On Modeling and Analysis of a Coded OFDMA Downlink in a Multi-Cell Environment

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***Abstract*—In this paper a coded OFDMA downlink concept in a multi-cell environment is analyzed. A resource management can be applied for the downlink transmission scheme and this can improve the performance for low system loads. The paper also examines the use of a time/frequency hopping component. For reducing simulation complexity, the Gaussian approximation is investigated as an assumption for the existing inter-cell interference. Simulation results are given to determine the effectiveness of the proposed resource management, time/frequency hopping, and the assumed interference approximation.**

I. INTRODUCTION

Several proposals of transmission schemes for the 4G system are based on orthogonal frequency division multiplexing (OFDM) [1]. Recently, the downlink of such systems is intensively studied and the extension to more realistic scenarios, i.e., cellular structures, is necessary. This requires the investigation of inter-cell interference in a multi-cell environment model.

II. CELLULAR OFDMA SYSTEM

The assignment of one or several sub-carriers to each user in an OFDM system leads to the multiple access scheme OFDMA [1]. For the used OFDMA system in this paper, the information bits are convolutionally encoded, interleaved, symbol mapped, and distributed for each user over several sub-carriers. Then an OFDM modulation is performed which includes an inverse fast Fourier transformation and insertion of a guard interval to avoid inter-symbol and inter-carrier interference. On the receiver side, the transmitter signal process is inverted. Before symbol demapping, detection is applied using a single-user minimum mean squared error (MMSE) equalizer.

To exploit the diversity in the OFDMA scheme, the assigned sub-carriers can be interleaved. A one-dimensional (1D) interleaving in frequency direction is possible, and by taking into account a whole OFDM frame, a two-dimensional (2D) interleaving in frequency and time direction is also practicable. This methods can also be referred to as frequency or time/frequency hopping. The latter introduces an additional TDMA component.

The resource load (RL) of an OFDMA system can be seen as the ratio of the number of assigned sub-carriers and the total number of available sub-carriers.

Introduction of a resource management (RM) for assigning the sub-carriers should maximize the performance. Thus, synchronized base stations (BS) with RM guarantee a distribution of assigned sub-carriers without double allocation up to a resource load of $1/N_{\mathrm{Cell}}$, where N_{Cell} denotes the number of cells.

The cellular interference is modeled by a fully-synchronized system between the BSs and the mobile station. The ratio of the received signal energy from the desired BS and from the interfering BS is denoted by ΔE [2]. Therefore, the received interfering signal energy is weighted by the factor ΔE.

For system level simulations, the simulation of all interfering signal paths is complex. Thus, a simplification of the interference model is done by the Gaussian approximation (GA) which assumes the entire interference as Gaussian noise [3]. Hereby, the additional noise variance of the system has to be scaled appropriately:

$$\sigma_\eta^2 = \frac{E_0}{\Delta E}\frac{K_{\mathrm{u}}}{K_{\max}}\,, \tag{1}$$

where E_0, K_{u}, and $K_{\max}$ denote the signal energy, the number of active users, and the number of maximum users, respectively. Since one transmitted OFDM symbol has the averaged signal energy of one, the last term in (1) has to be scaled by $K_{\mathrm{u}}/K_{\max}$. With the GA, no information about the interfering signals is needed, except for their average signal strength. Thus, a multi-cell environment can be implemented very efficiently.

III. SIMULATION RESULTS

A WSSUS channel and perfect knowledge of the channel state information is assumed. For the following simulations, all interfering BSs have the same parameters as the desired BS. This also includes the number of active users K_{u} and the maximum number of users $K_{\max}$. The interfering cells are arranged counter-clockwise around the desired cell. The simulation environment is taken from [2].

Figure 1 depicts the number of interfered sub-carriers per transmitted OFDM frame versus the RL in a two-cell environment at $E_{\mathrm{b}}/N_0 = 10$ dB and $\Delta E = 10$ dB. The RM can avoid double allocations of sub-carriers up to the $1/2$ RL in contrast to the performance without any RM. Consequently, all sub-carriers are interfered by a fully-loaded scenario. Therefore, RM should improve the bit error rate (BER) performance for RLs smaller than 1/2.

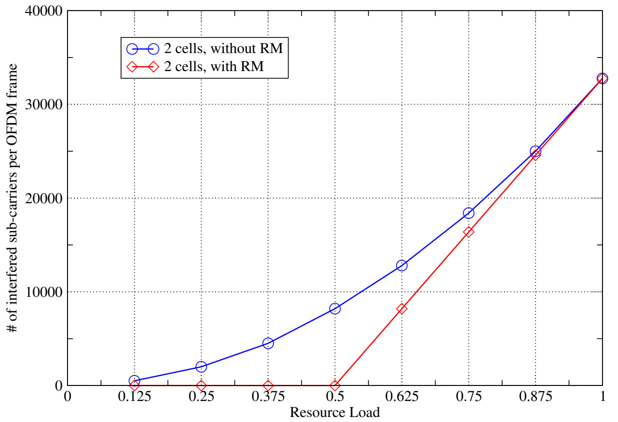

Fig. 1. Interfered sub-carriers per OFDM frame versus resource load for an OFDMA system in a two-cell environment

The simulations in Figure 2 show results of OFDMA systems in a two-cell environment at $E_{\mathrm{b}}/N_0 = 10$ dB and $\Delta E = 10$ dB. The BER is plotted as a function of the RL for different transmission schemes. The dashed marked curves represent the 1D hopping. Since the 2D hopping increases the diversity, the scenarios with 2D hopping always outperforms 1D hopping. As expected in Section II and Figure 1, the RM can ensure the maximum performance up to a half-loaded system in each cell. The performance of the system without any interfering cell represents the maximum performance and therefore a lower bound of the system.

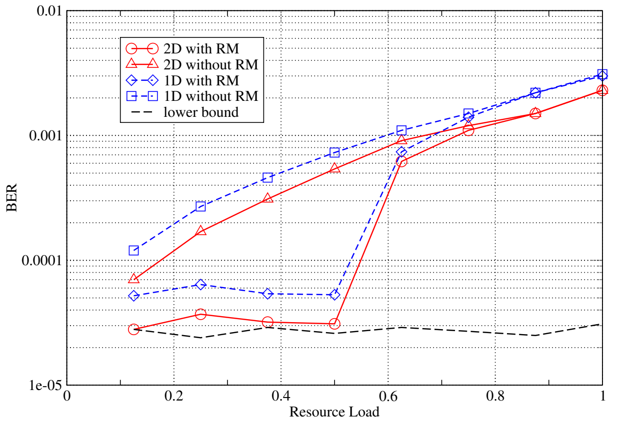

Fig. 2. BER versus resource load @$E_{\mathrm{b}}/N_0 = 10$dB,$\Delta E =$ 10dB for an OFDMA system in a two-cell environment and perfect channel state information

In order to verify the GA, Figure 3 shows simulation results of a half-loaded OFDMA system whereas all interfering cells have the same and constant weighting factor ΔE. The simulations show the BER versus the difference in received power between each interfering BS and the desired BS for different number of interfering cells. The dashed marked curves represent the GA. Since the MMSE equalizer is optimal for AWGN [4], the GA results in a better performance compared to a non-Gaussian distributed interfering signal for one and two interfering cells. The higher the number of interfering cells, the better do the superposed interfering signals achieve a Gaussian distribution. Therefore, the GA models accurately. A lower bound of the system, displayed by the unmarked dashed line, is defined by the performance without interfering cells and at constant $E_{\mathrm{b}}/N_0 = 10$ dB which has a BER of $2.4 \cdot 10^{-5}$.

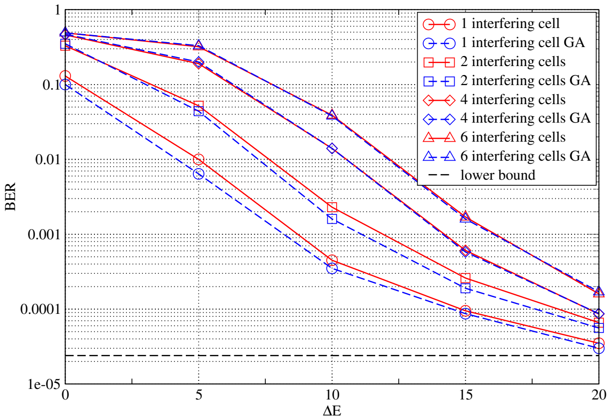

Fig. 3. BER versus ΔE @$E_{\mathrm{b}}/N_0 = 10$dB for a half-loaded OFDMA system in a multi-cell environment with different number of interfering cells and perfect channel state information

IV. CONCLUSION

Simulations showed that a RM in an OFDMA multi-cell system can achieve maximum performance up to a certain RL. A time/frequency hopping component can increase the diversity and therefore the performance. Finally, for a high number of interfering cells, the GA matches the real performance and decreases the complexity of the simulations.

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