated Design Enviroment
IDFT	Inverse Discrete Fourier Transform
IEEE	Institute of Electrical and Electronic Engineers
iff	if and only if
IFFT	Inverse Fast Fourier Transform
IFRAT	Inverse FRAT
IFT	Inverse Framelet Transform
IP	Intellectual Property
ISI	Inter-Symbol Interference
JTAG	Joint Test Action Group
LDPC	Low Density Parity-Check
LOS	Line -Of-Sigh
LTE	Long Term Evolution
MC-CDMA	Multi-Carrier Code Division Multiple Access
MCM	Multi-Carrier Modulation
MLD	Maximum Likelihood Detector
MMSE	Minimum Mean Square Error
M-PSK	M-array Phase Shift Keying
M-QAM	M-array Quadrature Amplitude Modulation
MRA	Multi-Resolution Analysis

MRRC	Maximal-Ratio Receiver Combining
NBI	Narrow-Band Interference
N-FRAT	N-Finite Radon transform
OFDM	Orthogonal Frequency Division Multiplexing
P/S	Parallel-to-Serial
RC	Row-Column
rms	root-mean-square
RS	Reed Solomon
RTL	Register Transfer Level
S/P	Serial-to-Parallel
SNR	Signal-to-Noise Ratio
SOS	Sum Of Sinusoid
STBC	Space-Time Block Coding
STCs	Space-Time Codes
TC	Turbo Code
TDL	Tapped Delay Line
VHDL	Very high speed Hardware Description Language
VLSI	Very Large Scale Integration
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WT	Wavelet Transform
XSG	Xilinx System Generator

LIST OF SYMBOLS

T_m	Delay spread
B_c	Coherence bandwidth
f_d	Doppler frequency
f_c	Carrier frequency
V	Speed of mobile
C	Speed of light
Θ	Incident angle of signal reception
B_d	Doppler spread
T_c	Coherence Time
B_s	Bandwidth
T_s	Symbol period
B_d	Doppler spread
$\mathrm{P_{df}}$	Probability distribution function
σ	Root-mean-square
σ^2	Average power
L	Number of paths in fading channel
h_k	Complex Gaussian fading coefficient corresponding to the k^{th} path
ϖ_d	Maximum radian Doppler frequency
α_k	Angle of arrival
ϕ_k	Initial phase of the k^{th} propagation path
$w(n)$	Additive White Gaussian Noise
$(.)^*$	Complex conjugate

Δf	Sub-carrier spacing
T_{cp}	Interval length of CP
$f(x,y)$	A function of the Cartesian coordinates x and y.
$\Re f = \breve{f}$	Radon transform of f
$\hat{f}(k) = F_n f$	n-dimensional Fourier transform of $f(x)$
F_n^{-1}	n-dimensional inverse Fourier transform
$\mathbb{R}$	Set of real numbers
δ	Dirac delta function
$\varphi(t)$	Scaling function
$\psi(t)$	Wavelet function
$h_0(n)$	Scaling function coefficients
$h_1(n)$	Coefficients for the first wavelet function
$h_2(n)$	Coefficients for the second wavelet function
$X_L(n)$	Low frequency (or coarse) sub-band
$X_{H1}(n)$	High frequency (or detail) sub-band for the first wavelet function
$X_{H2}(n)$	High frequency (or detail) sub-band for the second wavelet function
$\tilde{h}_0(n)$	Synthesis low pass filter
$\tilde{h}_1(n)$	First synthesis high pass filter
$\tilde{h}_2(n)$	Second synthesis high pass filter
Tx_i	i^{th} transmitter antenna
S	STBC transmitted signal matrix
Rx_i	i^{th} Receiver antenna
$y(n)$	Received signal

H	Channel impulse response
$\tilde{s}$	Combined signal
$dist\ (A, B)$	Euclidean distance between A and B
F_{opt}	Optimum ordering for matrix F
$\bar{\Re}$	Complex FRAT matrix from the real FRAT matrix $\Re$
$r_{i,j}$	Elements of real FRAT matrix $\Re$
$\bar{r}_{l,m}$	Elements of complex FRAT matrix $\bar{\Re}$
$[.]^T$	Transpose operation
L_f	Length of the analysis filters in the framelet transform matrix
W_1	Transformation matrix for framelet transform
W_2	Reconstruction matrix for framelet transform
D	Vector of binary random data
L_d	Length of the vector d
p	FRAT matrix size
N	Order of the mapping technique
N_{ofdm}	Number of OFDM symbol in each transmission
$X_d(k)$	Mapped data
$X_p(k)$	Pilot symbols or training data
Z_{sym}	Zero symbols
N_f	Number of subcarrier
N_{usf}	Number of useful subcarriers
$y_p(n)$	Received pilot
$y_d(n)$	Received data
$\hat{X}_d(k)$	Estimated data

$X_{enc}(k)$	Encoding matrix in STBC
$H(k)$	Channel frequency responses
B_{cent}	Centralize matrix of the *B* matrix
M_{pol}	Polar matrix
M_{max}	Maximum between two absolute matrices
M_{best}	Matrix of the best sequence of directions in the optimum order algorithm

Sistem OFDM Berdasarkan Transform Framelet dan Pemetaan Radon dengan Pelaksanaan FPGA

ABSTRAK

Peningkatan permintaan untuk penghantaran data berkelajuan tinggi dan kecekapan spektrum yang tiada tandingan adalah pemacu kepada sistem komunikasi wayarles kini dan masa depan. *Orthogonal Frequency Division Multiplexing* (OFDM) telah diiktiraf sebagai salah satu teknik yang menjanjikan untuk penghantaran kadar data yang tinggi disebabkan oleh ciri-cirinya. Namun begitu, walaupun dengan semua kelebihan teknik ini, isyarat OFDM masih mengalami implikasi-implikasi daripada saluran wayarles yang menyebabkan *Inter-Symbol Interference* (ISI) dan *Inter-Carrier Interference* (ICI). Oleh itu, *Cyclic Prefix* (CP) digunakan dalam OFDM tradisional untuk membasmi ISI/ICI sepenuhnya, tetapi pendekatan ini mempengaruhi kecekapan penghantaran dengan kehilangan kira-kira 25% dari jalur lebar yang tersedia. Dengan itu, sistem OFDM yang baru berdasarkan gabungan baru antara *Framelet Transform* (FT) dan pemetaan *Finite Radon* (FRAT) dicadangkan dalam tesis ini untuk meningkatkan imuniti sistem OFDM terhadap kesan buruk *multipath fading* dan meningkatkan keupayaannya untuk membasmi ISI dan ICI dengan adanya penyamaan yang mudah tanpa memerlukan CP. Sistem yang dicadangkan ini dipanggil N-FRAT-FT-OFDM, ianya disimulasikan dan dibandingkan dengan sistem-sistem OFDM lain seperti OFDM berasaskan FFT menggunakan pemetaan N-FRAT (N-FRAT-FFT-OFDM), OFDM berasaskan FT menggunakan pemetaan QAM (QAM-FT-OFDM), dan OFDM berasaskan FFT menggunakan pemetaan QAM (QAM-FFT-OFDM). Simulasi telah dijalankan untuk pelbagai titik konstelasi ke atas keadaan-keadaan saluran dan parameter yang berlainan menggunakan perisian MATLAB. Keputusan menunjukkan bahawa struktur baru ini dapat mengatasi ketiga-tiga sistem tersebut dengan pengurangan ISI/ICI, yang kemudiannya meningkatkan prestasi *Bit Error Rate* (BER). Sebagai contoh, dalam saluran pudar selektif frekuensi dan frekuensi Doppler maksimum (f_d = 100Hz) dengan pemetaan 4-FRAT, dimana ianya bersamaan dengan pemetaan 16-QAM, 4-FRAT-FT-OFDM dengan gandaan 12.35 dB dan 19.35 dB dalam nisbah tenaga per bit terhadap ketumpatan spektrum kuasa bunyi (Eb/No) diukur pada BER = 10^{-3} berbanding dengan 4-FRAT-FFT-OFDM dan 16-QAM-FFT-OFDM masing-masing, sementara pembersihan sistem 16-QAM-FT-OFDM untuk mencapai BER seperti itu. Selain itu, *Alamouti Space-Time Block Code* (STBC) dicadangkan dalam struktur sistem N-FRAT-FT-OFDM untuk mempertingkatkan lagi prestasi BER pada kadar data yang tinggi dan menambahkan kecekapan jalur lebar dengan meningkatkan sistem kepelbagaian spatial. Sistem yang dicadangkan ini dilengkapi dengan dua pendekatan STBC: pertama ialah sistem berasaskan STBC N-FRAT-FT-OFDM (STBC-N-FRAT-FT-OFDM) dengan dua antena pemancar dan satu penerima antena (2Tx-1Rx), manakala yang kedua adalah STBC-N-FRAT-FT-OFDM dengan dua pemancar dan dua penerima antena (2Tx-2Rx). Keputusan simulasi menunjukkan bahawa gabungan STBC dengan sistem N-FRAT-FT-OFDM dapat meningkatkan prestasi N-FRAT-FT-OFDM dalam saluran *multipath fading* dengan gandaan dalam Eb/No melebihi 2 dB dalam kes 2Tx-1Rx, dan lebih daripada 5 dB dalam kes 2Tx-2Rx. Akhirnya, transceiver N-FRAT-FT-OFDM telah direkabentuk dan berjaya dilaksanakan atas platform FPGA dengan menggunakan Xilinx System Generator (XSG). Keputusan simulasi perkakasan dan sintesis membuktikan bahawa sistem ini telah dilaksanakan