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COMMON ARCHITECTURES FOR TD-CDMA AND OFDM BASED MOBILE RADIO SYSTEMS WITHOUT THE NECESSITY OF A CYCLIC PREFIX

Abstract. In this article an OFDM system without the necessity of a cyclic prefix is presented. First a generalised data model that describes different mobile radio systems by a set of parameters is developed. That model is taken as a basis to perform data detection general enough to be applicable in different mobile radio systems. The differences and similarities of different systems with regard to the data model are elaborated. It comes out that in order to enable common detection strategies the cyclic prefix in OFDM based systems can be discarded, which implies that the information data rate is increased. The price is a higher computational requirement of the receiver. Following the desire not to increase the computational requirements for data detection significantly a technique is found to perform data detection in OFDM systems without cyclic prefix causing only a moderate increase in computational requirements.

1. INTRODUCTION

The development in the communication sector moves to the convergence of different systems. Among other things it is aimed at the convergence of different mobile radio systems. Besides the convergence development from a system's point of view the convergence plays an important role in designing multi-mode devices, e.g., the modelling of different mobile radio systems or the used algorithms and architectures. The advantage is that the same devices can be used in different telecommunication standards. This work focuses on common algebraic structures and the respective algorithms solving the data detection problem in TD-CDMA and OFDM based systems (OFDM, OFDMA) without the necessity of a cyclic prefix (CP).

Starting from a system model representing different mobile radio systems a generalised data model is developed, which describes the different systems by a set of parameters. This parameterised data model is taken as a basis to perform data detection. The algorithms for detection are all based on FFT computations, e.g., for TD-CDMA the algorithms of [7, 8] apply FFTs, for OFDM based systems the FFT is part of the detection anyway. After investigating the structure of the data model of different systems it turns out that to enable common data detection strategies for TD-CDMA and OFDM based systems the CP can be discarded, which implies that the information data rate is increased. Then, we consider the computational requirements of an OFDM based system without CP, which is very similar to the TD-CDMA system. It turns out that just applying the TD-CDMA detection algorithms to the OFDM system without CP is computational demanding. However, we can elaborate on the data model such that it boils down to an OFDM system without CP, where the detection problem can be solved based on FFTs of different sizes with reasonable computational requirements. Therefore FFT based detection schemes are presented.

The paper is organised as follows: In section 2 a generalised data model that describes different mobile radio systems is developed and analysed. On the basis of this data model it is shown in section 3 how data detection can be performed. In section 4 an OFDM system without CP is presented. The system is evaluated by simulation results concerning the BER and the computational requirements. In section 5 some conclusions are drawn.

2. DATA MODEL

2.1 System Model

This work focuses on a scenario where multiple mobile terminals transmit their data over a wireless channel to a base station (uplink). The data symbols are structured into bursts. Subsequent bursts do not interfere with each other as a guard period is appended to each burst. Different user's bursts are assumed to reach the base station simultaneously. A system example is depicted in figure 1.

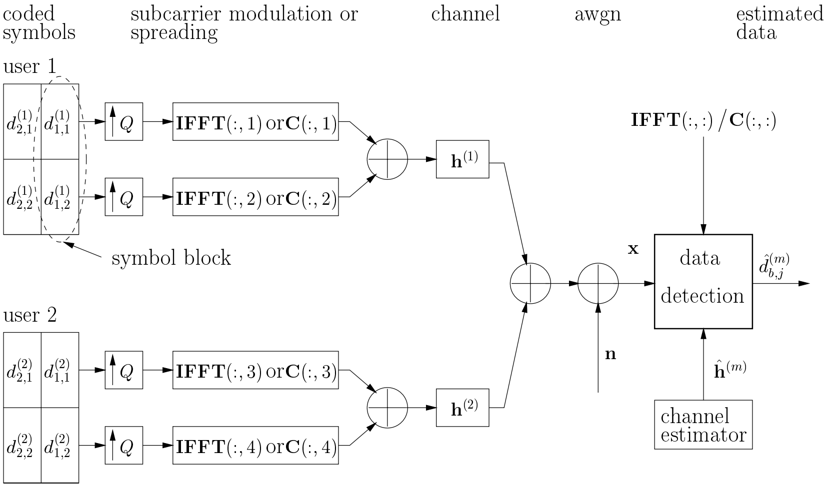


Figure 1. Example of generalised system model.

After serial to parallel conversion the data symbols of all users are upsampled and convolved with an FIR filter modelling either subcarrier modulation or spreading before passing through a user-specific channel. On the channel the data of different users are superimposed and white Gaussian noise is added. This model is general enough to describe TD-CDMA and OFDM based systems by a proper choice of the parameters. In the case of TD-CDMA there is only one data branch per user and the filter tap weights are given by the user's spreading code whereas in a CP-OFDM case the filter tap weights are given by the cyclically extended subcarriers. Based on the transmission system modelled in figure 1 a mathematical description is derived. The main relationship that enables the development of the generalised data model is that both the spreading in CDMA systems and the modulation in OFDM based systems can be expressed as a concatenation of an upsampling stage and a convolution. First a data model for OFDMA is developed, so that the other systems can be described with slight variations as well.

2.2 Data Model for OFDMA

The meaning of the used parameters is explained in table 1. Bold lower case letters are used to denote column or row vectors. Bold capital letters are used to denote matrices. A $Q \times Q$ identity matrix will be denoted as $\mathbf{I}_Q$. The symbol $*$ stands for convolution and $\otimes$ stands for the Kronecker product. In some equations a MATLAB typical notation is used.

Table 1. Denotation of parameters.

Parameter	Denotation
B	number of symbol blocks per burst
Q	upsampling factor, spreading factor, processing gain, $Q = MJ$
W	length of channel impulse response
K	information symbols per symbol block
J	coded information symbols per block, $K = J$ means no coding
M	number of active users
P	burst length after channel, $P = BQ + W - 1$
R	length of FIR filter combining subcarrier modulation and channel, $R = Q + W - 1$

All coded information symbols of M users' bursts $d_{b,j}^{(m)}$, $1 \le m \le M$, $1 \le b \le B$, $1 \le j \le J$ are arranged in vectors to enable an efficient processing using methods known from linear algebra. The bth block of the mth user is of the form

$$\mathbf{d}_b^{(m)} = \begin{bmatrix} d_{b,1}^{(m)} & d_{b,2}^{(m)} & \dots & d_{b,J}^{(m)} \end{bmatrix} \in \mathbb{C}^J, \ 1 \le m \le M, \ 1 \le b \le B.$$

During the development of the data model describing the system a separation of the data of each user is necessary:

$$\mathbf{d}^{(m)} = \left[\mathbf{d}_1^{(m)} \;\; \mathbf{d}_2^{(m)} \;\; \ldots \;\; \mathbf{d}_B^{(m)}\right]^T \in \mathbb{C}^{BJ}, \;\; 1 \le m \le M.$$

If the corresponding blocks of all M users are placed side by side the resulting vector is

$$\mathbf{d}_b = \left[\mathbf{d}_b^{(1)} \;\; \mathbf{d}_b^{(2)} \;\; \ldots \;\; \mathbf{d}_b^{(M)}\right] \in \mathbb{C}^{MJ}, \;\; 1 \le b \le B.$$

All symbols of the M users during one burst are arranged in one vector

$$\mathbf{d} = \left[\mathbf{d}_1 \;\; \mathbf{d}_2 \;\; \ldots \;\; \mathbf{d}_B\right]^T \in \mathbb{C}^{BMJ}.$$

In an OFDMA system each symbol of a block is modulated on a specific column of the IFFT matrix, which form the subcarriers. This kind of modulation, namely OFDM, can be interpreted as spreading if a column of the IFFT matrix is interpreted as user- and symbol-specific code. As each parallel data symbol shall be modulated on a different subcarrier the IFFT matrix must at least be of size $Q = MJ$:

$$\mathbf{IFFT} = \sqrt{Q} \cdot ifft(\mathbf{eye}(Q)) \in \mathbb{C}^{Q \times Q}.$$

The selection of the subcarriers is made by the matrix $\mathbf{S}_m \in \mathbb{C}^{Q \times J}$ named subcarrier selector matrix. The entries are set to 1 for the index pairs $[(m-1)J+1 : mJ, j]$ for $1 \le m \le M$ and $1 \le j \le J$ otherwise they are set to zero. Each column and each row of $\mathbf{S}_m$ has exactly one nonzero entry. An element of a column of $\mathbf{S}_m$ is set to 1 if the corresponding column of the IFFT matrix shall be selected as a subcarrier, otherwise they are set to zero. Here the first J columns refer to the first user. The code matrix that is used to describe the symbols to be transmitted of each user is given by:

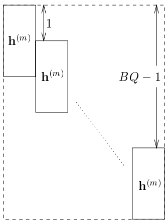
$$\mathbf{C}_b^{(m)} = \mathbf{IFFT} \cdot \mathbf{S}_m \in \mathbb{C}^{Q \times J}, \;\; 1 \le m \le M, \;\; 1 \le b \le B.$$

The coding matrix $\mathbf{C}_b^{(m)}$ is multiplied by the bth data block of the mth user $\mathbf{d}_b^{(m)}$. All subsequent data blocks of one user are multiplied with the same code matrix. For the given arrangement of the data blocks of one user $\mathbf{d}^{(m)}$ the code matrix for the mth user becomes block diagonal:

$$\mathbf{C}^{(m)} = \mathbf{I}_B \otimes \mathbf{C}_b^{(m)} = \begin{bmatrix} \mathbf{C}_b^{(m)} & & & \\ & \mathbf{C}_b^{(m)} & & \\ & & \ddots & \\ & & & \mathbf{C}_b^{(m)} \end{bmatrix} \in \mathbb{C}^{BQ\times BJ},\ 1 \le m \le M.$$

Each data block of J symbols is spread to Q symbols. Therefore the spreading factor in this system is equal to the number of users M. The Q symbols form one OFDM symbol, which is then passed through a user-specific channel. As the channel is assumed to be time invariant during one burst the mth user's channel is described by the impulse response $\mathbf{h}^{(m)} \in \mathbb{C}^W$ or by the channel convolution matrix:

$$\mathbf{H}^{(m)} =$$



$$\in \mathbb{C}^{(BQ+W-1)\times BQ},\ 1 \le m \le M.$$

Each nonzero entry in the convolution matrix is given by the samples of the channel impulse response between the transmitter of the mth user and the receiver.

$$\mathbf{h}^{(m)} = \begin{bmatrix} h_1^{(m)} & h_2^{(m)} & \dots & h_W^{(m)} \end{bmatrix}^T \in \mathbb{C}^W,\ 1 \le m \le M.$$

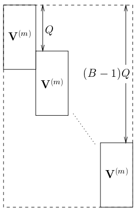
The modulated data symbols of the mth user $\mathbf{C}^{(m)} \cdot \mathbf{d}^{(m)}$ are passed through a user-specific channel. The received signal can be expressed as:

$$\mathbf{x} = \sum_{m=1}^{M} \underbrace{\mathbf{H}^{(m)} \cdot \mathbf{C}^{(m)}}_{\mathbf{B}^{(m)}} \cdot \mathbf{d}^{(m)} + \mathbf{n} \in \mathbb{C}^P,$$

$$\text{with } \mathbf{x} = \begin{bmatrix} x_1 & x_2 & \dots & x_P \end{bmatrix}^T \text{ and } \mathbf{n} = \begin{bmatrix} n_1 & n_2 & \dots & n_P \end{bmatrix}^T \in \mathbb{C}^P.$$

The value x_p is the pth sample of the received vector whereas n_p is the pth sample of additive white Gaussian noise. The knowledge about the channel and the subcarriers is contained in the matrices $\mathbf{H}^{(m)}$ and $\mathbf{C}^{(m)}$, respectively. Therefore the matrix that combines this knowledge equals:

$$\mathbf{B}^{(m)} = \mathbf{H}^{(m)} \cdot \mathbf{C}^{(m)} =$$



$$\in \mathbb{C}^{(BQ+W-1)\times BJ},$$

$$\text{with} \quad \mathbf{V}^{(m)} = \left[\mathbf{b}_1^{(m)} \ \ \mathbf{b}_2^{(m)} \ \ \ldots \ \ \mathbf{b}_J^{(m)}\right] \in \mathbb{C}^{R\times J}, \ \ 1 \le m \le M.$$

The structure of a convolution matrix is retained as channel and subcarrier modulation is interpreted as an FIR filter. The shift of length Q between two neighbouring blocks refers to the upsampling stage in which Q zeros are padded into the data flow after each data symbol. The columns of $\mathbf{V}^{(m)}$ contain the samples of the FIR filter summarising subcarrier modulation and channel (see figure 2). They are given by the vectors

$$\mathbf{b}_j^{(m)} = \left[b_{j,1}^{(m)} \ \ b_{j,2}^{(m)} \ \ \ldots \ \ b_{j,P}^{(m)}\right]^T = \mathbf{h}^{(m)} * \mathbf{IFFT}(:,(m-1)J+j) \in \mathbb{C}^{Q+W-1},$$
$$1 \le m \le M, \ \ 1 \le j \le J.$$

Each column vector $\mathbf{b}_j^{(m)}$ refers to one data symbol of one block or to one branch in figure 1.

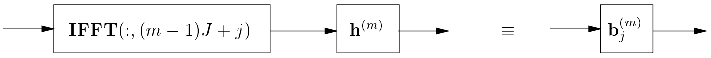


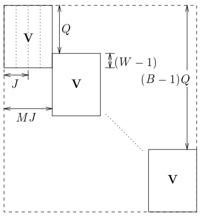
Figure 2. Combination of channel and subcarrier modulation to an FIR filter of length R.

The equation to calculate the received vector can be rewritten by incorporating the sum over the M users into a matrix operation:

$$\mathbf{x} = \sum_{m=1}^{M} \mathbf{B}^{(m)} \cdot \mathbf{d}^{(m)} + \mathbf{n} = \mathbf{T} \cdot \mathbf{d} + \mathbf{n}.$$

The matrix $\mathbf{T}$ is called the system matrix as it describes the transmission system consisting of M transmitter, upsampling, modulation and channel. The structure of $\mathbf{T}$ is given by

$$\mathbf{T} =$$



$$\in \mathbb{C}^{(BQ+W-1)\times BQ},$$

$$\text{with} \quad \mathbf{V} = \left[\mathbf{V}^{(1)} \; \mathbf{V}^{(2)} \; \ldots \mathbf{V}^{(M)} \right] \in \mathbb{C}^{R\times MJ}.$$

The system matrix $\mathbf{T}$ is block-Toeplitz- and band-structured. The structure is retained if multiple receiving antennas are utilised. The matrix refers to one data burst. It consists of B matrices $\mathbf{V}$ shifted by Q against each other. The shift expresses the upsampling stage. Each matrix $\mathbf{V}$ corresponds to M blocks of data symbols. The processing of the $b\text{th}$ blocks of all M users and the channels influence is combined in $\mathbf{V}$. Due to the channel influence subsequent blocks of data symbols will interfere with each other. Therefore adjacent matrices $\mathbf{V}$ overlap each other in $(W-1)$ rows.

2.3 Generalised data model

The introduced data model is general enough to describe OFDMA, TD-CDMA and OFDM systems with or without CP/ZP by a proper choice of parameters. In OFDM-CDMA systems explained in [3, 4, 10] an additional coding/spreading matrix needs to be multiplied first. A TD – CDMA system is described if the number of parallel branches per user is reduced to 1 and the code matrix consisting of columns of the IFFT matrix is replaced by a code commonly used in CDMA systems. Such a model is described in detail in [8]. An OFDM system is described if only one user is active in a time slot $(M=1)$ and all subcarriers are allocated to this user.

As OFDMA and CDMA offer complementary strength in coping with the characteristics of a wireless channel the idea to join forces provided by the two systems to mitigate channels influence leads to combined systems known as OFDM-CDMA. According to [3] OFDM-CDMA systems can be classified in two groups. One spreads the K data symbols to J coded data symbols $(K \le J)$, each of which is modelled on its own subcarrier. So the K data symbols jointly use the J subcarriers. As instead of K subcarriers J subcarriers are necessary the spreading can be viewed as taking place in the frequency domain. According to our system this kind of OFDM-CDMA systems can be incorporated by an additional channel coding matrix mapping the K data symbols to J coded data symbols. The J symbols are then processed as shown. After the data detection the channel coding needs to be reversed. The other performs a serial to parallel conversion first. In each parallel branch referring to a certain subcarrier spreading is achieved by using a multiplicative spreading code. This spreading takes place in the time domain. Now different symbols of either one or multiple user can share the same subcarrier as they can be separated on the basis of their user- and symbol-specific code. If the spreading factor is Q_{CDMA}, one data block is spread to Q_{CDMA} subsequent blocks following each other. These blocks are processed as shown and can be detected again by the use of the detection scheme to be given in the following. Out of these detected blocks data detection and user separation can be performed by utilising the knowledge of the codes as it is done in CDMA systems.

The columns of the $\mathbf{V}$ matrix correspond to the subcarriers in OFDM based systems whereas they correspond to the user's spreading codes in TD-CDMA. Each column contains the FIR-Filter tap weights combining either the subcarriers and the respective channel or the spreading codes and the respective channel. The submatrix $\mathbf{V}$ corresponds either to one OFDM symbol or to one data symbol of all users in TD-CDMA. The channel causes that subsequent $\mathbf{V}$ matrices are coupled. Here is the main difference to CP/ZP-OFDM in terms of the structure of the system matrix. If a CP/ZP is used the $\mathbf{V}$ matrices become independent (i.e. $\mathbf{T}$ becomes block-diagonal) and can thus be processed independently of each other, which results in significant lower computational requirements for performing data detection. Depending on the system described by $\mathbf{T}$ the solution of the corresponding system of equations will perform data and multi-user or subcarrier detection.

Now we focus on the importance of the CP in OFDM based systems. The adoption of a cyclic prefix in an OFDM based system has some major advantages: First, the data detection problem is reduced to performing a FFT at the receiver and an additional division by a sample of the transfer function at the respective subcarrier frequency. Second, subsequent OFDM symbols belonging to one burst interfere only in redundant parts of the OFDM symbols, which can be ignored at the receiver. On the other hand, there are some striking disadvantages of the usage of a CP: First, the introduction of a CP is equivalent to introducing unprofitable redundancy into the information data. In proposed systems applying CP-OFDM such as HiperLAN/2 about 20 per cent of one data burst consists of CP parts, so that the information rate is decreased by 20 per cent as well. Second, symbol detectability is not guaranteed in a CP-OFDM based system unless extra redundancy is introduced. This is due to frequency selectivity of the wireless channel. If one subcarrier is hit by a channel null the respective subcarrier is suppressed and the information carried is lost. So extra channel coding introducing the extra redundancy mentioned becomes necessary [10]. If the CP-OFDM based system is regarded as one large system of equations the influence of the frequency selectivity reflected in the zeros of the transfer function on the FFT grid causes a singular system of equations (singular $\mathbf{T}$). Coded OFDM systems [5, 11] combat this problem at the cost of bandwidth efficiency. Third, the simple detection strategy is not reasonably transferable to existing CDMA systems. Therefore, multi-mode devices require different data detection techniques for different mobile communication standards.

Concerning these disadvantages, the idea to neglect the CP in the transmitter and thus enhance the information rate is promising. Thereby, the necessity of extra channel coding to guarantee symbol detectability becomes dispensable. The aim is to find a detection algorithm that is applicable to both TD-CDMA and OFDM based systems. Moreover, it should achieve a comparatively low bit error rate and should be executable at reasonable computational cost.

3. DATA DATECTION

It was shown in section 2 that the TD-CDMA and OFDM based systems can be expressed in one system of equations of the form

$$\mathbf{x} = \mathbf{T} \cdot \mathbf{d} + \mathbf{n}.$$

The vectors $\mathbf{d}$ and $\mathbf{x}$ contain the transmitted data and the received data, respectively. The vector $\mathbf{n}$ models co-channel interference and noise. The system matrices $\mathbf{T}$ for both CDMA and OFDM based systems are of the same beneficial structure, namely block-Toeplitz and band structured.

A data estimator has to estimate $\mathbf{d}$ from the knowledge of $\mathbf{T}$ and $\mathbf{x}$. This corresponds to solving an overdetermined system of equations. Suitable criteria are least squares (LS) and minimum mean square error (MMSE):

$$\text{LS:}\quad \hat{\mathbf{d}} = \left(\mathbf{T}^H \mathbf{T}\right)^{-1} \mathbf{T}^H \mathbf{x},$$

$$\text{MMSE:}\quad \hat{\mathbf{d}} = \left(\mathbf{T}^H \mathbf{T} - \sigma \mathbf{I}\right)^{-1} \mathbf{T}^H \mathbf{x},\ \text{ with }\ \sigma^2 = E\left\{\mathbf{n}^H \mathbf{n}\right\}\big/ l\,.$$

The MMSE technique can render better BER performance but has higher computational requirements as the noise power spectral density needs to be estimated for each burst. Frequency domain techniques are known to compute the estimates efficiently [7, 8]. The FFT method solves the system of equation in the frequency domain by a block-circular extension of the system matrix and by block-diagonalising the matrix with FFTs. Overlapping approximates the estimates and reduces computational requirements [7, 8]. The idea of the overlapping technique is that the large system matrix $\mathbf{T}$ is divided into smaller overlapping matrices, which are processed independently.

If a CP is inserted, each block of the system matrix $\mathbf{T}$ describing an OFDM system can be considered independently and can be diagonalised by performing an FFT. Thus the computational complexity to perform data detection is very low. In contrast to the LS or MMSE detection technique the BER performance will decrease if there is a channel with zeros on the FFT grid of the channel transfer function. In this case additional channel coding becomes necessary. The information transfer rate is lowered significantly (about 20 per cent in HiperLan/2) as compared to systems without CP. The CP-technique is only reasonably applicable to OFDM based systems. If the CP is neglected the information rate is increased by 20 per cent. The computational complexity increases significantly but efficient methods to reduce this complexity are known [2, 7, 8]. The resulting system matrix is non-singular even if there is a zero on the FFT grid of the channel transfer function. The techniques are reasonably applicable to both TD-CDMA and OFDM based systems without CP. The computational requirements for data detection in TD-CDMA are significantly higher than in CP-OFDM based systems. Therefore the neglect of the cyclic prefix causes a significant increase in the computational requirements if methods known from TD-CDMA [7, 8, 9] are applied. But they can be reduced to a manageable level by exploiting OFDM-specific characteristics or by choosing appropriate system parameters. Computational requirements for performing multi-user detection increase significantly with the number of active users in a TD-CDMA system [7]. The number of active users in a TD-CDMA system corresponds to the number of subcarriers in an OFDM based system in terms of the structure of the system matrix to be inverted. If we assume 64 subcarriers the computational requirements will explode. Furthermore, inverting $\mathbf{T}$ in the TD-CDMA case performs user and data detection whereas in the OFDM case subcarrier and data detection are performed. User detection becomes unnecessary as they are separated in time or frequency. An OFDM specific characteristic that can be exploited is that all subcarriers use the same channel.

4. OFDM SYSTEM WITHOUT CP

If we follow the goal to neglect the CP but keep a reasonable computational complexity one idea is not to transmit the CP after every OFDM symbol but once in a while, e.g., after each seventh OFDM symbol. Each block of OFDM symbols untill a CP is reached can be considered independently as subsequent blocks do not interfere with each other due to the CP (ZP). If the CP is neglected subsequent OFDM symbols interfere with each other and subcarriers crosstalk. So ISI and ICI arise, which need to be eliminated first. This can be done very efficiently by inverting the cyclic channel matrix $\tilde{\mathbf{H}}$ in the frequency domain (see figure 3). Thereby, the eigenvalue decomposition of cyclic matrices, $\tilde{\mathbf{H}} = \mathbf{F}^{-1}\mathbf{D}\mathbf{F}$, is utilised. Although the channel matrix referring to one block of OFDM symbols is much larger than the channel matrix referring to one CP-OFDM symbol, it is still cyclic and can thus be diagonalized with FFT's. The values on the diagonal can be calculated by the FFT of the channel impulse response, which is the first column of the channel convolution matrix. The system is depicted in figure 3.

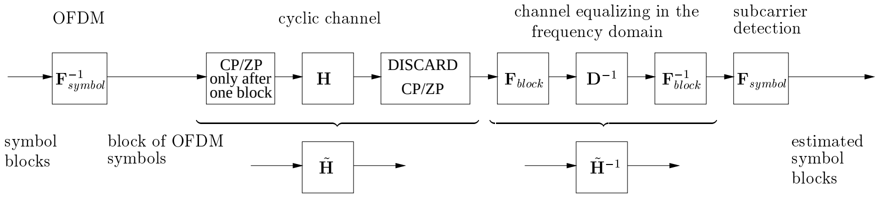


Figure 3. OFDM system without CP.

Example: If one OFDM symbol consists of $J = 64$ subcarriers and $B = 7$ blocks are sent before a ZP is inserted and the channel is of length $L = 16$ (HiperLAN/2 parameters), a 512-FFT is needed to diagonalise the channel matrix with the radix-2 algorithm and thus simplify the necessary inversion of the cyclic channel matrix as it can be achieved by two FFTs of size 512 and by $BJ = 448$ divisions.

However, the size of the involved FFT matrices can become very large if the number of OFDM symbols per block becomes very large. For example, if the number of OFDM symbols in one block is set to 31 a 2048-FFT is necessary for exact recovery of the data. But overlapping represents an approximation technique [8], which can lower the FFT sizes and the computational requirements at the expense of algebraic accuracy. The FFT matrices $\mathbf{F}_{block}$ and $\mathbf{F}_{symbol}$ are of the same size if a CP is inserted after each OFDM symbol. In this case the system is reduced to the CP-OFDM system as $\mathbf{F}_{symbol}\mathbf{F}_{block}^{-1} = \mathbf{I}$. In comparison to CP-OFDM the system without CP needs to spend two further comparatively large FFTs $\mathbf{F}_{block}$ and $\mathbf{F}_{block}^{-1}$ and a computational more expensive calculation of $\mathbf{D}^{-1}$. The simulation results show the BER performance as a function of the SNR for the CP case, which is regarded as the reference method and the method without the necessity of a CP. Furthermore, approximations with the overlapping technique are shown. The quality of the approximation depends more distinctly on the size of the FFT than on the prelap and postlap. Therefore, the prelap and postlap are set to zero in our simulations. However, the quality of the BER can often be improved without spending more computational complexity if the prelap and postlap are set to other values. The system without CP can achieve the same BER performance as the CP system, additionally having an increased information data rate of nearly 20 per cent. The price we pay for this increased data rate is that computational requirements of the receiver increase. The BER and the computational complexity of the different schemes are given in figure 4. The parameters are " FFT-size - prelap - postlap". The technique is especially suited for an uplink scenario, as the transmitter (mobile terminal) just neglects the CP (ZP) in most cases and thus saves transmit power for the cyclic prefix and enhances the data rate. To correct the interference appearing due to the neglect of the CP a moderate increase of the computational requirement becomes necessary at the receiver (base station), where it is not that problematic.

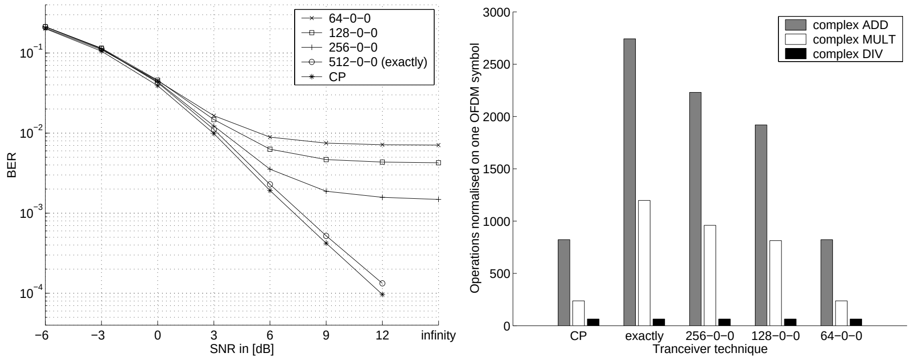


Figure 4. BER and computational requirements of different OFDM based transceiver techniques for B=7 OFDM symbols without CP.

5. CONCLUSIONS

To enhance the information data rate in OFDM based systems and to enable common data detection algorithms for OFDM and TD-CDMA based systems it is reasonable to neglect the CP. Computational requirements of common detection schemes will increase significantly compared to OFDM unless proper parameters are chosen. This corresponds mainly to the number of subcarriers, which should be kept small. Computational requirements can be lowered to a reasonable level in OFDM systems without CP by exploiting OFDM-specific characteristics. That is all subcarriers are transmitted over the same channel.

6. REFERENCES

[1] ETSI, “Broadband Radio Access Networks (BRAN), HIPERLAN Type 2, Physical (PHY) layer," Technical Specification ETSI TS 101 475, V. 1.2.1, November 2000.

[2] G. H. Golub and C. F. van Loan, "Matrix Computations," The John Hopkins´University Press, third edition, 1996.

[3] S. Hara and R. Prasad, "Overview of Multicarrier CDMA," IEEE Communications Magazine, December 1997.

[4] R. van Nee and R. Prasad, "OFDM for wireless multimedia communications," Artech House Publishers, 2000.

[5] H. Sari, "Orthogonal frequency division multiple access with frequency hopping and diversity," in Proc. MCSS, 1997, pp. 57-68.

[6] S. Verdu, "Multiuser Detection," Cambridge University Press, 1998.

[7] M. Vollmer, J. Götze and M. Haardt, "Joint-Detection using Fast Fourier Transforms in TD-CDMA based Mobile Radio Systems," International Conference on Telecommunications, ICT '99, Cheju, Korea, 1999

[8] M. Vollmer, M. Haardt and J. Götze, "Comparative Study of Joint-Detection Techniques for TD-CDMA based Mobile Radio Systems," IEEE J. Select. Areas Commun. (accepted).

[9] M. Vollmer, "Programmes for computing computational requirements of four JD algorithms," available online at http://www-dt.e-technik.uni-dortmund.de/mitarbeiter/mvo/compreq.html

[10] Z. Wang and G. B. Giannakis, "Wireless Multicarrier Communications," IEEE Signal Processing Magazine, vol. 17, no.3, pp. 29-48, May 2000.

[11] W. Zou and Y. Wu, "COFDM: An overview," IEEE Trans. Broadcasting, vol. 41, no.1, Mar. 1995

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