1 Introduction

With the expected development of new mobile multimedia services in the coming years, radio systems will have to meet demands for much higher data rates than today. Those variable and high data rates (20 Mbps and more) will be requested at all different levels of mobility, even at high vehicular speeds. Therefore future radio systems will have to offer data services at a high degree of flexibility, where additionally high adaptivity to the actual transmission situation is necessary. To meet this demand for higher data rates, new technologies need to be implemented.

In general, the design of communication systems depend strongly on the properties of the radio channel. Broad-band radio propagation is characterized by a multitude of propagation paths ("multi-path") which lead to a frequency selective behavior of the radio channel. In high data rate applications this leads to strong Inter-Symbol Interference (ISI), which requires a high equalization complexity at the receiver. Multicarrier techniques have been proposed to deal with the frequency selectivity while still keeping the implementation feasible. In these techniques, a high rate source data stream is distributed onto multiple parallel low rate substreams which are modulated individually and transmitted simultaneously. In *Orthogonal Frequency Division Multiplexing* (OFDM), those substreams are chosen to be orthogonal subcarriers. Due to this, OFDM is an effective transmission technique to deal with the frequency selectivity with low complexity.

An interesting new technology proposes to use multiple transmit and receive antennas simultaneously, denoted as *Multiple Input Multiple Output* (MIMO, figure 1.1), which will be used in combination with OFDM in this thesis. The multiple antennas will transmit simultaneously and in the same radio frequency. Even though conventionally this would result in degraded performance due to interference, suitable MIMO techniques exist so that this simultaneous transmission can be used to increase the resulting data rate significantly [Fos96, RC98, TSC98, Ala98]. With this MIMO techniques, the radio channel can have a much higher capacity, enabling very high data rates.

However, this improved channel capacity depends strongly on the properties of the radio channel: If there are a lot of different radio propagation paths

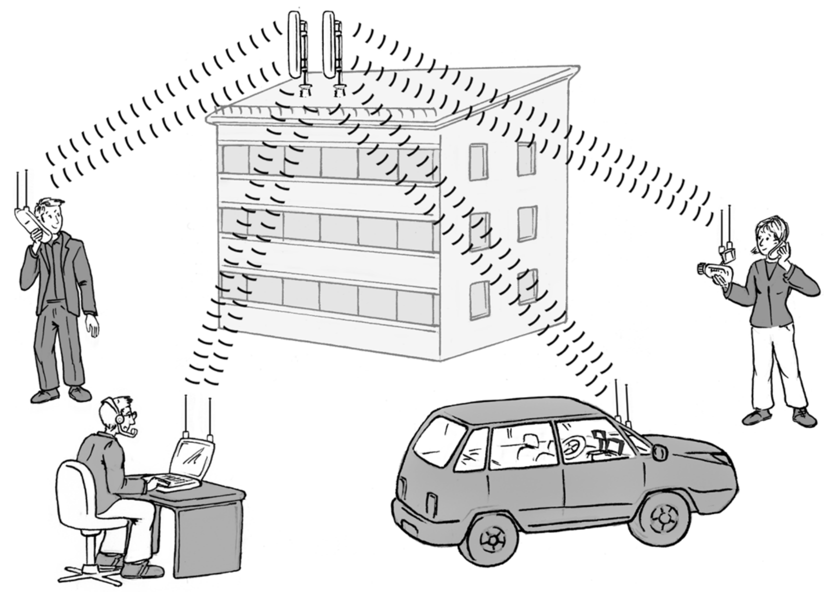

Figure 1.1: Multiple users using MIMO radio communication

through reflection and rich scattering, the capacity is indeed increased significantly. In contrast to this, a radio channel with only few propagation paths will offer almost no improvement compared to a single antenna system.

Simulations of communication systems are of crucial importance to evaluate the design and implementation of new systems. In such simulations the relevant radio channel properties need to be modeled realistically and an adequate statistical model for the essential properties of this channel need to be found. Unfortunately, simple multi-antenna radio channel models will predict the increased MIMO capacity to be available in all circumstances, which will result in too optimistic simulation results.

In this thesis, a new multi-antenna radio channel model will be developed that characterizes the relevant properties of the channel but is still easily configurable. The relevant parameters of a MIMO radio channel model are explained and lead to the newly introduced MIMO-WSSUS (Wide Sense Stationary Uncorrelated Scattering) radio channel model. This approach promises to represent the MIMO-related channel properties realistically enough, so that MIMO techniques can now be evaluated by simulations which give realistic performance results.

Subsequently, this thesis introduces several basic MIMO techniques:

- *Receiver Diversity* where multiple receiving antennas for combining several independent copies of the received signal are used.

- *Transmit Diversity* to send one data stream in precoded form over multiple transmit antennas simultaneously, which will be re-assembled in the receiver.

- *Spatial Multiplexing* to transmit multiple data streams in parallel, which can be distinguished in the receiver as long as the radio channel has rich enough scattering.

These techniques are evaluated by simulations in the context of high data rates and different radio channel conditions. Simulations are carried out both in a simple radio channel model and the newly proposed MIMO-WSSUS model.

Additionally, a linear precoding technique with variable amount of feedback from [Tau05] is explained and improved. This technique calculates a matrix factorization of the optimum precoding matrix into unitary product matrices, some or all of which can be used for the approximation of the optimum precoding matrix. All or only a subset of the factorization matrices can be fed back to the transmitter to reduce the required feedback data rate. This enables a trade-off between the amount of feedback information and system performance. In this thesis, an improvement to the matrix parameterization is introduced, which shows a performance gain over the original parameterization.

For all techniques, the performance will be evaluated and the dependency on the radio channel model and its chosen parameters will be shown. It is expected that in a rich scattering channel even the simple Spatial Multiplexing techniques with linear receiver will strongly increase the available data rate when increasing the number of transmit and receive antennas. However, in a more unfriendly radio channel with little scattering as modeled with the new MIMO-WSSUS model, it is expected that Spatial Multiplexing techniques perform not as good anymore.

It can be concluded that MIMO performance simulations must use a MIMO radio channel model which adequately describes the radio channel conditions even with little scattering. Otherwise unrealistically optimistic performance results will occur. The introduced MIMO-WSSUS radio channel model is a simple approach that represents these statistical properties accurately enough and is still easily configurable.

The thesis is divided as follows:

The general properties of radio channels are introduced in chapter 2 for single-antenna communication.

Chapter 3 explains the OFDM transmission technique as an effective way of broad-band communication.

In chapter 4, a new multi-antenna radio channel model is being developed in logic continuation to the single-antenna radio channel WSSUS model, but with adequately representing the important multi-antenna correlation. This introduces the new MIMO-WSSUS radio channel model.

Several basic MIMO techniques will be introduced in chapters 5 through 7. Each of the described MIMO techniques are evaluated both in simple MIMO radio channels and in the MIMO-WSSUS model, and in some cases this gives different results than what has been expected by previously proposed channel models.

To demonstrate the important influence of the MIMO radio channel model, eventually chapter 8 repeats some system evaluations but with different MIMO radio channel models as taken from literature. This will underline the importance of the radio channel model developed in this thesis and the required attention for the channel model when system performance is evaluated with simulations.

The thesis is finished by the conclusion and appendix.