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ADAPTIVE MULTIUSER OFDMA SYSTEMS WITH HIGH PRIORITY USERS IN THE PRESENCE OF IMPERFECT CQI

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Abstract In this paper, an adaptive multiuser Orthogonal Frequency Division Multiple Access (OFDMA) system in the downlink is investigated which serves two sets of users differing in their priority regarding channel access. A Weighted Proportional Fair Scheduling (WPFS) approach is applied using instantaneous Channel Quality Information (CQI) and user priorities to allocate the different subcarriers to the different users. These CQI values are assumed to be imperfect due to time delays and estimation errors. The joint impact of imperfect CQI and user priority on the performance of the system is investigated analytically and assessed by numerical results. It appears that serving users with different priorities comes at the expense of reduced system data rate and less robustness against imperfect CQI.

1. Introduction

The Orthogonal Frequency Division Multiple Access (OFDMA) transmission scheme is a promising candidate for future mobile networks [1]. It allows an efficient adaptation to the channel conditions by performing time-frequency scheduling of the different subcarriers to the different users. In systems where users experience different channel conditions, Proportional Fair Scheduling (PFS) approaches provide a good trade-off between system throughput and fairness. OFDMA systems applying PFS are well discussed in the literature [2, 3]. If furthermore different user priorities shall be considered, Weighted Proportional Fair Scheduling (WPFS) approaches can be applied, which are discussed, e.g., in [4]-[6]. These WPFS algorithms favour high priority users to get channel access even if their channel gain is low which leads to a degradation of the system throughput compared to PFS approaches. Both PFS and WPFS algorithms require channel knowledge at the transmitter. However, in a realistic scenario, the channels are not perfectly known at the transmitter which also results in performance degradations compared to the case of perfect channel knowledge. The joint impact of imperfect channel knowledge and different user priorities on the performance of an OFDMA system has rarely been mentioned in the literature and the present paper will contribute to this aspect. Assuming outdated and estimated Channel Quality Information (CQI) at the transmitter, we analytically investigate this joint impact on the performance of an OFDMA system applying WPFS. The remainder of this paper is organised as follows. In Section 2, the considered system model is presented. In Section 3, the assumptions on the CQI are discussed. Section 4 introduces the adaptive OFDMA scheme appyling WPFS. In Section 5, closed form expresssions for the data rate and Bit Error Rate (BER) are derived analytically taking into account the joint impact of imperfect CQI and user priorities. In Section 6, numerical results illustrate the impact of both user priorities and imperfect CQI on the achievable system data rate.

2. System model

In this work, we consider a one cell OFDMA downlink scenario with N subcarriers with index $n = 1, .., N$. One Base Station (BS) and U Mobile Stations (MSs) with user index $u = 1, \cdots, U$ are located in the cell. The BS and the MSs are equipped with one antenna each. Each user u experiences a different average Signal-to-Noise-Ratio (SNR) $\bar{\gamma}_u$ depending on the pathloss. The fast fading on the n-th subcarrier of user u in time slot k with $k \in \mathbb{Z}$ is expressed by the channel transfer function $H_u(n,k)$ which is modeled as a complex normal distributed random variable with zero mean and variance one. Thus, the instantaneous SNR $\gamma_u(n,k)$ in time slot k of subcarrier n of user u is calculated according to

$$\gamma_u(n,k) = \bar{\gamma}_u \cdot |H_u(n,k)|^2. \tag{1}$$

Further on, we assume that there are two disjoint sets of users. The first set $\mathcal{S}_H$ contains U_H high priority users and the second set $\mathcal{S}_L$ contains U_L low priority users, with $U_H + U_L = U$.

3. Channel Quality Information

In order to perform an adaptive transmission, channel knowledge at the BS is required. In this work, we use the instantaneous SNR values of (1) as CQI which are fed back from the MSs to the BS in a Frequency

Division Duplex system or measured at the BS in a Time Division Duplex system. In a realistic scenario, the CQI available at the BS suffers from different sources of error and, thus, cannot be assumed to be perfectly known. In the following, two sources of error together with the error modelling are introduced. To ease the comprehensibility, the user, subcarrier and time indices u, n and k are omitted in the notation of the channel transfer function.

3.1 Estimated CQI

The CQI values are assumed to be noisy estimates. The actual channel transfer factor H is modeled as a superposition of the estimated channel transfer factor $\hat{H}$ and an additional error term E leading to $H = \hat{H} + E$, where E is modeled as a complex normal distributed random variable with zero mean and variance σ_E^2. $\hat{H}$ is also modeled as zero-mean complex normal distributed random variable, but with variance $1 - \sigma_E^2$. The error variance $\sigma_E^2 \in [0, 1]$ depends on the conditions of the channel and the applied estimation scheme and, according to [7], is given by $\sigma_E^2 = \frac{1}{1+T_\tau P_\tau}$, where T_τ is the number of training symbols per coherence time and P_τ the SNR during the training phase. In the following, we assume $T_\tau = 1$ and $P_\tau = \bar{\gamma}_u$, i.e., the error variance $\sigma_{E,u}^2$ of user u is given by

$$\sigma_{E,u}^2 = (1 + \bar{\gamma}_u)^{-1}. \tag{2}$$

3.2 Outdated CQI

Since there exists a time delay T between the time instance when measuring the SNR and the actual time of data transmission, the CQI available at the BS is outdated. Assuming that the channel follows Jakes' model, the actual channel and the outdated channel are correlated with a correlation coefficient of $\rho = J_0(2\pi f_D T)$, with $J_0(x)$ denoting the 0th-order Bessel function of the first kind and f_D the Doppler frequency. Hence, the correlation coefficient ρ_u of user u is given by

$$\rho_u = J_0\left(2\pi f_{D,u} T\right), \tag{3}$$

where $f_{D,u}$ designates the Doppler frequency of user u.

4. Adaptive transmission applying WPFS

In the following, the CQI values are applied to perform WPFS in order to allocate the different subcarriers to the different users according to their priority and channel quality. Let p_u be the priority factor which is $p_u = 1$ for all users of set $\mathcal{S}_L$ and $p_u = p$, $p \geq 1$, for all users of set $\mathcal{S}_H$. Subcarrier n in time slot k is allocated to user $u^\star(n, k)$ with the highest ratio between the weighted instantaneous SNR and the average SNR given by

$$u^{\star}(n,k) = \arg\max_{u} \left\{ \frac{p_u \cdot \gamma_u(n,k)}{\bar{\gamma}_u} \right\}. \tag{4}$$

Integrating over the joint probability density function of the weighted and normalised SNR values of (4), the probability $F_H(p)$ that a subcarrier is allocated to a high priority user as a function of the priority factor p is calculated by

$$\begin{aligned} F_H(p) \; &= \int_{y_1=0}^{\infty} \int_{y_2=0}^{y_1} \cdots \int_{y_{U_H}=0}^{y_1} \int_{z_1=0}^{y_1} \cdots \int_{z_{U_L}=0}^{y_1} \left(\frac{1}{p} \cdot e^{-\frac{y_1}{p}}\right) \cdot \left(\frac{1}{p} \cdot e^{-\frac{y_2}{p}}\right) \\ &\quad \cdots \left(\frac{1}{p} \cdot e^{-\frac{y_{U_H}}{p}}\right) \cdot e^{-z_1} \cdot \ldots \cdot e^{-z_{U_L}} \; dy_1 dy_2 \ldots dy_{U_H} dz_1 \ldots dz_{U_L} \\ &= \int_0^{\infty} \left(1 - e^{-\frac{y_1}{p}}\right)^{U_H - 1} \cdot \left(1 - e^{-y_1}\right)^{U_L} \cdot \frac{1}{p} \cdot e^{-\frac{y_1}{p}} \; dy_1. \end{aligned} \tag{5}$$

Applying the binomial theorem, the integral in (5) can be solved resulting in

$$F_H(p) = \sum_{m=0}^{U_H - 1} \binom{U_H - 1}{m} \sum_{l=0}^{U_L} \binom{U_L}{l} \frac{(-1)^{m+l}}{1 + m + p \cdot l}. \tag{6}$$

The probability $F_L(p)$ that a subcarrier is allocated to a low priority user can be calculated directly from (6) resulting in

$$F_L(p) = \frac{1}{U_L} \cdot \left(1 - F_H(p) \cdot U_H\right) \;\text{ with } U_L \geq 1. \tag{7}$$

In the following, we introduce the priority gain g, which denotes the increase of channel access probability for high priority users compared to PFS, where all users have the same priority and the channel access probability is $1/U$ for each user. Hence, we have to determine the priority factor p in such a way that

$$F_H(p) = \frac{g}{U}, \tag{8}$$

which can be done numerically using for example the *fzero* function in MATLAB™. From (7) it can be seen that g is upper bounded by $g \leq \frac{U}{U_H}$ since $F_L(p)$ has to be non-negative. Furthermore, $g \geq 1$, since for the priority factor $p \geq 1$ holds true, with $g = 1$, i.e. $p = 1$, corresponding to PFS where each user has the same channel access probability. Thus,

$$1 \leq g \leq \frac{U}{U_H}. \tag{9}$$

After all subcarriers are allocated to the different users, the modulation scheme is selected for each allocated subcarrier based on the SNR value, i.e., the modulation is adapted to the pathloss and the fast fading. In this work, uncoded M-QAM and M-PSK modulation are considered.

5. Joint impact of imperfect CQI and user priority

In the following, the joint impact of imperfect CQI and user priority on the performance of an OFDMA system applying WPFS is considered. In order to do so, the distribution of the SNR values of the selected users has to be derived, i.e. the Probability Density Function (PDF) and the Cumulative Density Function (CDF). Subsequently, closed form expressions for the average data rate and BER are derived analytically taking into account imperfect CQI and user priority. Finally, the data rate is maximised subject to a target BER.

5.1 SNR distribution considering user priority

The PDF $p^{(u)}_{H,\hat{\gamma}}(\hat{\gamma})$ of the outdated and estimated SNR $\hat{\gamma}$ of a scheduled high priority user that successfully competed against $U_H - 1$ other high priority users and U_L low priority users is calculated according to

$$p^{(u)}_{H,\hat{\gamma}}(\hat{\gamma}) = a_H \underbrace{\int_0^{\hat{\gamma}} \cdots \int_0^{\hat{\gamma}}}_{U_{H-1}\text{ times}} \underbrace{\int_0^{p\cdot\hat{\gamma}} \cdots \int_0^{p\cdot\hat{\gamma}}}_{U_L\text{ times}} \left(\frac{1}{\bar{\gamma}_{E,u}} \cdot e^{\frac{-y_1}{\bar{\gamma}_{E,u}}}\right) \cdots \left(\frac{1}{\bar{\gamma}_{E,u}} \cdot e^{\frac{-y_{U_{H-1}}}{\bar{\gamma}_{E,u}}}\right) \cdot \quad (10)$$

$$\left(\frac{1}{\bar{\gamma}_{E,u}} e^{\frac{-z_1}{\bar{\gamma}_{E,u}}}\right) \cdots \left(\frac{1}{\bar{\gamma}_{E,u}} \cdot e^{\frac{-z_{U_L}}{\bar{\gamma}_{E,u}}}\right) \cdot \left(\frac{1}{\bar{\gamma}_{E,u}} \cdot e^{\frac{-\hat{\gamma}}{\bar{\gamma}_{E,u}}}\right) dy_1 \ldots dy_{U_{H-1}} dz_1 \ldots dz_{U_L}$$

$$= \frac{a_H}{\bar{\gamma}_{E,u}} \cdot e^{\frac{-\hat{\gamma}}{\bar{\gamma}_{E,u}}} \cdot \left(1 - e^{\frac{-p\cdot\hat{\gamma}}{\bar{\gamma}_{E,u}}}\right)^{U_L} \cdot \left(1 - e^{\frac{-\hat{\gamma}}{\bar{\gamma}_{E,u}}}\right)^{U_H-1},$$

with $\bar{\gamma}_{E,u} = \bar{\gamma}_u \cdot (1 - \sigma^2_{E,u})$. The factor a_H ensures that $\int_0^\infty p^{(u)}_{H,\hat{\gamma}}(\hat{\gamma}) d\hat{\gamma} = 1$, leading to

$$a_H = \left[\sum_{v=0}^{U_H-1} \binom{U_H - 1}{v} \sum_{w=0}^{U_L} \binom{U_L}{w} \frac{(-1)^{v+w}}{1 + v + p \cdot w}\right]^{-1}. \quad (11)$$

The PDF $p^{(u)}_{L,\hat{\gamma}}(\hat{\gamma})$ of the outdated and estimated SNR $\hat{\gamma}$ of a scheduled low priority user is calculated by exchanging U_L with U_H and $p \cdot \hat{\gamma}$ with $\hat{\gamma}/p$ in (10), respectively, resulting in

$$p^{(u)}_{L,\hat{\gamma}}(\hat{\gamma}) = \frac{a_L}{\bar{\gamma}_{E,u}} \cdot e^{\frac{-\hat{\gamma}}{\bar{\gamma}_{E,u}}} \cdot \left(1 - e^{\frac{-\hat{\gamma}}{p\cdot\bar{\gamma}_{E,u}}}\right)^{U_H} \cdot \left(1 - e^{\frac{-\hat{\gamma}}{\bar{\gamma}_{E,u}}}\right)^{U_L-1} \quad (12)$$

with

$$a_L = \left[\sum_{v=0}^{U_L-1} \binom{U_L-1}{v} \sum_{w=0}^{U_H} \binom{U_H}{w} \frac{p \cdot (-1)^{v+w}}{w + p \cdot (1+v)} \right]^{-1} . \qquad (13)$$

Integrating (10) and (12), the CDF $F_{\hat{\gamma}}^{(u)}(\hat{\gamma})$ of the outdated and estimated SNR of a scheduled high and low priority user is given by

$$F_{\hat{\gamma}}^{(u)}(\hat{\gamma}) = \alpha \cdot \sum_{v=0}^{V-1} \binom{V-1}{v} \sum_{w=0}^{W} \frac{\binom{W}{w}(-1)^{v+w}}{1+v+\varphi \cdot w} \cdot \left(1 - e^{-\frac{\hat{\gamma}(1+v+\varphi \cdot w)}{\bar{\gamma}_{E,u}}}\right) \qquad (14)$$

with $\alpha = a_H$, $\varphi = p$, $V = U_H$ and $W = U_L$ for high priority users and $\alpha = a_L$, $\varphi = 1/p$, $V = U_L$ and $W = U_H$ for a low priority users.

5.2 Average data rate

The average sum bit per symbol rate is formulated as the sum rate of the different modulation constellations weighted by their probability. Assuming that there are M modulation schemes available, $\gamma^{(u)} = [\gamma_0^{(u)}, \gamma_1^{(u)}, ..., \gamma_M^{(u)}]^{\mathrm{T}}$, with $\gamma_0^{(u)} = 0$ and $\gamma_M^{(u)} = \infty$, denotes the threshold vector of user u which contains the SNR threshold values determining the interval in which a particular modulation scheme is applied. Thus, the average data rate $\bar{R}_{H/L}^{(u)}$ of user u for high and low priority users can be formulated as

$$\bar{R}_{H/L}^{(u)} = \sum_{m=1}^{M} \int_{\gamma_{m-1}^{(u)}}^{\gamma_m^{(u)}} b_m \cdot p_{H/L,\hat{\gamma}}^{(u)}(\hat{\gamma}) \, d\hat{\gamma} \qquad (15)$$

with b_m denoting the number of bits per symbol corresponding to the applied modulation scheme. Using (14), (15) can be written as

$$\bar{R}_{H/L}^{(u)} = \sum_{m=1}^{M} b_m \cdot \left(F_{\hat{\gamma}}^{(u)}(\gamma_m^{(u)}) - F_{\hat{\gamma}}^{(u)}(\gamma_{m-1}^{(u)}) \right) . \qquad (16)$$

5.3 Average BER

In the following, we use the approximation of the instantaneous BER for M-QAM and M-PSK modulation introduced in [8] given by

$$BER_m(\gamma) = 0.2 \cdot \exp(-\beta_m \gamma) \qquad (17)$$

with $m = 1, .., M$, where $\beta_m = \frac{1.6}{2^{b_m}-1}$ using M-QAM modulation and $\beta_m = \frac{7}{2^{1.9 b_m}+1}$ using M-PSK modulation, respectively. The average BER is then defined as the sum of the average bit errors of the different modulation constellations divided by the average bit rate [9]. To determine the average BER, we introduce the conditional PDF $p^{(u)}_{\gamma|\hat{\gamma}}(\gamma|\hat{\gamma})$ of the actual SNR γ and the outdated and estimated SNR $\hat{\gamma}$ of user u given by

$$p^{(u)}_{\gamma|\hat{\gamma}}(\gamma|\hat{\gamma}) = \frac{1}{\bar{\gamma}_u \sigma^2_{r,u}} \cdot \exp\left(-\frac{\rho_u^2 \cdot \hat{\gamma} + \gamma}{\bar{\gamma}_u \sigma^2_{r,u}}\right) \cdot I_0\left(\frac{2\rho\sqrt{\gamma \cdot \hat{\gamma}}}{\bar{\gamma}_u \sigma^2_{r,u}}\right), \tag{18}$$

with $\sigma^2_{r,u} = 1 - \rho_u^2(1 - \sigma^2_{E,u})$ and $I_0(x)$ denoting the 0th-order modified Bessel function of the first kind. The average BER $\overline{BER}^{(u)}_{H/L}$ of user u for high and low priority users is then given by

$$\overline{BER}^{(u)}_{H/L} = \frac{1}{\bar{R}^{(u)}_{H/L}} \sum_{m=1}^{M} b_m \int_{\gamma^{(u)}_{m-1}}^{\gamma^{(u)}_m} p^{(u)}_{H/L,\hat{\gamma}}(\hat{\gamma}) \cdot \left[\int_0^\infty BER_m(\gamma) \cdot p^{(u)}_{\gamma|\hat{\gamma}}(\gamma|\hat{\gamma})\, d\gamma\right] d\hat{\gamma}. \tag{19}$$

Inserting (10), (12), (17) and (18) in (19), (19) can be rewritten to

$$\overline{BER}^{(u)}_{H/L} = \frac{\alpha \cdot U}{5 \cdot \bar{R}^{(u)}_{H/L}} \sum_{m=1}^{M} b_m \sum_{v=0}^{V-1} \binom{V-1}{v} \sum_{w=0}^{W} \binom{W}{w} \tag{20}$$

$$\cdot \frac{(-1)^{v+w}}{A(m,v,w)} \cdot \left[e^{\frac{-\gamma^{(u)}_{m-1} \cdot A(m,v,w)}{\bar{\gamma}_{E,u} \cdot (1+\beta_m \bar{\gamma}_u \sigma^2_{r,u})}} - e^{\frac{-\gamma^{(u)}_{m} \cdot A(m,v,w)}{\bar{\gamma}_{E,u} \cdot (1+\beta_m \bar{\gamma}_u \sigma^2_{r,u})}} \right]$$

with $A(m,v,w) = (1 + v + \varphi \cdot w) \cdot (1 + \beta_m \bar{\gamma}_u \sigma^2_{r,u}) + \bar{\gamma}_{E,u} \beta_m \rho_u^2$. Note that $\alpha = a_H$, $\varphi = p$, $V = U_H$ and $W = U_L$ for high priority users and $\alpha = a_L$, $\varphi = 1/p$, $V = U_L$ and $W = U_H$ for low priority users.

5.4 Optimising data rate

In the following, we are looking for the optimal modulation scheme threshold vector $\gamma^{(u)}$ of user u which maximises the average data rate under the constraint of a target BER BER_T, i.e., we have to solve the following optimization problem:

$$\bar{R}^{(u)}_{H/L,opt} = \max_{\gamma^{(u)}} \left(\bar{R}^{(u)}_{H/L}(\gamma^{(u)})\right) \tag{21}$$

$$\text{subject to } \overline{BER}^{(u)}_{H/L}(\gamma^{(u)}) \leq BER_T.$$

To solve (21), we perform a Lagrange multiplier approach similar to [9] where the objective function $\Phi^{(u)}(\gamma)$ is given by

$$\Phi^{(u)}(\gamma^{(u)}) = \bar{R}^{(u)}_{H/L}(\gamma^{(u)}) + \lambda \tag{22}$$

$$\cdot \left(\bar{R}^{(u)}_{H/L}(\gamma^{(u)}) \overline{BER}^{(u)}_{H/L}(\gamma^{(u)}) - \bar{R}^{(u)}_{H/L}(\gamma^{(u)}) BER_T\right)$$

with λ denoting the Lagrange multiplier. In order to determine the optimal threshold vector $\gamma^{(u)}_{opt}$, we have to differentiate $\Phi^{(u)}(\gamma^{(u)})$ with respect to the elements of $\gamma^{(u)}$, where $\frac{\partial \Phi^{(u)}(\gamma_{opt}^{(u)})}{\partial \gamma_m^{(u)}} = 0$ must hold for all $m = 1, .., M-1$. Let $\zeta^{(u)}(\hat{\gamma}, m, \sigma_{E,u}^2, \rho_u)$ denote the solution of the inner integral of (19) given by

$$\zeta^{(u)}(\hat{\gamma}, m, \sigma_{E,u}^2, \rho_u) = \frac{0.2}{1 + \beta_m \bar{\gamma}_u \sigma_{r,u}^2} \cdot \exp\left(-\frac{\hat{\gamma}\rho_u^2 \beta_m}{1 + \beta_m \bar{\gamma}_u \sigma_{r,u}^2}\right). \tag{23}$$

Inserting (15) and (19) in (22) and using (23), the derivation results in $M-1$ equations given by

$$\frac{(1 - \lambda BER_T)}{\lambda} = \frac{1}{b_{m+1} - b_m} \Big(\zeta^{(u)}(m, \gamma_m^{(u)}, \sigma_{E,u}^2, \rho_u) \tag{24}$$

$$\cdot b_m - \zeta^{(u)}(m+1, \gamma_m^{(u)}, \sigma_{E,u}^2, \rho_u) \cdot b_{m+1} \Big), \; m = 1, .., M-1.$$

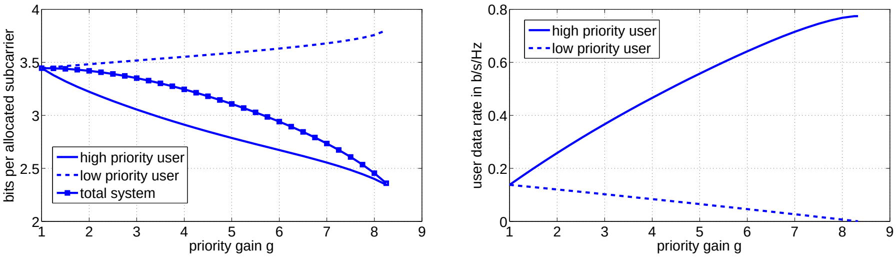
From (24) it can be seen that each element $\gamma_m^{(u)}$ of the optimal threshold vector $\gamma_{opt}^{(u)}$ can be calculated using an initial value $\gamma_1^{(u)}$. Thus, each threshold vector $\gamma^{(u)}$ is a function of the initial value $\gamma_1^{(u)}$, i.e., $\gamma^{(u)} = f(\gamma_1^{(u)})$. Determining the maximum average data rate subject to the target BER, we have to find the optimal initial value $\gamma_{1,opt}^{(u)}$ which fulfills

$$\overline{BER}_{H/L}^{(u)}(f(\gamma_{1,opt}^{(u)})) \leq BER_T, \tag{25}$$

which again can be done numerically using for example the *fzero* function in MATLAB™.

6. Numerical Results

In the following, we consider an OFDMA scheme applying WPFS with $U = 25$ users. For simplicity, we assume that the average SNR in the system is $\bar{\gamma} = 10$ dB for all users. The target BER is set to $BER_T = 10^{-3}$. First, we assume perfect CQI and $U_H = 3$ high priority users and consequently $U_L = 22$ low priority users, i.e., $1 \leq g \leq 8.33$. In Fig. 1(a), the average number of transmitted bits per allocated subcarriers is depicted as a function of the priority gain g, which is related to the priority factor p according to (8). As one can see from the figure, the total system data rate decreases when increasing the priority gain, since favouring the high priority users even if they are in bad channel conditions results in a performance degradation. From the solid line, representing the number of transmitted bits per subcarrier when allocated to a high priority user, one can see that the number of bits decreases with increasing gain g. In Fig. 1(b), the user data rate of a high priority user is depicted as a function of the priority gain. One can see that the user data rate increases due to the increased access to the channel. For the low priority users it

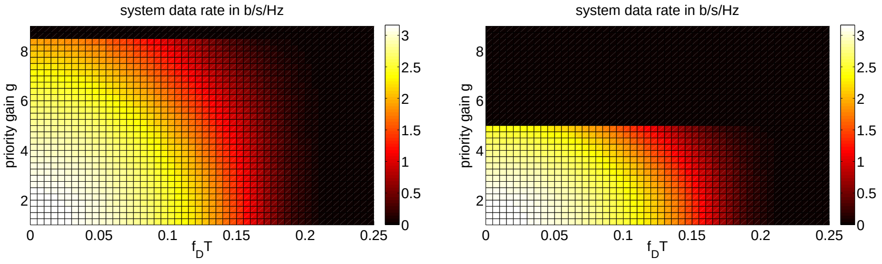


(a) (b)

Figure 1. (a) Number of transmitted bits per allocated subcarrier vs. priority gain, (b) user data rate vs. priority gain with $U_H = 3$ high and $U_L = 22$ low priority users

is vice versa, i.e., the number of bits per subcarrier, when allocated to a low priority user, increases with increasing g, see Fig. 1(a), since only strong channels of low priority users can compete successfully with the favoured channels of high priority users. However, the user data rate of a low priority user decreases due to the reduced channel access, see Fig. 1(b).

Next, the CQI is assumed to be outdated expressed by the normalised time delay $f_D T$, where the Doppler frequency f_D is assumed to be the same for each user. Furthermore, the SNR values are noisy estimates with $\sigma_E^2 = (1+\bar{\gamma})^{-1}$ for each user. In the following, we investigate the joint impact of imperfect CQI and user priority on the performance of the system. In Fig. 2(a), the number U_H of high priority users remains $U_H = 3$. The average system data rate indicated by different colours is depicted as a function of the time delay $f_D T$ and the priority gain g. As one can see, the achievable data rate is highest for small time delays and low priority gains. When increasing g for a given $f_D T$, the system data rate decreases as seen in Fig. 1(a). At a certain value of g_{max}, the priority gain cannot be achieved any more, i.e., the data rate



(a) (b)

Figure 2. System data rate vs. time delay $f_D T$ and priority gain g with (a) $U_H = 3$, (b) $U_H = 5$ high priority users

is zero, where g_{max} is upper bounded by $g_{max} \leq \frac{U}{U_H}$ as shown in Section 4. When increasing $f_D T$ for a given priority gain g, the data rate also decreases, since a more robust modulation scheme is required to cope with the outdated CQI in order to fulfill the BER requirements. In Fig. 2(b), the number U_H of high priority users is changed to $U_H = 5$. One can see that the region in which a transmission is possible diminishes, since the upper bound of g_{max} decreases with an increasing number U_H of high priority users.

7. Conclusions

In this paper, we analyse the performance of an adaptive OFDMA system applying WPFS with high priority users in the presence of imperfect CQI. Closed form expressions for the average data rate and BER are analytically derived taking into account the joint impact of imperfect CQI and user priority. From the numerical results one can conclude that serving users with different priorities comes at the expense of reduced system data rate and less robustness against outdated CQI.

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