

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

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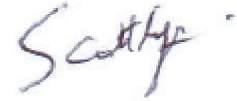
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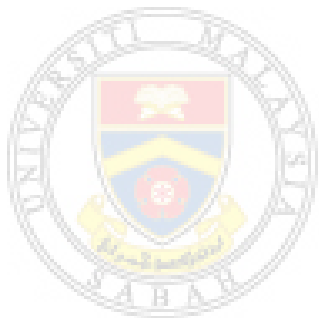
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Scott Lye Carr Ken  
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## ABSTRACT

### **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-Division Multiplexing" (OFDM) merupakan teknik transmisi data yang menggunakan beberapa isyarat subpembawa secara selari dalam pemodulasiannya. Kebanyakan sistem komunikasi yang berkecapan tinggi dalam penggunaan jalur lebar 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 meningkatkan 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 kombinasi 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.

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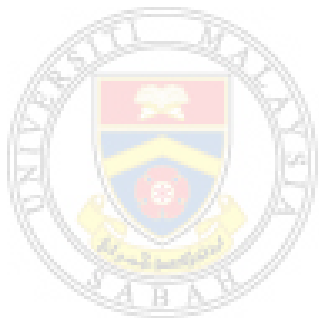
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## LIST OF ABBREVIATIONS

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



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

<b>NSR</b>	Noise-to-Signal Ratio
<b>NTT</b>	Nippon Telegraph and Telephone
<b>OFDM</b>	Orthogonal Frequency-Division Multiplexing
<b>OFDMA</b>	Orthogonal Frequency-Division Multiple Access
<b>P2P</b>	Peer-to-Peer
<b>PER</b>	Packet Error Rate
<b>PSK</b>	Phase Shift Keyring
<b>PSO</b>	Particle Swarm Optimization
<b>QoS</b>	Quality of Service
<b>RA</b>	Rate Adaptive
<b>RC</b>	Raised Cosine
<b>RF</b>	Radio Frequency
<b>R-PSO</b>	Particle Reselection Particle Swarm Optimization
<b>RR</b>	Round Robin
<b>RRM</b>	Radio Resource Management
<b>RRS</b>	Radio Resource Scheduler
<b>SI</b>	Swarm Intelligence
<b>SINR</b>	Signal-to-Interference Noise Ratio
<b>SISO</b>	Single Input Single Output
<b>SNR</b>	Signal-to-Noise Ratio
<b>TDMA</b>	Time-Division Multiple Access
<b>TPC</b>	Transmit Power Control
<b>TPSO</b>	Trained Particle Swarm Optimization
<b>WIMAX</b>	Worldwide Interoperability Microwave Access
<b>WLAN</b>	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 $k^{\text{th}}$ user of $n^{\text{th}}$ Sub-carrier
$T_m$	Delay Spread
$T_{sym}$	Transmission Time
$V_i$	Velocity of $i^{\text{th}}$ Particle
$V_{min}/V_{max}$	Minimum and Maximum Particle Velocity
$X_i$	Position of $i^{\text{th}}$ Particle
$X_{min}/X_{max}$	Minimum and Maximum Particle Position
$a_i$	Attenuation of $i^{\text{th}}$ 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
$f_k$	$k^{\text{th}}$ Sub-Carrier frequency
$q_{n,k}$	Required rate of $n^{\text{th}}$ Sub-carrier $k^{\text{th}}$ user
$r_1, r_2$	Random Gaussian Number
$t_c$	Coherence Time
$x_{i,k}$	$i^{\text{th}}$ OFDM symbol on $k^{\text{th}}$ Sub-carrier
$g_n$	Raised cosine filter
$\gamma_0$	Water-Filling Cut Off Value
$\gamma_k$	Signal-to-Noise Ratio for $k^{\text{th}}$ Sub-carrier
$\delta_{max}$	Delay Spread of Multipath Channel
$\sigma^2$	Variance
$\tau_i$	Time Delay of $i^{\text{th}}$ path
$\phi_i$	Phase of $i^{\text{th}}$ path
$\Delta f$	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
$\Psi$	OFDM Signal
$\beta$	Roll off factor
$\gamma$	Path Loss Exponent
$\eta$	Noise Power Spectral Density
$\lambda$	Wavelength of Carrier
$\psi$	Zero Mean Gaussian Random Variable (Shadowing)



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# 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 Corporation (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-