Preface

In typical mobile communication systems transmission takes place over a time-varying fading channel. The stochastic channel fading process can assumed to be bandlimited and its realization is usually unknown to the receiver. To allow for a coherent signal detection, the channel fading process is often estimated based on pilot symbols which are periodically inserted into the transmit symbols sequence. The achievable data rate with this approach depends on the dynamics of the channel fading process. For this conventional approach, i.e., performing channel estimation solely based on pilot symbols and using it for coherent detection (*synchronized detection*) in a second step, bounds on the achievable data rate are known. However, in recent years receiver structures got into the focus of research, where the channel estimation is iteratively enhanced based on the reliability information on data symbols (code-aided channel estimation). For this kind of systems, the bounds on the achievable data rate with synchronized detection based on a solely pilot based channel estimation are no longer valid.

The study of the possible performance gain when using such receivers with synchronized detection and a code-aided channel estimation in comparison to synchronized detection in combination with a solely pilot based channel estimation poses also the question on the capacity of stationary fading channels. Although such channels are typical for many practical mobile communication systems, already for the simple case of a Rayleigh flat-fading channel the capacity and the capacity-achieving input distribution are unknown. There exist bounds on the capacity, however, most of them are tight only in a limited SNR regime and rely on a peak power constraint.

Thinking of this, in the present thesis various aspects regarding the capacity/achievable data rate of stationary Rayleigh fading channels are treated. First, bounds on the achievable data rate with i.i.d. zero-mean proper Gaussian input symbols, which are capacity achieving in the coherent case, i.e., in case of perfect channel knowledge at the receiver, are derived. These bounds are tight in the sense that the difference between the upper and the lower bound is bounded for all SNRs. The lower bound converges to the coherent capacity for asymptotically small channel dynamics. Furthermore, these bounds are extended to the case of multiple-input multiple-output (MIMO) channels and to the case of frequency selective channels.

The comparison of these bounds on the achievable rate with i.i.d. zero-mean proper Gaussian input symbols to the achievable rate while using receivers with synchronized detection based on a solely pilot based channel estimation already gives an indication on the performance of such conventional receiver structures. However, for systems with receivers based on iterative code-aided channel estimation periodic pilot symbols are still used. Therefore, in a further part of the present work the achievable rate with receivers based on synchronized detection and a code-aided channel estimation is studied. For a specific type of such a receiver an approximate upper bound on the achievable rate is derived. The comparison of this approximate upper bound and the achievable data rate with receivers using synchronized detection based on a solely pilot based channel estimation gives an approximate upper bound on the possible gain by using this kind of code-aided channel estimation in comparison to the conventional receiver using a solely pilot based channel estimation. In addition, the achievable data rate with an optimal joint processing of pilot and data symbols is studied and a lower bound on the achievable rate for this case is derived. In this context, it is also shown which part of the mutual information of the transmitter and the receiver is discarded when using the conventional receiver with synchronized detection based on a solely pilot based channel estimation.

Concerning the typically applied periodic pilot symbols the question arises if these periodic pilot symbols are optimal from an information theoretic perspective. To address this question, the mutual information between transmitter and receiver is studied for a given discrete signaling set. The optimum input distribution, i.e., the one that maximizes the mutual information when restricting to the given signaling set, is given implicitly based on the Kullback-Leibler distance. Thereon it is shown that periodic pilot symbols are not capacity-achieving in general. However, for practical systems they allow for receivers with small computational complexity.

Acknowledgements

The work presented in this book has been carried out during my time as a research assistant at the Institute for Integrated Signal Processing Systems at RWTH Aachen University. Throughout this time I had the opportunity to work, discuss, and collaborate with many brilliant people. Their comments, thoughts, and also criticism has been very beneficial during the course of this work and helped me to learn, understand, and apply the fundamental concepts of information and communication theory.

There are a number of people I wish to thank making all this possible. First I thank my advisors Prof. Heinrich Meyr and Prof. Gerd Ascheid. The given

work was initiated by their intriguing question ’What can we gain by iteratively enhancing the channel estimation using reliability information on data symbols?’. Prof. Meyr and Prof. Ascheid gave me the freedom and time to follow my ideas to use information theory to find answers to the given question. I want to thank them for their support over the years. Their continuous encouragement and faith in my abilities have been very motivating. Especially, I would like to thank Prof. Meyr for very valuable discussions which have been particularly fruitful by bringing together his deep knowledge on estimation and detection theory and my thoughts and ideas in information theory.

Furthermore, I thank Prof. Helmut Bölcskei for reading an earlier version of the present manuscript. In addition, I appreciate that he invited me to the Communication Theory Group at ETH Zurich in June 2007. This exciting stay in Zurich gave me invaluable insights and the opportunity to discuss with Giuseppe Durisi, Ulrich Schuster, and Veniamin Morgenshtern. Besides the fact that all of them are outstanding researchers, I would like to thank them for their friendly welcome and their openness in sharing their knowledge. With Veniamin I have discussed my approach of bounding the achievable rate of a stationary Rayleigh flat-fading channel using means of random matrix theory. Although we did not came up with a solution, this collaboration has been rewarding as we understand the underlying problems. During these discussions I learned a lot from Veniamin who has a deep knowledge in random matrix theory. Furthermore, I have to thank Giuseppe and Uli for discussing several aspects of the capacity of noncoherent fading channels during my stay at ETH. In addition, I gracefully thank Giuseppe Durisi, with whom I discussed large parts of the present work when he came to Aachen in June 2009. By pinpointing weaknesses in some of my proofs, his comments and critics have enhanced the present work a lot.

I also thank Prof. Rudolf Mathar for interesting discussions on the parts regarding discrete input distributions covered in Chapter 10. This part of the work emerged after a talk on *Capacity-Achieving Discrete Signaling over Additive Noise Channels* given by him on the UMIC day in 2007. A few weeks later I discussed the application of this approach to the scenario of a stationary Rayleigh flat-fading channel with him, resulting in an ISIT publication.

In addition, I thank my colleagues at the Institute for Integrated Signal Processing Systems for a pleasant working environment. Especially I would like to thank Adrian Ispas, Lars Schmitt, Susanne Godtmann, Martin Senst, and Dan Zhang for many helpful and inspiring discussions. Special thanks are due to Adrian Ispas with whom I had endless discussions about the material in the present manuscript especially during the final phase of the work.

Last but not least, I thank my parents for their continuous support during my studies enabling all this. Lastly, I am particularly indebted to my girlfriend Anke, for her patience and her encouragement which essentially contributes to the success of this work.

Aachen, August 2010 *Meik Dörpinghaus*

On the Achievable Rate of Stationary Fading Channels
Dörpinghaus, M.
2011, XIV, 310 p., Hardcover
ISBN: 978-3-642-19779-6