Adaptive Precoding and Resource Allocation in Cognitive Radio Networks

Dissertation

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

vorgelegt von

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Kiel 2017

Tag der Einreichung:	29.11.2016
Tag der Disputation:	07.04.2017
Berichterstatter:	Prof. Dr.-Ing. Peter Adam Höher
	Prof. Dr.-Ing. Wolfgang Gerstacker

Digital Communications

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Shaker Verlag
Aachen 2017

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., 2017

Printed in Germany.

ISBN 978-3-8440-5372-2
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

To my wife, my daughters.

Acknowledgments

This thesis was conducted during the time of working as a research assistant at the Chair of Information and Coding Theory, Faculty of Engineering, University of Kiel, Germany. The investigations have been performed under the supervision of Prof. Dr.-Ing. Adam Höher.

I would like to praise the almighty God for the good health and the wellbeing that were necessary to complete the research and the dissertation work.

I would like to express my sincere thanks to Prof. Höher for his generous support and guidance throughout my study. His constant encouragement, valuable suggestions, constructive comments, and warm feelings have contributed significantly toward accomplishing this work.

I would like to express deep gratitude to the German Academic Exchange Service (DAAD) for their financial support granted to me as a Ph.D. scholarship.

I would like to thank the disputation committee: Prof. Dr.-Ing. Wolfgang Gerstacker, Prof. Dr.-Ing. Ludger Klinkenbusch, and Prof. Dr.-Ing. Michael Höft for serving as examiners as well as for their helpful discussion and technical notes during and after thesis defense. Deep gratitude goes to Prof. Klinkenbusch for his precious recommendations which were necessary for extending the financial support of my Ph.D. program.

Last but not the least, I am greatly indebted to my parents for their encouragement, support, and love throughout my life. Great indebtedness goes to my wife for her love and patience which without them the completion of this work would never have been possible.

Kiel, April 2017 Abdullah Yaqot

Abstract

The use of cognitive radio (CR) is anticipated to enable a couple of significant enhancements in wireless communications. The major enhancements include better configuration and dynamic adaptation of radio access technologies in tone with localized conditions and more independent localized options of spectrum usage and networking configuration. Consequently, improvements in spectrum efficiency, controllable mutual interference among users, and flexible coexistence with various radio access technologies are prominent benefits. These benefits have caused involvement of cognitive networking as an integral component of next generation mobile networks. The greatly increased complexity in next generation mobile networks (due to the localized variations, the heterogeneous networking, and the availability of various access methods) will not be optimally managed with human input, or with those conventional algorithms which lack adaptability to the environmental variations. Therefore, cognitive networking will enable next generation networks to be more adaptable and successfully able to manage these conditions with greatly reduced human intervention.

Among the operational networking paradigms, the underlay cognitive radio mode suffers from short communication range. This impact results from limiting the interference at the primary users which necessitates imposing constraints on the transmit power of the cognitive transmitter. Such power limitation in turn reduces the spectral efficiency of cognitive radio compared to conventional non-cognitive radios. The use of multiple antennas is an effective technique to manage the interference at the primary radio via multiuser transmit precoding. Furthermore, by means of multiuser multiple-input multiple-output (multiuser MIMO), the spectral efficiency of the cognitive radio network can be enhanced due to enabling the management of mutual interference among the cognitive users.

In this thesis, we develop efficient resource allocation and adaptive precoding schemes for two scenarios: multiuser MIMO-OFDM and multiuser MIMO based CR networks. The aim of the adaptive precoding is to squeeze more efficiency in the low SNR regime. In the context of

the multiuser MIMO-OFDM CR network, we have developed resource allocation and adaptive precoding schemes for both the downlink (DL) and uplink (UL). The proposed schemes are characterized by both computational and spectral efficiencies. The adaptive precoder operates based on generating countable degrees of freedom (DoF) by combining the spaces of the block interference channel. The resource allocation has been formulated as a sum-rate maximization problem subject to the upper-limit of total power and interference at primary user constraints. The variables of the problem were matrix of the precoding and integer indicator of the subcarrier mapping. The formulated optimization problem is a mixed integer programming having a combinatorial complexity which is hard to solve, and therefore we separated it into a two-phase procedure to elaborate computational efficiency: Adaptive precoding (DoF assignment) and subcarrier mapping.

From the implementation perspective, the resource allocation of the DL is central based processing, but the UL is semi-distributed based. Central resource allocation task is solved to maintain central adaptive precoding and subcarrier mapping for both the DL and UL. The subcarrier mapping is performed by optimal and efficient method for the DL as the problem is modeled as convex. But, it is characterized by near-optimality for the UL despite the convexity due to the per-user resource constraints of the UL problem. The DL problem is sorted out using the Lagrange multiplier theory which is regarded as an efficient alternative methodology compared to the convex optimization theory. The solution is not only characterized by low-complexity, but also by optimality. Concerning the UL, the distributive resource allocation task is necessary to resolve the power allocation of the UL. The prominent advantages of the semi-distributed scheme in the UL are the provided computational and spectral efficiencies. Moreover, such scheme also leads to a small data overhead and helps simplify the terminal structure. Numerical simulations illustrate remarkable spectral and SNR gains provided by the proposed scheme. In addition, robustness is demonstrated against the tight and relaxed transmission conditions, i.e. interference constraints. Therefore, the proposed schemes enable larger communication range for underlay CR networks.

Concerning the multiuser MIMO CR based network, we develop an adaptive non-iterative linear precoder, namely Adaptive Minimum mean square error Block diagonalization (AMB). The proposed AMB precoder employs the proposed DoF concept which we call it here *precoding diversity*. In this context, DoFs of the proposed precoder are generated by space combining and channel path combining methods. We have also developed adaptive Zero-Forcing Block diagonalization (AZB) engaging the precoding diversity concept. The proposed AMB precoder illustrate a notable spectral and SNR gains over the conventional MMSE as well as the AZB precoders in the SNR region of interest: The low SNR region. Unlike non-linear iterative precoders, the proposed precoders are linear non-iterative and therefore provide low-complexity along with a gainful spectral efficiency.

The complexity provided by the proposed precoders is an indispensable price for the acquired spectral efficiency compared to the state-of-the-art linear precoders. More specifically, the antenna configuration affects the complexity of both AMB and AZB precoders, which is designed according to the capacity-complexity trade-off. The growth in complexity of the proposed AMB and AZB precoders is exponential. However, possible complexity reduction aspects include parallel computing which is facilitated by the independence of the DoFs in the adaptive precoding. The other aspect relaxes the exponential complexity by working off those DoFs which don't take the entire set of cognitive users into account.

Keywords: Cognitive radio, next generation networks, adaptive precoding, precoding diversity, multiuser MIMO, OFDMA, resource allocation, convex optimization theory, Lagrange multiplier theory.

Kurzfassung

In dieser Dissertation werden effiziente Ressourcenallokation und adaptive Vorkodierungsverfahren für zwei Szenarios entwickelt: Mehrbenutzer-MIMO-OFDM und Mehrbenutzer-MIMO jeweils basierend auf CR-Netzwerken.

Im Bereich der Mehrbenutzer-MIMO-OFDM CR-Netzwerke wurden Verfahren zur Ressourcenallokation und zur adaptiven Vorkodierung jeweils für den Downlink (DL) und den Uplink (UL) entwickelt. Die Ressourcenallokation wurde als Optimierungsproblem formuliert, bei dem die Summenrate maximiert wird, wobei die Gesamtsendeleistung und die Interferenz an den Primärnutzern begrenzt ist. Das formulierte Optimierungsproblem ist ein sogenanntes Mixed-Integer-Programm, dessen kombinatorische Komplexität nur extrem aufwendig lösbar ist. Auf Grund dessen wurde es zur Komplexitätsreduktion in zwei Phasen aufgeteilt: Adaptive Vorkodierung (DoF-Zuordnung) und Subkanalzuordnung. Während die Ressourcenallokation für den DL aus Implementierungssicht ein zentralistischer Prozess ist, kann sie für den UL als semiverteilt eingeordnet werden. Die Aufgabe der zentralen Ressourcenallokation wird gelöst, um die zentrale adaptive Vorkodierung und die Subkanalzuordnung für UL und DL zu verwalten. Die Subkanalzuordnung ist für den DL optimal und effizient gelöst, indem das Problem als konvexes Problem modelliert ist. Für den UL wiederum ist das Problem trotz der Konvexität quasi-optimal gelöst, da in der Problemformulierung eine Begrenzung der Ressourcen pro Benutzer existiert.

Im Falle der Mehrbenutzer-MIMO CR-Netzwerke wurde ein adaptiver, nichtiterativer, linearer Vorkodierer entwickelt, genannt "Adaptive Minimum mean square error Block diagonalization" (AMB). Die AMB Vorkodierung generiert Freiheitsgrade und wird hier als *Vorkodierungsdiversität* bezeichnet. Der vorgestellte AMB Vorkodierer zeigt im wichtigen Bereich des niedrigen SNR bemerkbare Gewinne im SNR und der spektralen Effizient gegenüber dem konventionellen MMSE Vorkodierer. Der vorgestellte Kodierer ist linear und nichtiterativ und kann so eine geringe Komplexität zusammen mit einer Steigerung der spektralen Effizienz bieten.

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