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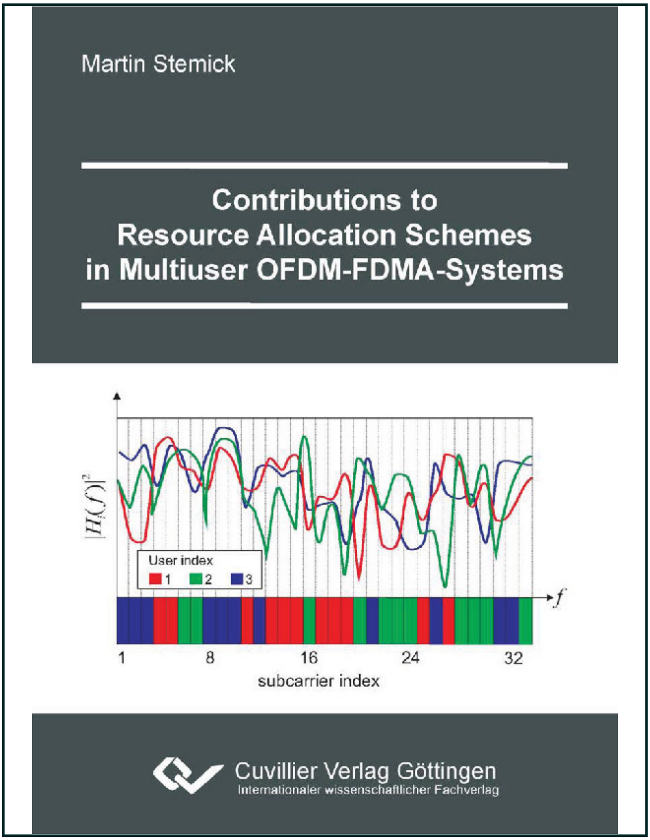
Contributions to Resource Allocation Schemes in Multiuser OFDM-FDMA-Systems



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2 Mobile Radio Channel

Communication over wireless channels is used since the beginning of the 20th century [Wea13]. The great advantage of wireless over wireline communication lies in the mobility it provides for the user. In principle, this enables message and data exchange at any location and over long distances. In order to exploit these benefits, the designer of a wireless communication system has to be well aware of the propagation properties inside the present radio channel. *To put it another way, it is the channel that actually designs the system, not the system designer*.

In wireline channels, the signals propagate along a fixed dimension and therefore experience only moderate losses and disturbances. In contrast to this, in mobile radio channels the transmitted signals propagate through space, which leads to a rapid loss of signal power and gives rise to multiple signal reflections.

In this thesis, the considered direction of transmission is the *downlink* from a fixed *Base Station* (BS) to a *Mobile Terminal* (MT), cf. Fig. 1. Due to the reciprocity of the radio channel, the following analysis of the downlink can also be applied to the *uplink* direction. The transmission area covered by the BS is referred to as a cell.

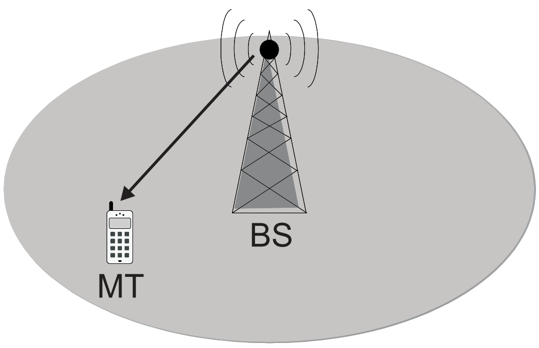

Fig. 1: Wireless transmission in downlink direction

In order to enable an error-free transmission link between an MT and its BS a detailed understanding of the signal propagation through the channel is necessary. Hence, the main properties of a mobile radio channel are introduced in this chapter.

Mobile radio channels are mostly described by division into three parts: *Large*, *Medium* and *Small Scale Effects*. First are the so-called *Large Scale Effects,* which apply to the average power of the transmit signal and describe effects that occur due to the general geometry of the propagation path. Therefore, large scale effects only change gradually with the (large scale) movement of the MT. The large scale effects are also often referred to as *Path Loss* and are assumed to show no frequency selectivity [Tra04].

Medium scale effects describe the influence of obstacles in the local area around the MT. These effects change when the MT moves over distances, which are in the order of some tens or hundreds of meters. These effects are also known as *Shadowing* and are assumed to show no frequency selectivity.

The third part considers so-called *Small Scale Effects,* which stem from multiple reflections of the transmit signal at various objects. Hence, these effects are also referred to as *Multipath Propagation*. At the receiver the reflected and delayed versions of the original transmit signal combine, which leads to constructive or destructive interference. The instantaneous interference situation depends on amplitude and phase of the individual reflections and therefore will change rapidly upon movements of the MT in the order of a signal wavelength. For the same reasons, multipath fading causes frequency selectivity if the duration of a transmit symbol is in the order of the maximum path delay.

Since large, medium, and small scale effects are based on different physical phenomena, they can be described and modeled independently. The following sections will give an introduction to these classes of channel effects with a deterministic approach on the one hand and with a stochastic approach on the other hand. The analysis will take place in the baseband.

Additionally, a brief introduction to the channel models and simulation methodologies used in this thesis is given. The intention is to enable the reader to interpret the performance results of the considered transmission systems given in later chapters.

2.1 Path Loss and Shadowing

Path loss and shadowing effects describe the fading of the transmit signal when it propagates through free space, the atmosphere or absorbent materials. The attenuation thus inflicted on a signal varies when the user moves over distances which are significantly larger than the signal wavelength, therefore also the terms *large scale-* as well as *medium scale effects* are found in literature, cf. [Lin91]. These effects show only minor time-variations, especially if the user moves at low speeds. The dependency on the frequency is also very moderate. *Thus, fading caused by path loss or shadowing is assumed to be constant in the frequency- and time-domain throughout this thesis*. Hence, the influence of these effects can be described by constant factors G^{PL} and G^{SH} on the transmit power P_{TX} :

$$P_{RX} = G^{PL} G^{SH} P_{TX}. \tag{2.1}$$

In (2.1), P_{RX} represents the receive power at the mobile terminal. Both effects will be introduced in the following, starting with path loss.

The main contribution to path loss stems from signal propagation through free space, since the transmit power P_{TX} disperses over a spherical area which is proportional to the square of the distance d as it propagates through space. If furthermore omnidirectional antennas at the MT and the BS are assumed, the path loss solely depends on the relative distance d between MT and BS. This leads to the following definition of the path loss factor G^{PL}:

$$G^{PL}(d) = G_0 \left(\frac{d}{d_0} \right)^{-\alpha} \tag{2.2}$$

where the path loss exponent α has a value of $\alpha = 2$ in free space. For typical mobile channels, additional path loss contributions stem from diffraction losses at obstacles and ground-wave losses due to reflections at the earth's surface. To account for these effects, the parameter α can be adjusted in the range $\alpha \in [2, 4]$. The reference factor G_0 describes the loss at the reference distance d_0, which is defined in this work to be the maximum distance $d_{\max}$ between MT and BS. The general geometry inside a cell is shown in Fig. 2.

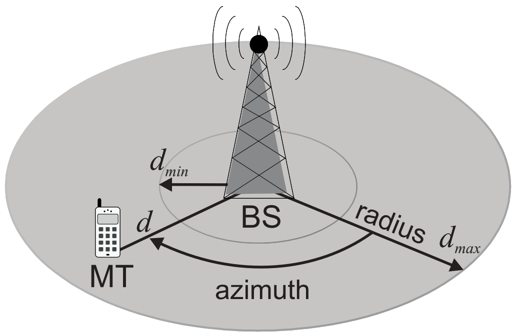

Fig. 2: Determination of cell dimension and MT position

Since multiuser communication systems are covered in this thesis, it is generally assumed that inside a cell multiple MTs are situated around the BS. To evaluate the effects of path loss on the transmission links between MTs and BS, various cellular scenarios are considered. Each cellular scenario is distinguished by the spatial distribution of the MTs inside the cell. The positions of the individual MTs can be modeled as a random variable with a characteristic distribution. Based on this assumption, the *Probability Density Function* (PDF) $p(d)$ of the distance d between BS and MT can be derived. In the following, a uniformly distributed azimuth between the connecting line from BS to each MT and the radius vector of the cell is assumed, as seen in Fig. 2.

In this case, the PDF (2.3) of distance d between MT and BS given below represents the first considered cellular scenario where the MTs are *distributed uniformly over the cell area* [Tra04]. In the given formula, $d_{\min}$ and $d_{\max}$ represent the minimum and maximum distance between MT and BS, respectively.

$$p(d) = \frac{2d}{d_{\max}^2 - d_{\min}^2} \qquad d_{\min} \le d \le d_{\max} \tag{2.3}$$

Because the path loss factor G^{PL} between each MT and the BS strongly depends on the corresponding distance d between both, the spatial distribution of MTs over the cell area influences the range of path loss factors G^{PL} observed inside the cell. Thus, given the PDF $p(d)$ in conjunction with (2.2) determines the PDF $p(G^{PL})$ of the path loss factor. There, $G_{\min}$ and $G_{\max}$ represent the path loss factors at the minimum and the maximum distance ($d_{\min}$ and $d_{\max}$) to the BS, respectively.

$$p(G^{PL}) = \frac{\left(G^{PL}\right)^{-1-\frac{2}{\alpha}}}{\left(G_{\min}\right)^{-\frac{2}{\alpha}} - \left(G_{\max}\right)^{-\frac{2}{\alpha}}} \quad \mathrm{G}_{\min} \le G^{PL} \le G_{\max} \tag{2.4}$$

Another possible cell scenario is to place all MTs at the same distance d to the BS, which corresponds to a *circular distribution of MTs around the BS*. In this case all MTs have an identical path loss factor G^{PL}.

Both cell scenarios introduced above - the uniform as well as the circular distribution - are used as system models in this thesis.

After this introduction to the path loss effect, the focus will now be turned to shadowing. In the following, the shadowing effect is quantified by the power factor G^{SH} . The physical cause for this effect is the power loss by propagation through obstacles like e. g. walls. Every obstacle can be modeled by an individual loss factor G_m, which leads to the overall shadowing loss factor G^{SH} between a user and a BS as shown below:

$$G^{SH} = \prod_{m=1}^{M} G_m \tag{2.5}$$

On a logarithmic scale, the loss factor $G^{SH}_{(dB)}$ is expressed by summation as in (2.6). If the number of obstacles M is sufficiently large, the shadowing $G^{SH}_{(dB)}$ can be modeled by a Gaussian random variable with the normal PDF $p\left(G^{SH}_{(dB)}\right)$, see (2.7). In equation (2.7), the parameter σ_{dB} describes the standard deviation of $G^{SH}_{(dB)}$ while μ_{dB} represents the corresponding expectation value. Both parameters σ_{dB} and μ_{dB} are also expressed on a dB-scale.

$$G^{SH}_{(dB)} = 10 \cdot \log_{10}(G^{SH}) = \sum_{m=1}^{M} 10 \cdot \log_{10}(G_m) = \sum_{m=1}^{M} G_{m(dB)} \tag{2.6}$$

$$p\left(G^{SH}_{(dB)}\right) = \frac{1}{\sqrt{2\pi}\sigma_{dB}} \exp\left(-\frac{\left(G^{SH}_{(dB)} - \mu_{dB}\right)^2}{2\sigma^2_{dB}} \right) \tag{2.7}$$

The values considered for the parameter σ_{dB} range from 4dB to 12dB. Generally, the standard deviation σ_{dB} increases, if a larger area around the MT is considered to evaluate the shadowing effects. This is due to the larger variation of obstacle positions in a wide area.

The choice of the value for μ_{dB} in (2.7) also deserves some attention: In order to avoid a constant offset to the receive power P_{RX}, the expectation value of the linear shadowing factor G^{SH} should be defined as $E\{G^{SH}\}=1$, cf. (2.1). This condition leads to the definition of the corresponding logarithmic expectation value μ_{dB} as shown in (2.8).

$$\mu_{dB} = -\sigma_{dB}^2 \frac{\ln(10)}{20} \tag{2.8}$$

The implementation of the factor G^{SH} as a random variable in computer simulations can be simplified, if $\mu_{dB} = 0$ is assumed. This causes a constant power offset in (2.1), which can later be corrected by a simple subtraction.

2.2 Multipath Propagation

So far solely the channel influence due to general wave propagation was considered. The corresponding effects path loss and shadowing have no other influence on the transmission link than limiting the maximum distance in which the transmit signal can be correctly received. These effects can be mitigated by increasing the transmit power P_{TX} or using a more sensitive receiver.

But there is another channel influence, which has a much more disturbing effect on the transmission link and thus will be described in extensive detail. This channel influence is known as *multipath propagation*. It is caused by the fact that a transmit signal not necessarily reaches the receiver over a straight path. In contrast, the transmit signal can be reflected at conducting surfaces of stationary or moving obstacles and thus reaches the receiver multiple times via different paths. Such a situation is depicted in Fig. 3. The reflecting objects are also referred to as *scatterers*. Each reflection leads to an individual attenuation and phase shift of the transmit signal, depending on the material and shape of the reflecting scatterer. Additionally, the length of each path causes the signal to be delayed. Thus, multiple attenuated and delayed versions of the original transmit signal superimpose at the receiver. The multipath channel can therefore be described as a superposition of signal paths with individual delay, attenuation and phase. In addition to these indirect propagation paths, a direct *line-of-sight* (LOS) path may also exist.

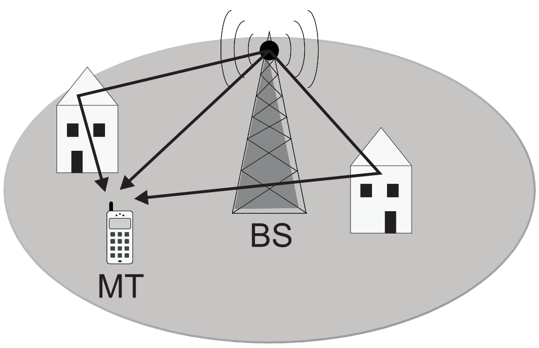

Fig. 3: Signal reflections causing multipath propagation