Adaptive Multi-user MIMO Resource Allocation for Uplink DFT-precoded OFDMA

Dissertation

zur Erlangung des akademischen Grades
Doktor der Ingenieurwissenschaften
(Dr.-Ing.)
der Technischen Fakultät
der Christian-Albrechts-Universität zu Kiel

vorgelegt von

Hanguang Wu

Kiel 2010

Tag der Einreichung:	15.05.2010
Tag der Disputation:	10.09.2010
Berichterstatter:	Prof. Dr.-Ing. Peter Adam Höher
	Prof. Dr.-Ing. Eduard Axel Jorswieck
	Prof. Dr.-Ing. Martin Haardt

Digital Communications

Hanguang Wu

Adaptive Multi-user MIMO Resource Allocation for Uplink DFT-precoded OFDMA

Shaker Verlag
Aachen 2010

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Kiel, Univ., Diss., 2010

Printed in Germany.

ISBN 978-3-8322-9560-8
ISSN 1860-7535

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

Acknowledgements

This thesis is the result of joint research between the Radio System Technology Department of Nokia Siemens Networks GmbH & Co. KG in Munich, Germany and the Information and Coding Theory Lab (ICT) at the Faculty of Engineering of the University of Kiel. The investigation has been conducted under the supervision of Prof. Dr.-Ing. Peter Adam Höher.

During the research work, I have received a lot of support from many people. Without their support, this thesis would have never been accomplished.

I wish to thank Prof. Höher for his tremendous support during the supervision of my studies. His constant encouragement, meticulous guidance, valuable suggestions and instructive comments have contributed significantly to this work. I am grateful to Prof. Dr.-Ing. Eduard Axel Jorswieck from Technical University of Dresden for inspiring discussions, especially those related to channel capacity regions and optimization theory. I would like to express my gratitude to Prof. Dr.-Ing. Martin Haardt from Technical University of Ilmenau for providing valuable feedback and suggestions to improve the quality of this thesis.

I am deeply indebt to my supervisor in Nokia Siemens Networks, Dr. Thomas Haustein, not only for technical guidance, fruitful discussions and timely feedback, but also for all kinds of support I received in the work and in the life. His enthusiasm, creativity and vision motivate me greatly. His conceptual thinking and strong problem-solving skills both in theory and practice will always remain my professional goals.

A special thank goes to the director of Radio System Technology Department, Dr. Egon Schulz, for providing me the opportunity to work in such an inspiring and joyful environment. The special thank also extends to the workmates and staff at the department, Dr. Jijun Luo, Rüdiger Halfmann, Wolfgang Zirwas, Ying Zhang, Wolfgang Mennerich, Jee Hyun Kim and Yikang Xiang for their helpful discussions and for creating the friendly working atmosphere. I am also grateful to my previous colleagues at Siemens AG - Mobile Phones, Dr. Wen Xu, Dr. Ralf Heddergott and Dr. Thomas Hindelang for their support at the initial stage of the thesis.

Last but not the least, I would like to specially thank my parents for their constant encouragement and support throughout my life and studies. My special thank also goes to my wife Hui for her love and understanding at all times.

Munich, 15. May 2010 Hanguang Wu

Abstract

To meet the demand for higher data rates, also in uplink, in wireless communications, OFDMA (orthogonal frequency-division multiple access) and MIMO (multiple-input multiple-output) has been recognized as a promising solution. An example is its application in the successor of the 3rd Generation (3G) mobile communication system 3GPP-LTE (Long Term Evolution). Despite the well-known medium access control (MAC) capabilities of MIMO-OFDMA systems, specific aspects and detailed investigation of high-performance, cost-effective practical solutions in future LTE and LTE-advanced products remain challenging.

Due to the limitation of available resources, e.g., transmit power, time slots and frequency spectrum, future high data rate wireless communication systems need to be highly flexible and efficient in order to deliver the best possible service at minimum cost to the users. In particular, uplink transmission needs to be power efficient because user equipments (UEs) are usually power-limited, especially it is important for the UEs at the cell edge, because they have to bridge a large distance to reach their serving base station. In order to achieve the goal using low cost power amplifiers, an important method is to employ transmit waveforms with low peak-to-average power ratio (PAPR). The use of DFT-precoding combined with OFDMA has been considered as an attractive uplink transmission scheme to meet these requirements.

This thesis focuses on the resource allocation problem in DFT-precoded OFDMA uplink, where adaptive resource assignment according to the channel conditions to optimize the system performance is considered. Emphasis is put on the performance limit of a practical system with reasonable signal processing complexity. We aim to provide insight into the achievable system sum rate of a DFT-precoded OFDMA uplink transmission subject to individual power constraints of the UEs. Based on the analysis, we investigate potential solutions to improve the system rate performance.

At the beginning, we propose a new structure which associates multiple DFT-precodings with a single UE to overcome the limitations in conventional DFT-precoded OFDMA. The proposed structure allows a more flexible usage of the frequency resources in the system and enables multiple services for users with different quality of service and error protection requirements. We study both the PAPR and the achievable spectral efficiency for different transmitter structures using a finite bit loading table in LTE uplink scenarios. Additionally, we show potential performance improvements by applying spectrum shaping for the cell edge UEs.

We further focus on the fundamental achievable rate for a DFT-precoded OFDMA uplink with linear frequency domain equalization subject to individual power constraints of the UEs. Starting with the single user single-input single-output (SU-SISO) system, we derive a general framework for calculating the achievable sum rate for any arbitrary assignment of the sub-carriers. Based on this, we design an optimal sub-carrier allocation algorithm to maximize the system sum rate. Furthermore, we reformulate the problem of sum rate maximization into a problem of performing equal gain power (EGP) allocation in the corresponding non-precoded OFDMA system. A geometrical interpretation of EGP allocation is provided and the relation to the well-known capacity achieving waterfilling solution is pointed out. Using the derived framework, the sum rate achieved by different sub-carrier and power allocation methods are compared and discussed. By introducing the concept of equivalent channel gain, the results derived for the SU-SISO case can be straightforwardly extended to the SU-SIMO case, where multiple antennas are available at the base station (BS). For the case where multiple antennas are available at both the UE and the BS (SU-MIMO), the achievable rate is also formulated and discussed.

Based on the obtained sum rate result from the SU-SISO case, the achievable system sum rate in the multi-user (MU-SISO) case can be formulated as the sum of rates achieved by all UEs jointly performing EGP allocation among their assigned set of sub-carriers, subject to their individual power constraints. We propose a heuristic approach which shows very close performance to the multi-user channel capacity. Furthermore, we propose a channel-dependent resource fair score-based scheduler to adaptively assign sub-carriers for UEs. A significant gain is observed compared to other non-adaptive sub-carrier assignment methods. For the case where multiple antennas are available at the BS (MU-SIMO), we further discuss and analyze the achievable rate performance using different transmission strategies including frequency-division multiple access (FDMA), space-division multiple access (SDMA) and a combination of both.

When multiple antennas are available at both the BS and the UEs (MU-MIMO), compared to the MU-SIMO case an additional degree of freedom, namely spatial processing of the transmitted signal for each UE is possible. In this work, we propose a joint multi-user precoder optimization algorithm to maximize the system spectral efficiency. This algorithm has linear complexity in the number of used sub-carriers. Moreover, depending on the requirements, at least one of the UEs can optionally apply a frequency non-selective precoder to maintain the nice PAPR property of the transmitted signal. Additionally, the required feedback overhead to convey the precoder decision to the UE is significantly reduced. Furthermore, to handle the fairness issues between the UEs, a simple spatial scheduler is proposed to effectively steer and balance the individual user rate exemplarily. We apply this algorithm to a DFT-precoded OFDMA system with two UEs and a BS, where each UE has 2 antennas and the BS also has 2 antennas. Simulation results show that the system spectral efficiency almost doubles for various SNR conditions compared to the case where each UE has only one transmit antenna. Finally, weighted sum rate maximization is also incorporated in the algorithm and its achievable rate region is presented and compared to the rate achieved by other popular precoding schemes for LTE uplink scenarios.

Keywords: adaptive resource allocation, DFT-precoded orthogonal frequency-division multiple access (DFT-precoded OFDMA), single carrier frequency-division multiple access (SC-FDMA), long term evolution (LTE), peak-to-average power ratio (PAPR), uplink channel capacity, multiple-input multiple-output (MIMO), system sum rate

Contents