# Unequal Error Protection Adaptive Modulation in Multicarrier Systems

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## Abstract

*Unequal Error Protection* (UEP) is the key to future prioritized data communication, multilevel quality of services (QoSs), and scalable multimedia transmission. This means that these applications provide data of different importance and require different error protection. Under these conditions, multicarrier modulation is highly recommended due to its suitability for adapting individual sub-carriers, which are subject to different channel conditions, with different bit rates, code rates, and powers according to any given performance constraints.

So far, many channel adaptive bit-loading algorithms in multicarrier systems have been developed and new coding schemes have dramatically enhanced the system performance. However, these algorithms treat all sub-carriers equally (non-UEP), i.e., the average error rate will roughly be the same for all subcarriers. Based on some of these readily available bit-loading algorithms, we propose a set of new UEP bit-loading schemes that allow for allocating an arbitrary number of bits with arbitrary noise margins or symbol error-ratios (SERs), thereby realizing UEP at the modulation level. In these schemes, the subcarriers are subdivided into smaller sets, where each set is dedicated to a certain priority class. Moreover, we propose different partitioning schemes that require minimum complexity and overhead.

In general, adaptive transmission techniques require closed-loop communications by using feedback links or exploiting channel reciprocity. In this thesis, closed-loop adaptive schemes have been realized for two different physical single-input single-output (SISO) channels, the wired and the wireless. In wired systems, the channel transfer function is considered to be deterministic and, therefore, requires very limited monitoring. However, it suffers from non-stationary impulse noise. In this case, a robust signal-to-noise ratio (SNR) sorting scheme has been proposed to better protect the high-priority data. In contrast to the wired channels, the wireless ones are more susceptible to varying conditions due to mobility. This implicates a study of the feedback link quality and reliability.

We introduce two different subcarrier allocation methods. The first method is a sub-carrier partitioning mechanism, where a given set of (sorted) subcarriers are divided amongst different priority classes in order to preserve certain QoSs. This can be realized, or approximated, using a set of complex nested iterations. As an alternative to the first method, a multilevel (hierarchical and non-hierarchical) modulation technique has been introduced to avoid lengthy searching and sorting.

As an extension to our work, we modify these prioritized adaptation schemes to realize UEP in multiple-input multiple-output (MIMO) channels as well. Hereto, the spatial and the spectral information, provided by the channel state information (CSI), will be exploited to realize UEP. This new prioritized adaptation, combined with the SNR robust sorting, results in a trade-off between spatial multiplexing and diversity gains in case of CSI uncertainties and different antenna correlations.

Moreover, we consider bit-loading and channel adaptation techniques for multiuser systems with different QoS requirements. This has been performed by extending our conventional UEP approaches to achieve prioritized transmission across a given number of users using orthogonal

frequency division multiple access (OFDMA), block-diagonalized (BD) space division multiple access (SDMA), and non-orthogonal SDMA. Using MIMO-OFDMA, we succeed in maximizing the capacity by utilizing the different users' eigenchannels and exploiting the multiuser diversity. One user in a BD-SDMA enjoys the orthogonal projection to the other users' null-space. Thus, multiuser interference (MUI) is completely eliminated unless the CSI at the transmitter is incorrect. Even then, our UEP adaptive scheme succeeds in protecting the important classes. Finally, we consider the non-diagonal SDMA, which is the most challenging approach in this thesis. However, in this case, our prioritized transmission outperforms the multiuser multiple access technique using minimum mean-square error (MMSE) linear filtering without QoS constraints. After all, our proposed algorithms succeed in realizing the proposed UEP in wireline and wireless environments under diverse channel conditions and different link-qualities. Furthermore, we show that our prioritized transmission schemes exploit limited feedback regimes efficiently, where they consistently outperform either non-adaptive or adaptive methods with equal error protection (EEP).

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I confirm that this dissertation represents my own work. The contribution of any supervisors and others to the research and to the dissertation was consistent with normal supervisory practice.

Khaled Shawky Hassan
Bremen, November 2010

# Dedication

*To my mother, my father, and my wife Hala*

# Contents

# List of Algorithms