PARTICLE SWARM OPTIMIZATION IN MULTI-USER ORTHOGONAL FREQUENCY-DIVISION MULTIPLEXING SYSTEMS

SCOTT LYE CARR KEN

THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF MASTER OF ENGINEERING

**SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY
UNIVERSITI MALAYSIA SABAH**
2013

PUMS 99:1

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN TESIS

JUDUL : ____
____
____

IJAZAH : ____
____

SAYA : ______________________________________ **SESI PENGAJIAN** : __________________________________

(HURUF BESAR)

Mengaku membenarkan tesis *(LPSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis adalah hak milik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (/)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☐ TIDAK TERHAD

Disahkan oleh:

_____________________ (TANDATANGAN PENULIS)

_________________________ (TANDATANGAN PUSTAKAWAN)

Alamat Tetap: _______________
____
____
____

_________________________ (NAMA PENYELIA)

TARIKH: ______________

TARIKH: __________________

Catatan:
*Potong yang tidak berkenaan.
*Jika tesis ini SULIT dan TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.
*Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana Secara Penyelidikan atau disertai bagi pengajian secara kerja kursus dan Laporan Projek Sarjana Muda (LPSM).

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

7 April 2013

Scott Lye Carr Ken
PK2010-8095

CERTIFICATION

NAME : **SCOTT LYE CARR KEN**

MATRIC NO. : **PK2010-8095**

TITLE : **PARTICLE SWARM OPTIMIZATION IN MULTI-USER ORTHOGONAL FREQUENCY-DIVISION MULTIPLEXING SYSTEMS**

DEGREE : **MASTER OF ENGINEERING (ELECTRICAL AND ELECTRONIC ENGINEERING)**

VIVA DATE : **5 AUGUST 2013**

DECLARED BY

1. SUPERVISOR
Mr. Kenneth Teo Tze Kin

Signature

ACKNOWLEDGEMENT

First and foremost, I would like to convey my gratitude to my supervisor, Mr. Kenneth Teo Tze Kin, for his helpful guidance and support throughout the course of this research. His lessons taught me to how deal obstacles with strength and grace.

My appreciation goes to Dr. Sigit Arifianto and Mr. Liau Chung Fan for the valuable discussions.

I would also like to dedicate special thanks to my parents, who have moulded me into the person I am today. Their unconditional love, support and motivation will always be my driving force. I deeply thank my brother Terence, for his encouragement and affection, and also Yu Li for believing in me.

Last but not least, warmest thanks to my friends and colleagues from Modelling, Simulation and Computing Laboratory (mscLab) who made the experience so much more meaningful and memorable.

Scott Lye Carr Ken
7 April 2013

ABSTRACT

PARTICLE SWARM OPTIMIZATION IN MULTI-USER ORTHOGONAL FREQUENCY-DIVISION MULTIPLEXING SYSTEMS

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique of transferring an information bit stream on several sub-carrier frequencies. OFDM is used in many communication systems which exhibit high spectral efficiency and robustness against multipath fading channels. However, scheduling and resource allocation in multiuser OFDM system is complicated due to the different possibilities faced by the sub-channel assignments, furthermore the requirements for each user is not homogeneous. Therefore, it is challenging to strategically allocate radio resources and maximize system performance in a multiuser environment. Through modelling of the multiuser OFDM communication system, investigation in simulations shows that adaptive modulation in OFDM uses Channel State Information (CSI) to optimize the sub-carrier modulation scheme. While maintaining a target Bit Error Rate (BER), adaptive modulation optimizes the selection of modulation scheme and transmit power for each sub-carrier so that spectral efficiency is maximized. In this research, the overall system performance improvement is achieved by allocating the best user-to-sub-carrier combinations. To minimize the power consumption, Particle Swarm Optimization (PSO) is utilized to find the exact or near optimal resource allocation for the users. PSO is efficient in handling big solution space akin to resource allocation problems with different permutations mentioned. As a part of enhancing the performance of PSO, investigation of the control parameters effect on multi-user OFDM resource allocation is presented, resulting in particle reselection and dynamic inertia approach which shows 8 % of improvement over the standard PSO algorithm. Results also prove that the combination of both enhancements helped the algorithm to perform significantly better compared to a single enhancement. Furthermore, the introduction of PSO showed 70-75 % of power saving advantage over suboptimal resource allocation techniques.

ABSTRAK

"Orthogonal Frequency-Divison Multplexing" (OFDM) merupakan teknik transmisi data yang menggunakan beberapa isyarat subpembawa secara selari dalam pemodulasiannya. Kebanyakan sistem komunikasi yang bercekapan tinggi dalam penggunaan jalurlebar dan teguh terhadap kesan negatif saluran "multipath fading" mengaplikasikan kaedah OFDM. Walaubagaimanapun, pengurusan sumber komunikasi OFDM adalah rumit disebabkan proses peruntukkan subpembawa untuk setiap pengguna tidak seragam. Oleh kerana itu, isu pemaksimuman kapasiti saluran tanpa wayar di samping memperuntukkan sumber secara strategik adalah amat mencabar. Dalam penyiasatan simulasi melalui permodelan sistem komunikasi OFDM yang berdasarkan pelbagai pengguna, kaedah "Adaptive Modulation" menunjukkan keperluan "Channel State Information" (CSI) untuk mengoptimumkan kadar data di samping mengekalkan Bit Error Rate (BER) yang memuaskan. Dalam saluran "multipath" yang bersifat frekuensi terpilih, kombinasi peruntukkan kepada pengguna yang terbaik dapat memanfaatkan sistem komunikasi. Dalam penyelidikan ini, peningkatan prestasi sistem dicapai melalui peruntukan sumber subpembawa yang terbaik. Selain itu, dalam peningkatkan prestasi kuasa sistem komunikasi, "Particle Swarm Optimization" (PSO) digunakan untuk mencari penyelesaian yang paling optimum untuk pelbagai pengguna. Ini adalah kerana PSO mempunyai kecekapan dalam pengendalian ruang penyelesaian yang besar bersamaan dengan kes situasi peruntukkan sumber yang mempunyai pelbagai kombinasi. Dalam usaha meningkatkan prestasi PSO, penyiasatan kesan-kesan parameter kawalan PSO terhadap sistem komunikasi OFDM oleh pelbagai pengguna dibentangkan. Hasil kerja menunjukkan bahawa kaedah pilihan semula zarah dan inersia dinamik merekodkan sebanyak 8% peningkatan prestasi terhadap penjimatan kuasa transmisi berbanding dengan algoritma asas PSO. Keputusan juga menunjukkan bahawa combinasi kedua-dua kaedah membantu algoritma bertambah baik berbanding dengan satu jenis peningkatan. Tambahan pula, pengenalan PSO menunjukkan peningkatan 70-75% penjimatan kuasa transmisi berbanding teknik-teknik peruntukan sumber suboptimum.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Program
ACO	Ant Colony Optimization
ADSL	Asymmetrical Digital Subscriber Line
AMC	Adaptive Modulation and Coding
ANN	Artificial Neural Network
AWGN	Additive White Gaussian Noise
BC	Best Channel
BER	Bit Error Rate
BPF	Band Pass Filter
CAC	Connection Admin Control
CDMA	Code-Division Multiple Access
CIR	Carrie-to-interference Ratio
CLUSTERPOW	Cluster Power
COMPOW	Common Power
CSI	Channel State Information
DAB	Digital Audio Broadcasting
DE	Differential Evolution
DFT	Discrete Fourier Transform
D-PSO	Dynamic Inertia Weights Particle Swarm Optimization
DR-PSO	Dynamic Inertia Weights plus Reselection Particle Swarm Optimization
DVB	Digital Video Broadcasting
FDM	Frequency-Division Multiplexing
FDMA	Frequency-Division Multiple Access

FEC	Forward Error Correction
FER	Frame Error Rate
FFT	Fast Fourier Transform
FM	Frequency Modulation
GA	Genetic Algorithm
GIMCV	Global Information Multimedia Communication Village
HIPERLAN	High Performance Radio Local Area Network
ICI	Inter-Carrier Interference
IDFT	Inverse Discrete Fourier Transform
IEEE	Institute of Electrical and Electronic Engineers
IFFT	Inverse Fast Fourier Transform
IP	Integer Programming
ISI	Inter-Symbol Interference
ITU	International Telecommunications Union
LAN	Local Area Network
LOS	Line-of-Sight
LP	Linear Programming
LTE	Long Term Evolution
MA	Margin Adaptive
MAC	Medium Access Control
MCCC	Multi-Carrier Cooperative Communications
MCMC	Malaysian Communications and Multimedia Commission
MIMO	Multiple Input Multiple Output
MMSE-IC	Minimum Mean Squared Error Interference Cancellation
M-QAM	M-Quaternary Amplitude Modulation

NSR	Noise-to-Signal Ratio
NTT	Nippon Telegraph and Telephone
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
P2P	Peer-to-Peer
PER	Packet Error Rate
PSK	Phase Shift Keyring
PSO	Particle Swarm Optimization
QoS	Quality of Service
RA	Rate Adaptive
RC	Raised Cosine
RF	Radio Frequency
R-PSO	Particle Reselection Particle Swarm Optimization
RR	Round Robin
RRM	Radio Resource Management
RRS	Radio Resource Scheduler
SI	Swarm Intelligence
SINR	Signal-to-Interference Noise Ratio
SISO	Single Input Single Output
SNR	Signal-to-Noise Ratio
TDMA	Time-Division Multiple Access
TPC	Transmit Power Control
TPSO	Trained Particle Swarm Optimization
WIMAX	Worldwide Interoperability Microwave Access
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

$\frac{E_b}{N_0}$	Energy per Bit to Noise Power Spectral Density Ratio
G_R	Receiver Antenna Gain
G_T	Transmit Antenna Gain
H_k	Channel Gain of Carrier k
N_T	Samples per Symbol
N_c	OFDM Cyclic Prefix
N_{fft}	FFT Size
$N_{postfix}$	OFDM Postfix Samples
N_{prefix}	OFDM Prefix Samples
N_s	Swarm Size
P_L	Path Loss
P_R	Receive Power
P_T	Transmit Power
P_g	Particle Global Best
P_i	Particle Local Best
$P_{n,k}$	Required power for the k^{th} user of n^{th} Sub-carrier
T_m	Delay Spread
T_{sym}	Transmission Time
V_i	Velocity of i^{th} Particle
V_{min}/V_{max}	Minimum and Maximum Particle Velocity
X_i	Position of i^{th} Particle
X_{min}/X_{max}	Minimum and Maximum Particle Position
a_i	Attenuation of i^{th} path

c_1	Cognitive Acceleration Coefficient
c_2	Social Acceleration Coefficient
c_k	Capacity of Carrier k
d_0	Far Field Reference Distance
f_d	Doppler Spread
f_k	k^{th} Sub-Carrier frequency
$q_{n,k}$	Required rate of n^{th} Sub-carrier k^{th} user
r_1, r_2	Random Gaussian Number
t_c	Coherence Time
$x_{i,k}$	i^{th} OFDM symbol on k^{th} Sub-carrier
$\boldsymbol{g}_n$	Raised cosine filter
γ_0	Water-Filling Cut Off Value
γ_k	Signal-to-Noise Ratio for k^{th} Sub-carrier
δ_{max}	Delay Spread of Multipath Channel
σ^2	Variance
τ_i	Time Delay of i^{th} path
ϕ_i	Phase of i^{th} path
Δf	Sub-carrier Spacing
B	Bandwidth
C	Total Link Capacity
G	Generation Count
K	Number of Users
L	Number of Paths
M	Modulation Order
N	Total Number of Sub-carriers

R	Transmit Distance
T	Symbol Period
d	Distance from transmitter
$f(x)$	Fitness Function (Required Transmitter Power)
$u(t)$	Additive White Gaussian Noise
y	Received Signal
$\mathbf{\Psi}$	OFDM Signal
β	Roll off factor
γ	Path Loss Exponent
η	Noise Power Spectral Density
λ	Wavelength of Carrier
ψ	Zero Mean Gaussian Random Variable (Shadowing)

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Over the last few decades, wireless communication systems have evolved substantially in the information age. The trends signify an escalating demand for wireless services over a wide population. The drive for wireless broadband markets in populous countries is the lack of fixed-line infrastructure. In Malaysia year 2011, mobile broadband is the most used access technology at 60.4% followed by Asymmetric Digital Subscriber Line (ADSL) 44.3% and Worldwide Interoperability for Microwave Access (WiMAX) 11.2% (MCMC, 2011). The rise of service providers in Asia-pacific bidding for long term evolution (LTE) and WiMAX spectrum is due to the boost in mobile broadband market and proliferation of smart phones and wireless devices. In 2004, at the time of his publication, Prasad (2004) foresee that in the near future applications that require 1Gbps will come out soon, although at that time it seems 'academic' to develop a system of much higher than reasonable. At present, third generation partnership programme 3GPP showcases technology components like 1Gbps data rates, higher cell throughput and lower cost per bit in LTE-Advanced technology (Mogensen, 2009). Nippon Telegraph and Telephone Coporation (NTT, 2007) had a trial run which reportedly achieved up to an impressive 5Gbps. In time, the rapid development will shrink the world in a global information multimedia communication village (GIMCV) by 2020 (Prasad, 2004).

Orthogonal frequency-division multiplexing (OFDM) is a multi-carrier modulation technique, recognized as the most promising modulation techniques for standard of fourth generation mobile communications. The general idea of multi-carrier transmission is a high rate single data stream transmitted over several low rate sub-carriers. The advantages of OFDM are robustness against frequency-selective fading and high spectral efficiency. A single carrier transmission might entirely fail because a part of it is distorted, compared to a multi-carrier system, only one or few sub-carriers will be affected. The concept of parallel transmission and frequency-division multiplexing (FDM) was researched upon in the mid-1960s (Chang, 1966; Salzberg, 1967; Chang and Gibby, 1968). A patent was also filed in 1966 and issued in January 1970 (Chang, 1970)

Wireless communications are constrained to operate within a limited frequency range or bandwidth. More bandwidth means more information can be transmitted. The International Telecommunication Union (ITU) controls the frequency spectrum through licensing processes. Given the need for future applications to use more data-centric services compared to the conventional voice-only, resulting in extra precious and congested spectrum. Growing subscriber numbers expect to access information at the tip of their fingers anywhere, anytime. It is predicted that the telecommunications market must provide increased data rates and wider coverage to accommodate. Thus, efficient management and usage of the scarce radio resources, e.g. spectrum, power and time are of great importance.

1.2 Management of Radio Resources

The management of limited resources such as spectrum and transmit power is imperative as many connected users must maintain their quality of service (QoS) over the time-varying channel which affects the communications link. Therefore, it is intuitive to use dynamic resource allocation approaches to manage valuable frequency spectrum strategically and conserve transmit power (Lee *et al.*, 2000). The multi-user OFDM resource allocation problem is characterised as a multi-objective and full of different dynamics.

OFDM provides a good interface for implementing multiple access, thus, researchers found out a way to allocate users using frequency-division multiple access (FDMA) and time-division multiple access (TDMA). The earlier multi-user wireless systems which utilize OFDM physical layer are IEEE 802.11a/g and IEEE 802.16. However, the static resource allocation of FDMA and TDMA does not exploit multi-user diversity. Multi-user diversity can be observed by the exploitation of the time-varying characteristics of each user (Tse, 2001). This paves way to multi-user OFDM or orthogonal frequency-division multiplexing (OFDMA), which allows multiple users to transmit simultaneously on the different sub-carriers. The probability of all users experiencing severe fading on a particular sub-carrier is low. For this reason, strategic allocation of sub-carriers can ensure the users have transmission links which are advantageous to them.

Radio resource management (RRM) is the field of systems engineering which practice the optimization of limited resources usage in wireless network (Koivo and Elmusrati, 2009). The performance of a wireless system depends on various parameters, including bandwidth, power, time and etc. The impact of these resources often spans across the network layers where the allocation must be satisfactory to both user and service provider. Typically, several resources must be traded off against each other. Therefore, consideration of acceptable constraints must be made before optimizing an aspect of performance. Finally, the analysis and simulations to study the impact will be translated into the implementation of the resource allocation scheme in the wireless network.

The problem of allocating time slots, sub-carriers, rates and power in an OFDMA system has been an active area of research. Power control in wireless links is complex because the transmit power level affects: the quality of the signal, the range of transmission and the magnitude of interference creates for other users (Kawadia and Kumar, 2005). Energy constrained networks usually focus on overall power consumption of a transceiver for a target QoS level. The motivations for this approach are usually: to extend the battery life, to minimize the electromagnetic radiation in populated areas, to reduce the cost in infrastructure-based networks, and to reduce the interference.

In multi-user OFDM downlink, the users experience the wireless channel differently from each other. To provide downlink data at a required rate and QoS, the base station must be able to overcome the degrading effects of the channel by adapting the transmit power. It requires less power to transmit in sub-carriers with favourable channel gain compared to the ones with poor channel gain. If the base station can allocate the sub-carriers according to which sub-carriers each user is experiencing best, then the transmit power can be optimized. In OFDM each sub-