AN OFFSET MODULATION METHOD USED TO CONTROL THE PAPR OF AN OFFDM TRANSMISSION

by

Kahesh Dhuness

Submitted in partial fulfilment of the requirements for the degree

Philosophiae Doctor (Engineering)

in the

Department of Electrical, Electronic and Computer Engineering
Faculty of Engineering, Built Environment and Information Technology
UNIVERSITY OF PRETORIA

April 2012

SUMMARY

AN OFFSET MODULATION METHOD USED TO CONTROL THE PAPR OF AN OFDM TRANSMISSION

by

Kahesh Dhuness

Promoter(s):	Professor Dr B.T. Maharaj
Department:	Electrical, Electronic and Computer Engineering
University:	University of Pretoria
Degree:	Philosophiae Doctor (Engineering)

Keywords:	ACE, Clipping, Cognitive Radio, DVB-T2, OFDM, OM-ACE, OM- OFDM, PAPR, ROC, TR

Orthogonal frequency division multiplexing (OFDM) has become a very popular method for high-data-rate communication. However, it is well known that OFDM is plagued by a large peak-to-average power ratio (PAPR) problem. This high PAPR results in overdesigned power amplifiers, which amongst other things leads to inefficient amplifier usage, which is undesirable. Various methods have been recommended to reduce the PAPR of an OFDM transmission; however, all these methods result in a number of drawbacks.

In this thesis, a novel method called offset modulation (OM-OFDM) is proposed to control the PAPR of an OFDM signal. The proposed OM-OFDM method does not result in a number of the drawbacks being experienced by current methods in the field. The theoretical bandwidth occupancy and theoretical bit error rate (BER) expression for an OM-OFDM transmission is derived. A newly applied power performance decision metric is also introduced, which can be utilised throughout the PAPR field, in order to compare various methods.

The proposed OM-OFDM method appears to be similar to a well-known constant envelope OFDM (CE-OFDM) transmission. The modulation, structural and performance differences between an OM-OFDM and a CE-OFDM method are discussed. By applying the power performance decision metric, the OM-OFDM method is shown to offer significant performance gains when compared to CE-OFDM and traditional OFDM transmissions.

In addition, the OM-OFDM method is able to accurately control the PAPR of a transmission for a targeted BER. By applying the power performance decision metric and complementary cumulative distribution function (CCDF), the proposed OM-OFDM method is shown to offer further performance gains when compared to existing PAPR methods, under frequency selective fading conditions.

In this thesis, the OM-OFDM method has been combined with an existing active constellation extended (ACE) PAPR reduction method. To introduce a novel method called offset modulation with active constellation extension (OM-ACE), to control the PAPR of an OFDM signal. The theoretical BER expression for an OM-ACE transmission is presented and validated. Thereafter, by applying the decision metric and CCDF, the OM-ACE method is shown to offer performance improvements when compared to various PAPR methods.

The use of OM-OFDM for cognitive radio applications is also investigated. Cognitive radio applications require transmissions that are easily detectable. The detection characteristics of an OM-OFDM and OFDM transmission are studied by using receiver operating characteristic curves. A derivation of a simplified theoretical closed-form expression, which relates the probability of a missed detection to the probability of a false alarm, for an unknown deterministic signal, at various signal-to-noise ratio (SNR) values is derived and validated. Previous expressions have been derived, which relate the probability of a missed detection to the probability of a false alarm. However, they have not been presented in such a generic closed-form expression that can be used for any unknown deterministic signal (for instance OFDM and OM-OFDM). Thereafter, an examination of the spectrum characteristics of an OM-OFDM transmission indicates its attractive detection characteristics. The proposed OM-OFDM method is further shown to operate at a significantly lower SNR value than an OFDM transmission, while still offering better detection characteristics than that of an OFDM transmission under Rician, Rayleigh and frequency selective fading channel conditions.

In addition to its attractive PAPR properties, OM-OFDM also offers good detection characteristics for cognitive radio applications. These aspects make OM-OFDM a promising candidate for future deployment.

OPSOMMING

’N AFSETMODULASIE METODE OM DIE PGDV VAN ’N OFVM-SEIN TE BEHEER

deur

Kahesh Dhuness

Promotor(s):	Professor Dr B.T. Maharaj
Departement:	Elektriese, Elektroniese en Rekenaar-Ingenieurswese
Universiteit:	Universiteit van Pretoria
Graad:	Philosophiae Doctor (Ingenieurswese)

Sleutelwoorde:	AKV, Knip, Kognitiewe Radio, DVB-T2, OFVM, OM-AKV, OM- OFVM, PGDV, ROC, TR

Ortogonale-frekwensie-verdeling-multipleksering (OFVM) is ’n baie gewilde metode vir hoëdata-tempokommunikasie. Dit is egter bekend dat OFVM deur ’n groot piek-tot-gemiddelde drywingverhouding (PGDV) probleem geteister word. Hierdie hoë PGDV, verminder die batteryleeftyd van die mobiele toestel, wat ongewens is. Daar is verskeie metodes om die PGDV van ’n OFVM-sein te verminder, maar al hierdie metodes het nadele. Hierdie proefskrif beskryf dus ’n nuwe metode, genaamd afsetmodulasie (OM-OFVM), om die PGDV-effek van ’n OFVM-sein te beheer. Die voorgestelde OM-OFVM-metode vermy van die nadele van die ander methodes. Die teoretiese bandwydte wat benodig word, sowel as die teoretiese bisfoutwaarskynlikheid (BFW), vir ’n afsetgemoduleerde oordrag, word afgelei en bevestig. ’n Nuwe toegepaste drywings-prestasie-besluitnemings-maatstaf word voorgestel, wat gebruik kan word in die PGDV-veld, om die verskillende metodes met mekaar te vergelyk.

Die voorgestelde OM-OFVM-metode lyk soos die welbekende konstante omhalling-OFVM-methode (KO-OFVM). Die voorgestelde modulasie, strukturele en prestasie-verskille tussen

die OM-OFVM-en KO-OFVM-metodes word bespreek. Deur gebruik te maak van die nuwe toegepaste drywing-prestasie-besluitnemingsmaatstaf, toon die OM-OFVM-metode beduidende prestasie-winste wanneer dit vergelyk word met ’n KO-OFVM-en tradisionele OFVM-metode.

Verder kan die OM-OFVM-metode die PGDV van ’n sein vir ’n geteikende BFW akkuraat beheer. Deur gebruik te maak van ’n nuwe toegepaste drywing-prestasie-besluitnemingsmaatstaf en die kumulatiewe verdelingsfunksie (KV), toon die voorgestelde OM-OFVM-metode dat dit verdere prestasiewinste kan aan bied wanneer dit vergelyk word met bestaande PGDV metodes, onder frekwensie-selektiewe deiningtoestande.

In hierdie proefskrif word dit voorgestel om die OM-OFVM-metode te kombineer met ’n bestaande aktiewe konstellasie-uitbreiding (AKU) PGDV-verminderingmetode om die PGDV van ’n OFVM-sein te beheer. Die voorgestelde metode word afsetmodulasie met aktiewe konstellasie-uitbreiding (OM-AKU) genoem. Die teoretiese BFW-uitdrukking vir ’n OM-AKV-oordrag word aangebied en geverifieer. Daarna, deur gebruik te maak van die voorgestelde drywings-prestasie-besluitnemings-maatstaf en KV, word daar getoon dat die OM-AKU metode prestasie-verbeterings teweegbring wanneer dit vergelyk word met bestaande PGDV-metodes.

Die gebruik van OM-OFVM vir kognitiewe radio word ook ondersoek. Die opsporing-seienskappe van ’n OM-OFVM-en OFVM-sein word bestudeer deur gebruik te maak van die ontvanger-bedryfstelsel se kenmerkende kurwes. ’n Afleiding van die vereenvoudigde teoretiese geslote vormuitdrukking, wat die verband tussen die waarskynlikheid van ’n gemisde opsporing tot die waarskynlikheid van ’n vals alarm op verskillende sein-tot-geraas-verhouding (SGV) waardes vir ’n onbekende deterministiese sein beskryf, is afgelei en geverifieer. Daarna het ’n ondersoek van die spektrum-eienskappe van ’n OM-OFVM-oordrag daarop gedui dat aantreklike opsporingseienskappe gevind is. Die voorgestelde OM-OFVM-metode blyk verder teen ’n aansienlik laer SGV-waarde te funksioneer as ’n OFVM-sein, terwyl dit steeds beter sein-opsporingseienskappe bied as ’n OFVM oordrag onder Rician, Rayleigh en frekwensie-selektiewe deiningkanaal-toestande. Benewens sy aantreklike PGDV-eienskappe, bied OM-OFVM ook goeie sein-opsporing-eienskappe vir kognitiewe radio. Hierdie aspekte maak OM-OFVM ’n belowende kandidaat vir toekomstige gebruik.

I dedicate this work to

My Creator for giving me the ability and opportunity to undertake it

All those from whom I have come to understand what Ubuntu means

ACKNOWLEDGEMENT

I would like to thank

- My parents, Jyothi and Rajindranath, and sister Laticia for their enduring love, support and encouragement.
- My study leader Professor, B. T. Maharaj, for his sage advice and support throughout the course of my studies.
- All my colleagues and a special thanks to Dare Sokoya, Philip Botha, Pieter Jansen van Vuuren, Robin Thomas, Simon Barnes and Thinus Prinsloo at the Sentech Chair in Broadband Wireless Multimedia Communication at the University of Pretoria.
- The University of Pretoria, the Sentech Chair in Broadband Wireless Multimedia Communication and the National Research Foundation for the financial sponsorship of my PhD degree.
- My entire family and my friends for their continuous encouragement during this study.

LIST OF ABBREVIATIONS

ACE	Active Constellation Extension
ADC	Analog-to-digital Converter
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCDF	Complementary Cumulative Distribution Function
CE-OFDM	Constant Envelope OFDM phase modulation
CP	Cyclic Prefix
CR	Cognitive Radio
CSI	Channel State Information
DAC	Digital-to-analog Converter
DAR	Decision-aided Reconstruction
DRM	Digital Radio Mondiale
DVB	Digital Video Broadcasting
FCC	Federal Communications Commission
FDE	Frequency-domain Equaliser
FDM	Frequency-division Multiplexing
FFT	Fast Fourier Transform
GI	Guard Intervals
HPA	High-power Amplifier
IFFT	Inverse Fast Fourier Transform
IFT	Inverse Fourier Transform
ISI	Inter-symbol Interference

LNA	Low-noise Amplifier
LPF	Low Pass Filter
LTE	Long-term Evolution
OFDM	Orthogonal Frequency Division Multiplexing
OM-ACE	Offset Modulation with Active Constellation Extension
OM-OFDM	Offset Modulation
OTS	Off-the-Shelf
PAE	Power Added Efficiency
PAM	Pulse-amplitude Modulation
PAPR	Peak-to-average Power Ratio
PDF	Probability Density Function
PDP	Power Delay Profile
PEP	Peak Envelop Power
POCS	Projection Onto Convex Sets
PSK	Phase-shift Keying
PTS	Partial Transmitted Sequence
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-shift Keying
RF	Radio Frequency
RMS	Root Mean Square
ROC	Receiver Operating Characteristic
SER	Symbol Error Rate
SLM	Selective Mapping
SNR	Signal-to-noise Ratio
TR	Tone Reservation
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide inter-operability for Microwave Access

LIST OF NOTATION

$\chi(.,.)$	Lower incomplete gamma function
$\Gamma(.,.)$	Upper incomplete gamma function
$\Im$	The imaginary number field
$\log(.)$	The natural logarithm
$\log_2(.)$	The binary logarithm
erfc	Error function
$\max(.)$	The maximum
$\min(.)$	The minimum
$\Re$	The real number field
$\star$	Convolution
$E\,[\,]$	Expected value
$G(f)$	Fourier transform
$J_l(\beta)$	Bessel functions of the first kind of order l with argument β
$Q_u(.,.)$	Marcum Q-function

LIST OF SYMBOLS

α	Phase deviations of the OFDM signal
α_1	Real phase deviations of the OFDM signal
α_2	Imaginary phase deviations of the OFDM signal
β	Adapted phase deviation of an OM-OFDM signal
β_1	Adapted real phase deviation of an OM-OFDM signal
β_2	Adapted imaginary phase deviation of an OM-OFDM signal
λ	Decision threshold
$\overline{\Upsilon}$	Average signal-to-noise ratio
$\Phi(t)$	Phase of the offset modulated signal
$\Phi_1(t)$	Real OFDM phase mapping
$\Phi_2(t)$	Imaginary OFDM phase mapping
$\Phi_n(t)$	Phase of the band-pass noise
Φ_{1n}	Discrete real OFDM phase mapping
Φ_{2n}	Discrete imaginary OFDM phase mapping
σ	Variance
Υ	Signal-to-noise ratio
ς	Constant division term
ξ_{av}	Average energy per symbol
ξ_s	Energy per symbol
Ψ_{os}	Constant offset term
a	Non-centrality parameter
A_c	Signal amplitude
D	Decision metric
d	Euclidean distance
E_b	Energy per bit
E_s	Energy per symbol
E_t	Total energy per bit

E_w	Wasted energy per bit
f_c	Carrier frequency
f_d	Integer multiple of the modulation frequency
h	Modulation index
Hz	Hertz
K	Rician distribution factor
L	Maximum constellation extension limit
n	Additive white Gaussian noise
N	N-Point FFT/IFFT
n_c	Co-sinusoidal noise
N_o	Noise power spectrum
n_s	Sinusoidal noise
$N_s(t)$	Quadrature components of noise
$N_c(t)$	In-phase components of noise
P_{fa}	Probability of a false alarm
P_{md}	Probability of a missed detection
P_d	Probability of a detection
R_b	Data rate
T_s	The signal duration
T_G	Guard interval
$V_n(t)$	Envelope of the band-pass noise
W	Bandwidth occupancy
M	Constellation size

TABLE OF CONTENTS