Exhibit G-19

Invalidity of U.S. Patent No. 11,381,285 in View of Motorola StarTAC 7868 ("StarTAC")

The asserted claims of U.S. Patent No. 11,381,285 ("the '285 patent") are obvious over Motorola StarTAC 7868 (including StarTAC 7868w) ("StarTAC") in view of the knowledge of the person of ordinary skill in the art ("POSA") and one or more of the following references: "Multi-Carrier CDMA Mobile Radio Systems - Analysis and Optimization of Detection, Decoding, and Channel Estimation" ("Kaiser-1998"), "On the Duality of Multi-Carrier Spread Spectrum and Single-Carrier Transmission" to Brüninghaus et al. ("Brüninghaus-1997"), "A New Spread-Spectrum Multiple-Access Scheme" ("Sorger-1997"), "Multi-Carrier Spread Spectrum and Its Relationship to Single-Carrier Transmission" to Brüninghaus et al. ("Brüninghaus-1998"), "Interleaved FDMA-A New Spread-Spectrum Multiple-Access Scheme" ("Sorger-1998"), "An Improved MMSE Based Block Decision Feedback Equalizer" ("Bury-1999"), "Comparison of Amplitude Distributions for Hadamard Spreading and Fourier Spreading in Multi-Carrier Code Division Multiplexing" ("Bury-2000"), "Broadband OFDM-FDMA System for the Uplink of a Wireless LAN" ("Galda-2001"), "A Low Complexity Transmitter Structure for OFDM-FDMA Uplink Systems" ("Galda-2002"), "Proposed Baseline OFDM Systems for Study" ("R1-021246"), U.S. Patent No. 6,535,501 to Böhnke ("Böhnke-501"), WO 2003/026193 A1, "Method and Communication System Device for the Generation or Processing of OFDM Symbols in a Transmission System with Spread User Data," to Costa et al. ("Costa-193"), U.S. Patent No. 6,609,010 to Dolle et al. ("Dolle-010"), and U.S. Patent App. Pub. 2005/0018782 A1 to Costa et al. ("Costa-782").

Motorola StarTAC 7868 was released in or before 2000 and thus qualifies as prior art under pre-AIA § 102(b) or post-AIA §-102(a)(1).

Kaiser-1998 published in Jan. 1998. Therefore, Kaiser-1998 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Brüninghaus-1997 published on Aug. 31, 1997. Therefore, Brüninghaus-1997 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Sorger-1997 published on Aug. 31, 1997. Therefore, Sorger-1997 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Brüninghaus-1998 published on May 18, 1998. Therefore, Brüninghaus-1998 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Sorger-1998 published in June 1998. Therefore, Sorger-1998 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Bury-1999 published on Dec. 31, 1999. Therefore, Bury-1999 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Bury-2000 published in 2000. Therefore, Bury-2000 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Galda-2001 published on Sept. 27, 2001. Therefore, Galda-2001 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Galda-2002 was published on May 06, 2002. Therefore, Galda-2002 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

R1-021246 published on Oct. 08, 2002. Therefore, R1-021246 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Böhnke-501 issued on Mar. 18, 2003. Therefore, Böhnke-501 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Costa-193 published on Mar. 27, 2003. Therefore Costa-193 qualifies as prior art under pre-AIA 35 U.S.C. § 102(b) or post-AIA § 102(a)(1).

Dolle-010 issued on Aug. 19, 2003. Therefore, Dolle-010 qualifies as prior art under pre-AIA 35 U.S.C. § 102(a) or post-AIA § 102(a)(1).

Costa-782 was filed on Sept. 16, 2002 and published on Jan 27, 2005. Therefore, Costa-782 qualifies as prior art under pre-AIA 35 U.S.C. § 102(e) or post-AIA § 102(a)(2).

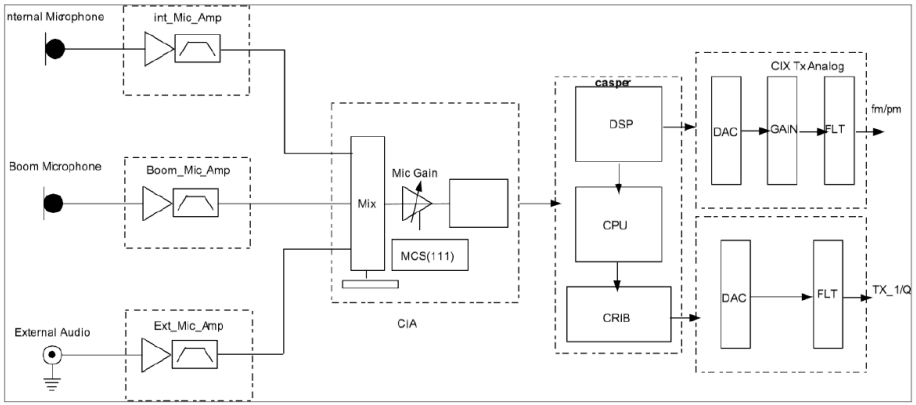
The asserted claims and the alleged priority date of the '285 patent are identified below:

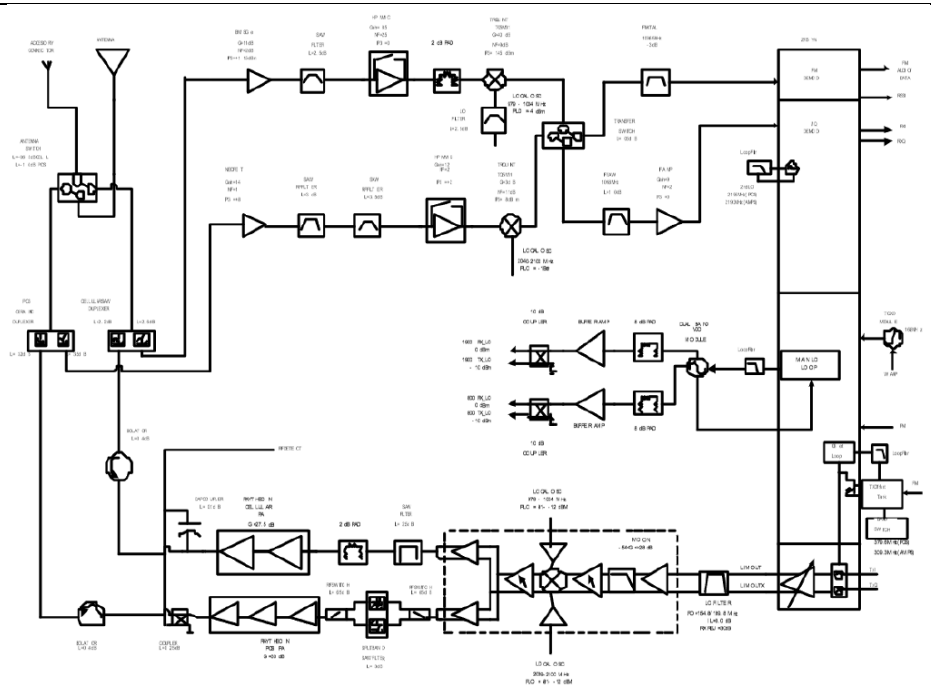
'285 Patent Asserted Claims	Alleged Priority Date
11, 17, 19	"August 2, 2004" (ACICS at 8)

The Court has not yet construed the claims and therefore the meaning of the terms in the claims has yet to be resolved by the Court. The support identified herein may be responsive at least in part to Plaintiff's infringement contentions, with which Defendant does not necessarily agree. As such, nothing in Defendant's claim charts should be construed as an admission regarding infringement, or as an admission regarding Defendant's understanding of the proper scope of the asserted claims. Defendant reserves the right to rely on additional citations or sources of evidence that also may be applicable, or that may become applicable in light of claim construction, changes in Plaintiff's infringement contentions, and/or information obtained during discovery.

Where Defendant cites a particular figure, such citation should be understood to encompass the caption and description of the figure, in addition to the figure itself. Conversely, where a cited portion of text refers to a figure, the citation should be understood to include the figure as well.

Defendant reserves the right to amend or supplement this claim chart at a later date as more fully set forth in the Cover Pleading based on, for example and without limitation, any amendments to the pleadings, or applicable rulings from the Court.

Claim Language	StarTAC and Other References
[11PRE] An apparatus for communication in a wireless communication network, the apparatus comprising:	To the extent the preamble of claim 13 is found to be limiting, StarTAC had a DS-CDMA transmitter, which is an apparatus for communication in a wireless network. *See, e.g.*, Motorola CDMA ST7868W Dual Band/Tri Mode, Service Manual Level III, pp. 15-17 (describing the "Transmitter Circuitry" used in the StarTAC).  *Id.*, p.19.



Id., p.21; *see also id.*, pp.80-84 (schematics showing processor, transmitter, and other RF communications components for CDMA communications).

But, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter:

For example, Kaiser-1998 discloses:

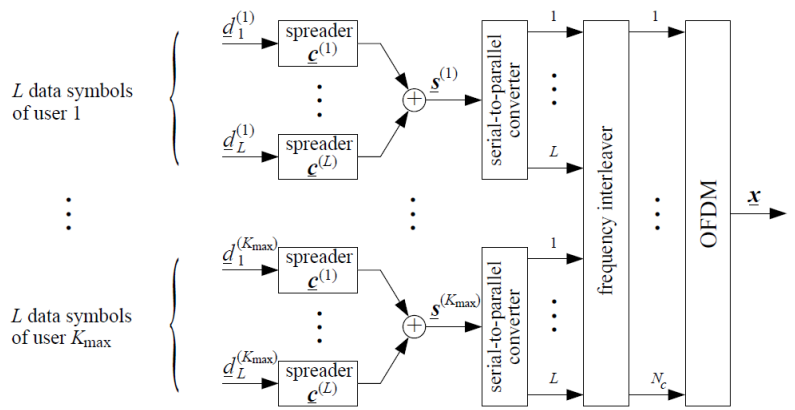


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

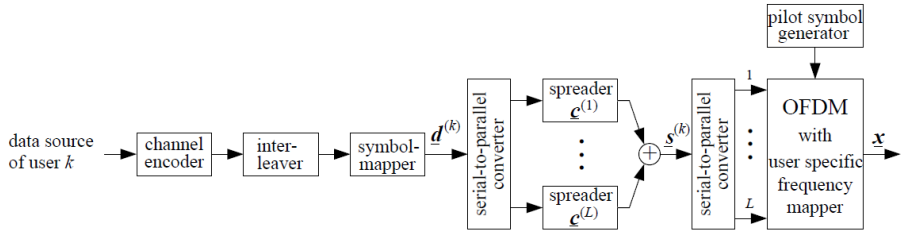


Figure B.2: SS-MC-MA transmitter of the kth user for the uplink

Kaiser-1998 at Fig. B.2.

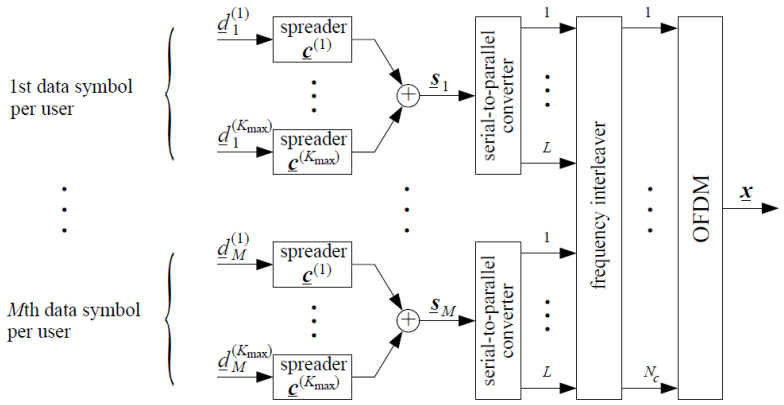


Figure 3.8: M-Modification: MC-CDMA transmitter with simultaneous transmission of M data symbols per user and OFDM symbol; BS with $K_{\max} = L$ active users and $N_c = ML$ subcarriers

Kaiser-1998 at Fig. 3.8.

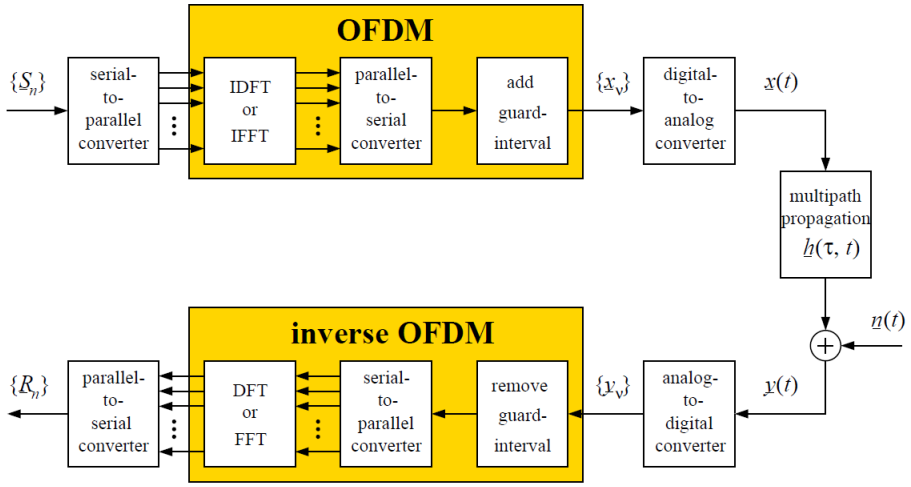


Figure 3.2: MC transmission system with OFDM

Kaiser-1998 at Fig. 3.2.

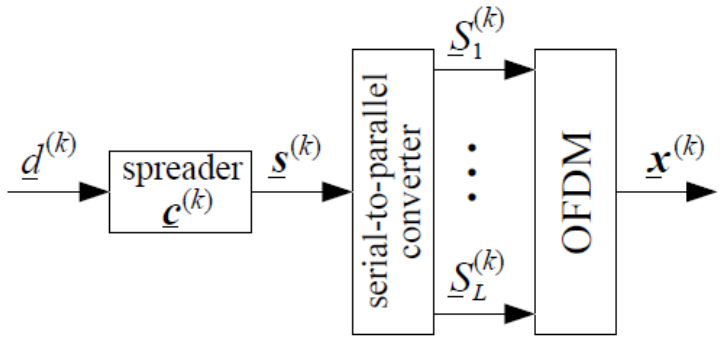


Figure 3.6: MC spread spectrum signal generation

Kaiser-1998 at Fig. 3.6.

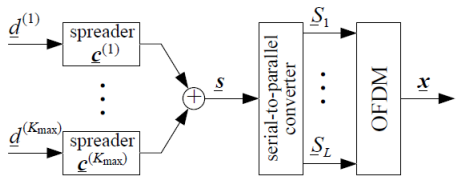


Figure 3.7: Basic MC-CDMA transmitter for the downlink; BS with $K_{\max} = L$ active users and $N_c = L$ subcarriers

Kaiser-1998 at Fig. 3.7.

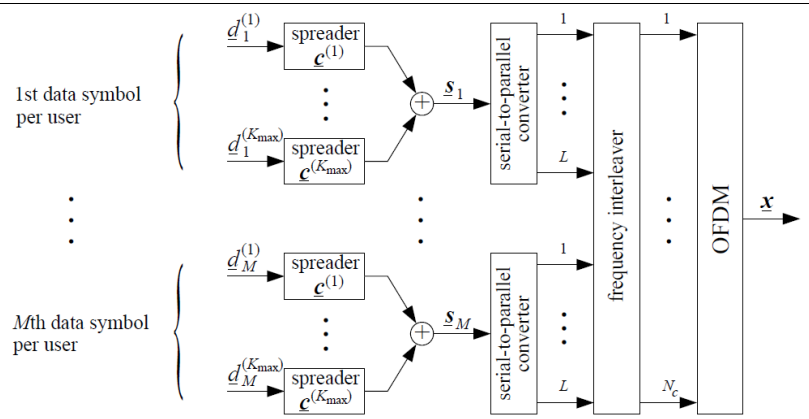
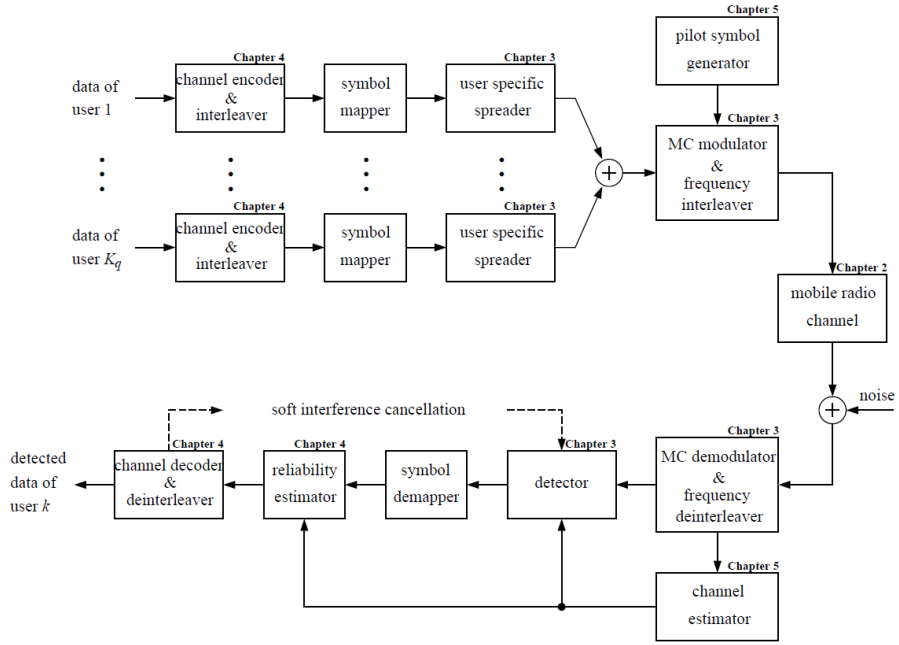


Figure 3.8: M-Modification: MC-CDMA transmitter with simultaneous transmission of M data symbols per user and OFDM symbol; BS with $K_{\max} = L$ active users and $N_c = ML$ subcarriers

Kaiser-1998 at Fig. 3.8.

	 Figure 6.1: MC-CDMA mobile radio system in the downlink Kaiser-1998 at 6.1.
[11A] at least one processor; and	StarTAC included at least one processor. *See, e.g.*, Motorola CDMA ST7868W Dual Band/Tri Mode, Service Manual Level III, pp. 16-17 (describing a "microprocessor U1100" used in the StarTAC). StarTAC's processor used CDMA, an earlier generation of wireless communication technology. As such it did not include a processor that used OFDM wireless communication technology. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the processor used in, for example, StarTAC. A POSA thus

would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter:

For example, Kaiser-1998 discloses:

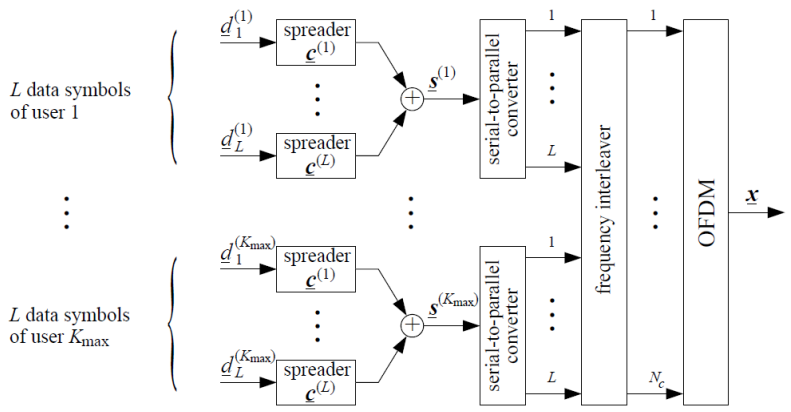


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

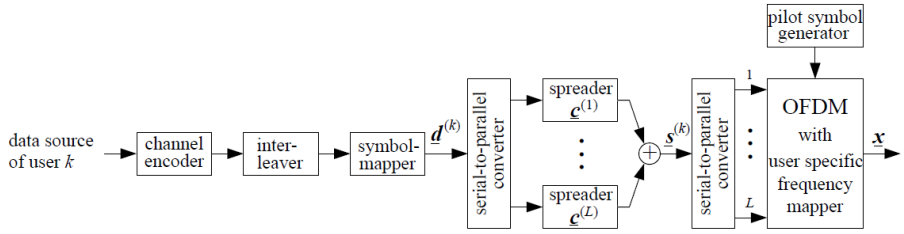


Figure B.2: SS-MC-MA transmitter of the kth user for the uplink

Kaiser-1998 at Fig. B.2.

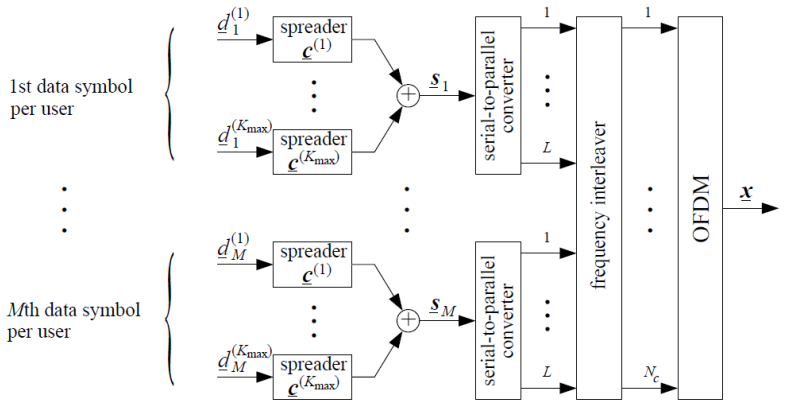


Figure 3.8: M-Modification: MC-CDMA transmitter with simultaneous transmission of M data symbols per user and OFDM symbol; BS with $K_{\max} = L$ active users and $N_c = ML$ subcarriers

Kaiser-1998 at Fig. 3.8.

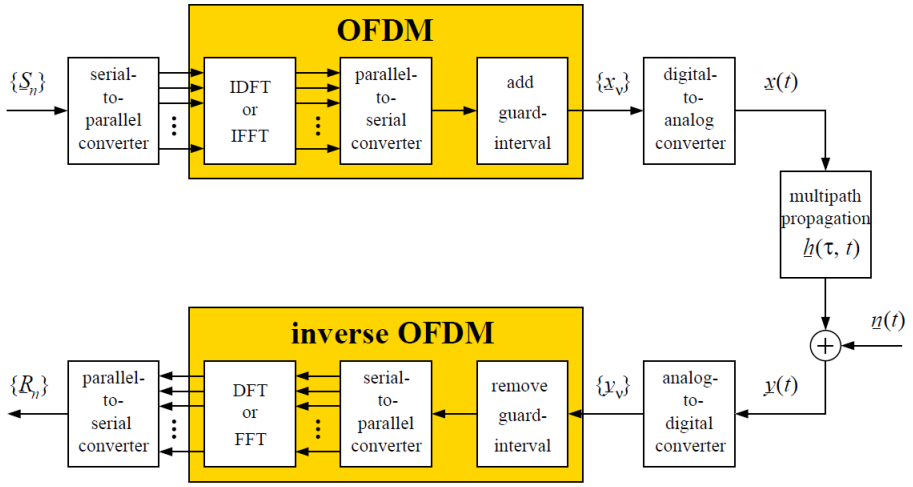


Figure 3.2: MC transmission system with OFDM

Kaiser-1998 at Fig. 3.2.

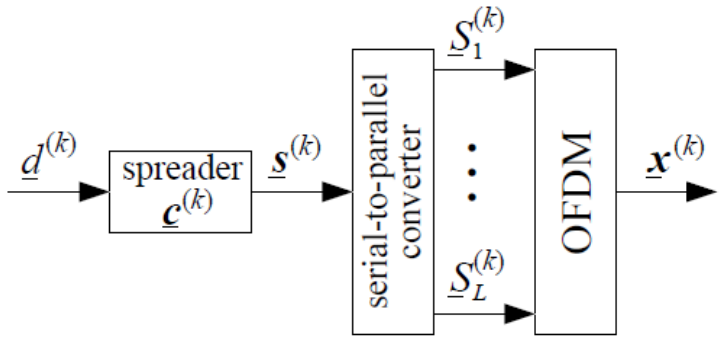


Figure 3.6: MC spread spectrum signal generation

Kaiser-1998 at Fig. 3.6.

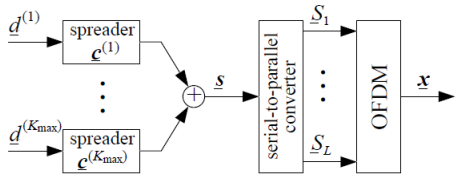


Figure 3.7: Basic MC-CDMA transmitter for the downlink; BS with $K_{max} = L$ active users and $N_c = L$ subcarriers

Kaiser-1998 at Fig. 3.7.

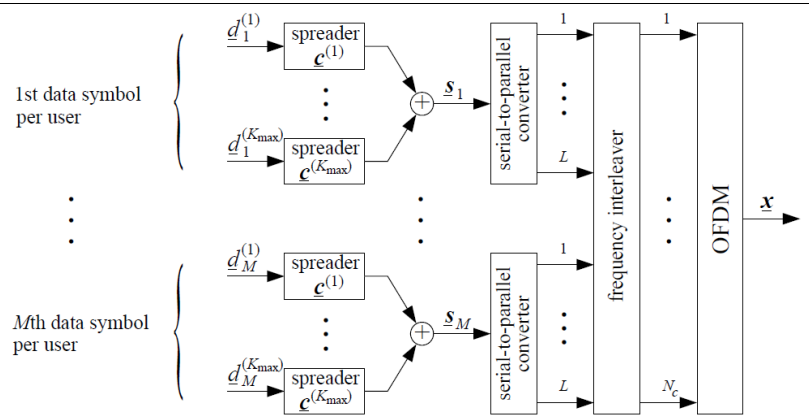
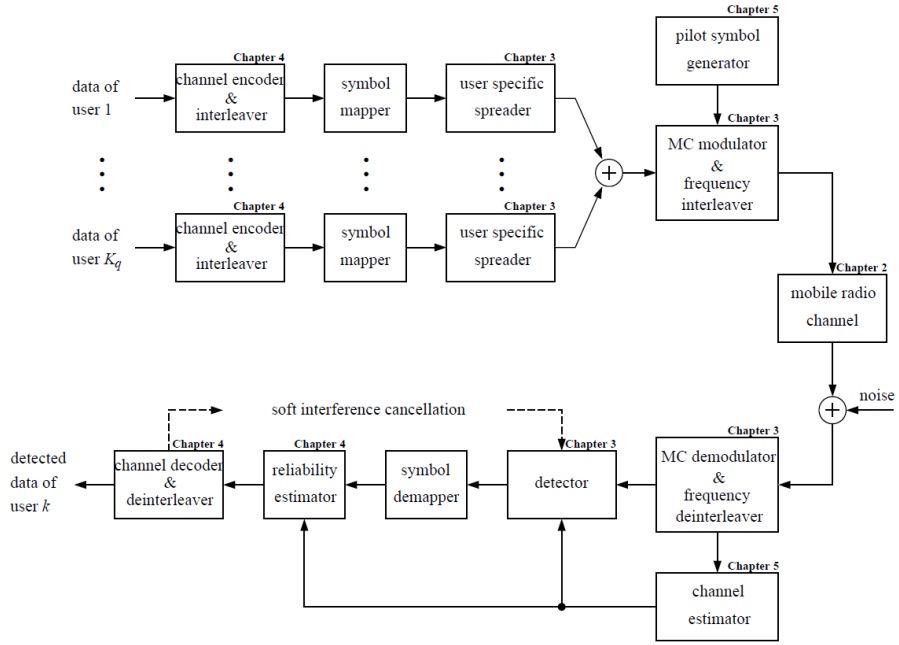


Figure 3.8: M-Modification: MC-CDMA transmitter with simultaneous transmission of M data symbols per user and OFDM symbol; BS with $K_{\max} = L$ active users and $N_c = ML$ subcarriers

Kaiser-1998 at Fig. 3.8.

	 Figure 6.1: MC-CDMA mobile radio system in the downlink Kaiser-1998 at 6.1.
[11B] a non-transitory computer-readable memory communicatively coupled to the at least one processor, the non-transitory computer-readable memory including a set of instructions stored thereon and executable by the at least one processor for:	StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. *See, e.g.*, Motorola CDMA ST7868W Dual Band/Tri Mode, Service Manual Level III, pp.5, 23, 37, 43 (describing memory used in the StarTAC). Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus

would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality:

For example, Kaiser-1998 discloses:

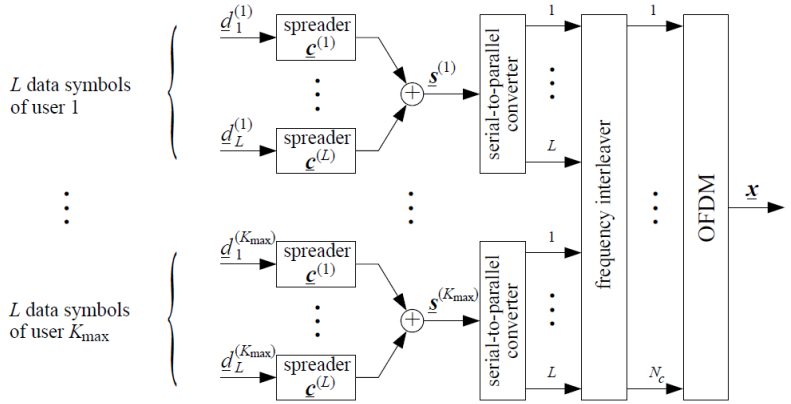


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

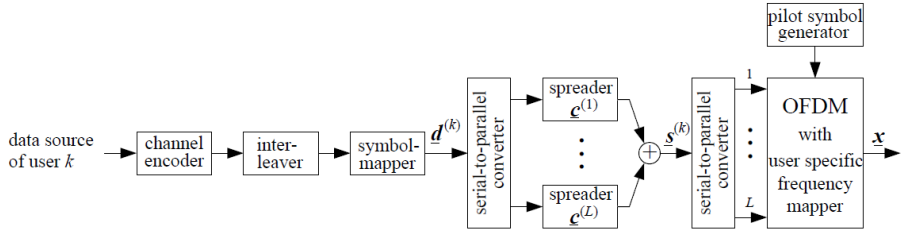


Figure B.2: SS-MC-MA transmitter of the kth user for the uplink

Kaiser-1998 at Fig. B.2.

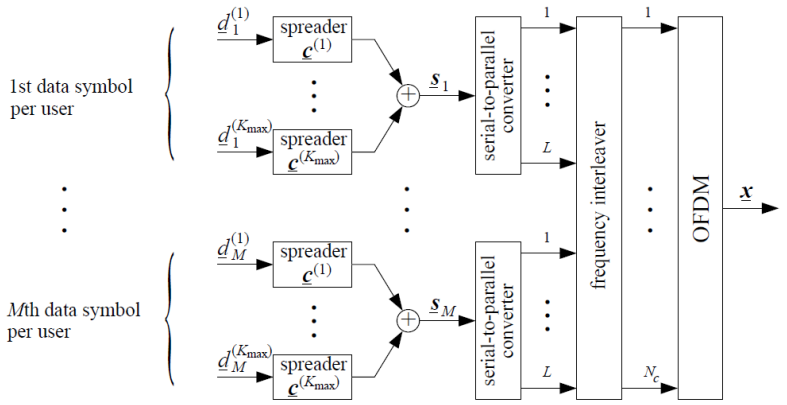


Figure 3.8: M-Modification: MC-CDMA transmitter with simultaneous transmission of M data symbols per user and OFDM symbol; BS with $K_{max} = L$ active users and $N_c = ML$ subcarriers

Kaiser-1998 at Fig. 3.8.

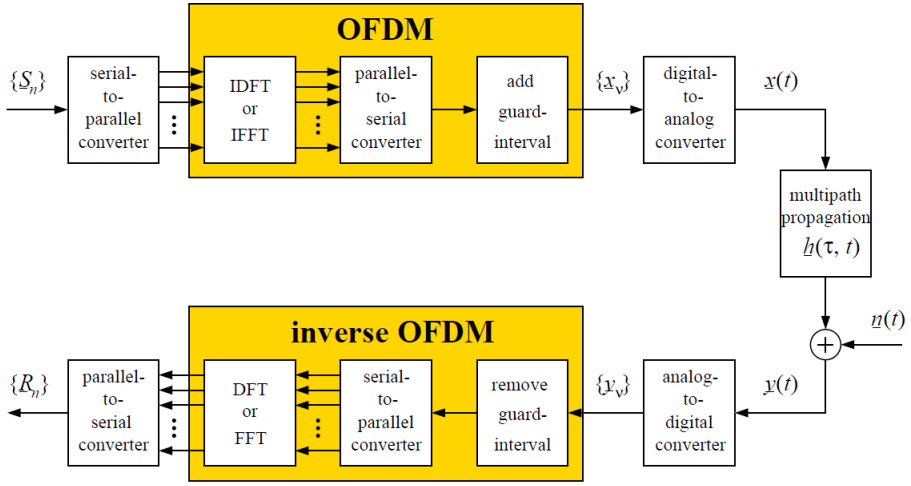


Figure 3.2: MC transmission system with OFDM

Kaiser-1998 at Fig. 3.2.

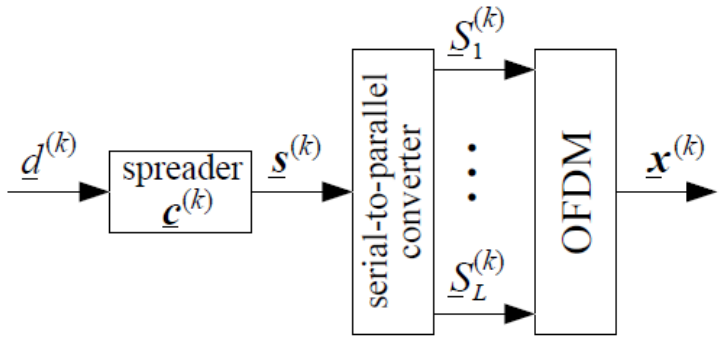


Figure 3.6: MC spread spectrum signal generation

Kaiser-1998 at Fig. 3.6.

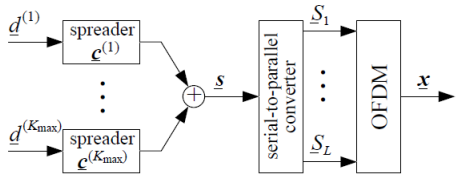


Figure 3.7: Basic MC-CDMA transmitter for the downlink; BS with $K_{\max} = L$ active users and $N_c = L$ subcarriers

Kaiser-1998 at Fig. 3.7.

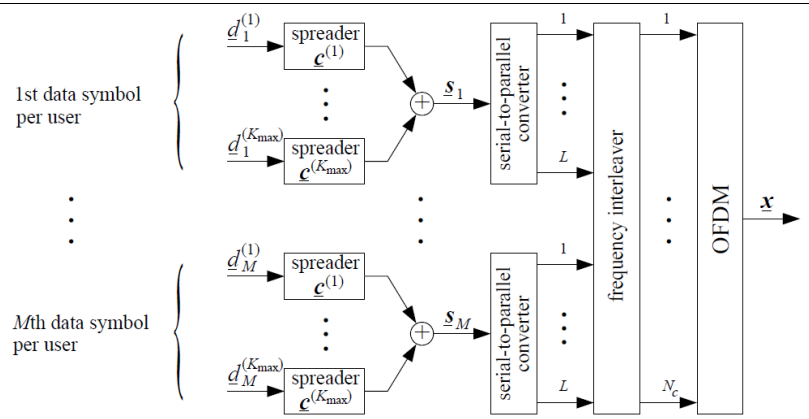


Figure 3.8: M-Modification: MC-CDMA transmitter with simultaneous transmission of M data symbols per user and OFDM symbol; BS with $K_{\max} = L$ active users and $N_c = ML$ subcarriers

Kaiser-1998 at Fig. 3.8.

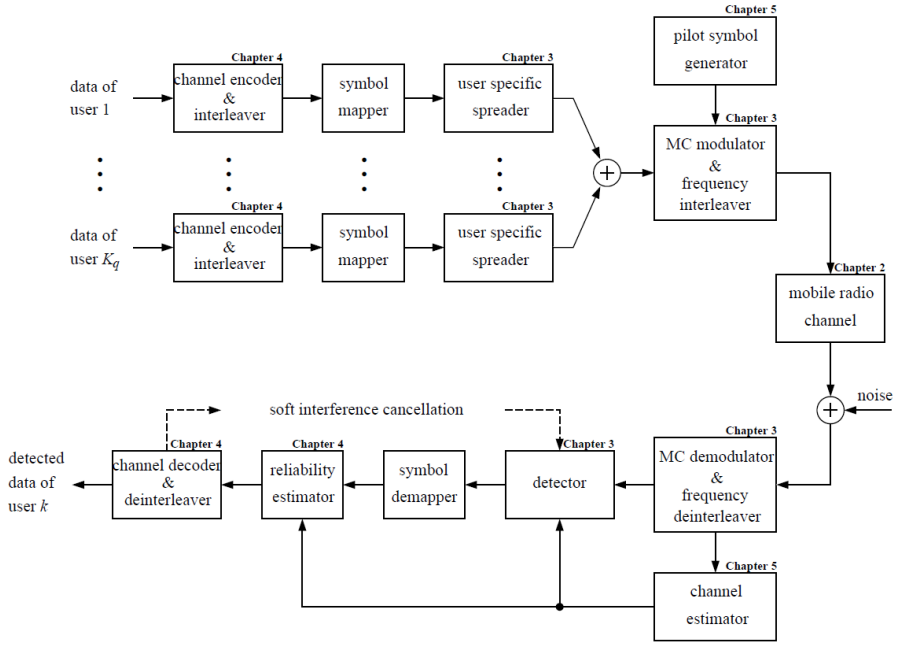


Figure 6.1: MC-CDMA mobile radio system in the downlink

Kaiser-1998 at 6.1.

[11C] encoding a set of data symbols with a set of complex-valued codes, to produce a set of subcarrier values;	StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and

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For example, Kaiser-1998 discloses:

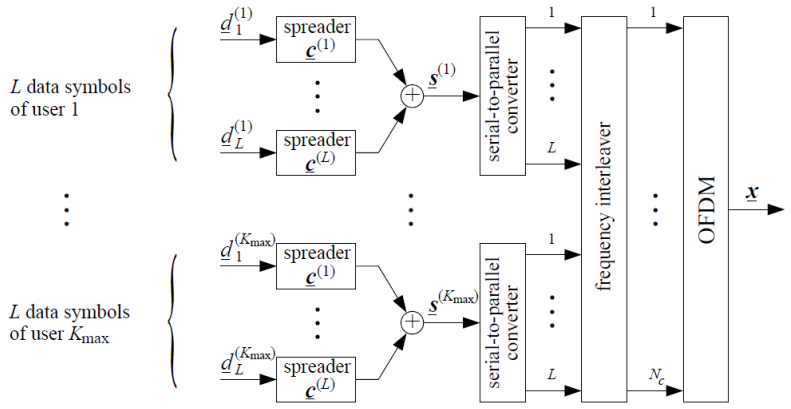


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

> This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA

transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users.

Kaiser-1998 at 130-131.

Between SS-MC-MA and MC-CDMA systems exist the following similarities:

• SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers.

• Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems.

• ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques.

Kaiser-1998 at 131.

Between SS-MC-MA and MC-CDMA systems exist the following differences:

• In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA

scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme.

• MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user.

• In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

• In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity.

Kaiser-1998 at 131.

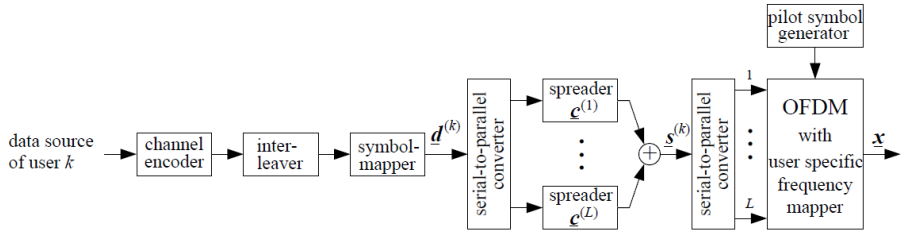


Figure B.2: SS-MC-MA transmitter of the kth user for the uplink

Kaiser-1998 at Fig. B.2.

SS-MC-MA Transmitter: Fig. B.2 shows an SS-MC-MA transmitter with channel coding for the data of the kth user, $k = 1 \ldots K$, for the uplink. The components channel encoding, interleaving, and symbol mapping are identical to those described in Chapter 4 for MC-CDMA systems. In SS-MC-MA systems, L subsequent complex-valued data symbols $\underline{d}_l^{(k)}, l = 1 \ldots L$, of user k are serial-to-parallel converted. The vector

$$\underline{d}^{(k)} = \left(\underline{d}_1^{(k)}, \underline{d}_2^{(k)}, \ldots, \underline{d}_L^{(k)}\right)^T \qquad (B.1)$$

represents one block of L parallel converted data symbols of the kth user. Each of the L data symbols is multiplied with another orthogonal spreading code of length L. The $L \times L$ matrix

$$\underline{C} = \left(\underline{c}_1\ \underline{c}_2\ \ldots\ \underline{c}_L\right) = \begin{pmatrix} \underline{C}_{1,1} & \underline{C}_{2,1} & \cdots & \underline{C}_{L,1} \\ \underline{C}_{1,2} & \underline{C}_{2,2} & \cdots & \underline{C}_{L,2} \\ \vdots & \ddots & \cdots & \vdots \\ \underline{C}_{1,L} & \underline{C}_{2,L} & \cdots & \underline{C}_{L,L} \end{pmatrix} \qquad (B.2)$$

represents the L different spreading codes $\underline{c}_l, l = 1, \ldots, L$, used by user k. The matrix $\underline{C}$ is the same for all users. The modulated spreading codes are data symbol and, thus, chip synchronously added, resulting in the transmission vector

$$\underline{s}^{(k)} = \underline{C}\,\underline{d}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \ldots, \underline{S}_L^{(k)}\right)^T \qquad (B.3)$$

consisting of L components. To increase the robustness of SS-MC-MA systems e.g. against inter cell interference, less than L data modulated spreading codes can be added to one transmission vector $\underline{s}^{(k)}$.

Kaiser-1998 at 131-132.

In the following, the performance of an SS-MC-MA mobile radio system in the uplink is presented. Table B.1 shows the SS-MC-MA system parameters used in the uplink. These parameters are chosen such that they

	correspond as far as possible with the MC-CDMA system parameters for the downlink presented in Table 6.1. The SS-MC-MA system parameters described in the following differ from those of the MC-CDMA system presented in Chapter 6. The SS-MC-MA system transmits only on 256 subcarriers. Since the channel estimation in the considered SS-MC-MA system is based on a 1-D filtering in time direction which should fulfill two-times oversampling of the time-variant fading process, the overhead due to pilot symbols can be reduced with decreasing OFDM symbol durations. However, it has to be taken into account that with decreasing OFDM symbol duration the loss in bandwidth efficiency due to the guard interval increases. The used TDMA frame structure consisting of 4 time slots. A time slot corresponds to an OFDM frame consisting of 31 OFDM symbols as illustrated in Fig. B.4. Each user exclusively transmits on 8 subcarriers, where 3 of the 8 subcarriers used by the kth user are depicted. Hence, per user, a block of 8 serial data symbols is parallel converted and spread with orthogonal Walsh Hadamard codes of length L equal to 8, resulting after superposition in the transmission sequence $\underline{s}^{(k)}$, cf. (B.3). Note that in contrast to Fig. B.2, an additional interleaver is applied which scrambles 192 components of 24 transmission sequences $\underline{s}^{(k)}$ with the intention to increase the diversity potential of the system. Per OFDM symbol, 8 randomly interleaved components are mapped on 8 subcarriers exclusively used by the kth user. The 8 user specific subcarriers are distributed over the whole bandwidth. The receiver applies an MLSSE for data detection. The channel coding part is identical to that of the MC-CDMA system presented in Chapter 6. Kaiser-1998 at 133-135.

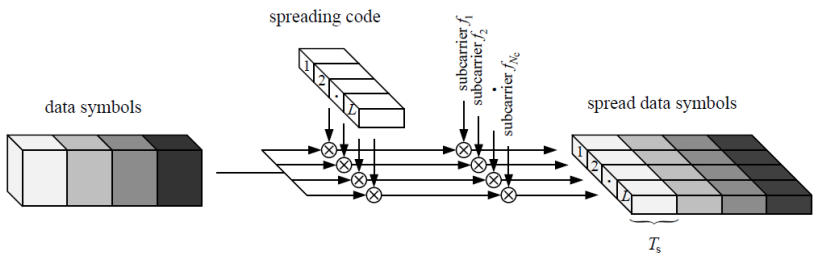
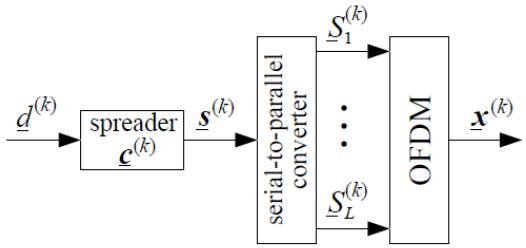


Figure 1.4: Principle of spreading of the data of a single user by MC-CDMA for the case $N_c = L$, i.e., $T_s = T_d$ and $T'_c = T_d$

Kaiser-1998 at Fig. 1.4.

Concept I: MC-CDMA is based on a serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, [FaP93, YLF93, CBJ93]. The high rate DS spread data stream is MC modulated in such a way, that the L chips of a spread data symbol are transmitted in parallel on different subcarriers. Thus, the assigned data symbol is simultaneously transmitted on L subcarriers. If the number of subcarriers N_c is equal to the spreading code length L, MC-CDMA requires the total bandwidth for the transmission of a single data symbol comparable to DS-CDMA. When choosing L smaller than N_c and introducing an appropriate frequency interleaving, the flexibility of an MC-CDMA system can be increased and the complexity of the data detector can be reduced [FaP93, Faz93]. Fig. 1.4 shows the principle of an equivalent realization of the serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3. Each data symbol is copied onto L substreams before multiplication with one chip of the spreading code per substream. A chip of the MC-CDMA spreading code grouped in the frequency domain has the duration T'_c, cf. Fig. 1.1, which is by a factor of N_c greater than the duration T_c of a chip of the DS-CDMA spreading code. The case of N_c equal to L is illustrated in Fig. 1.4, yielding that the data symbol duration T_d, the chip duration T'_c, and the OFDM symbol duration T_s are identical. Fig. 1.4 reflects the fact that MC-CDMA has a spreading code grouped in the frequency domain. Comparing

	the spread data symbols of DS-CDMA, cf. Fig. 1.2, with those of MC-CDMA, cf. Fig. 1.4, it can be seen that MC-CDMA offers an additional flexibility in the frequency domain, which results in simple methods for signal reconstruction in the frequency domain. MC-CDMA was introduced with OFDM for optimum use of the available bandwidth [FaP93, YLF93, CBJ93]. Most MC-CDMA systems were proposed for the downlink from a base station (BS) to a mobile station (MS) where powerful mobile receivers with low complexity are required [FaP93, YLF93, CBJ93]. The time/frequency synchronism between the users in the downlink allows a simple realization of an efficient channel estimation required for coherent detection. Kaiser-1998 at 6-7.  Figure 3.6: MC spread spectrum signal generation Kaiser-1998 at Fig. 3.6. The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be

transmitted over the radio channel is taken from the complex data symbol alphabet

$$\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \tag{3.24}$$

of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

$$\underline{c}^{(k)} = \left(\underline{C}_1^{(k)}, \underline{C}_2^{(k)}, \dots, \underline{C}_L^{(k)}\right)^{\mathrm{T}} \tag{3.25}$$

of the kth user. The chips $\underline{C}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet

$$\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \tag{3.26}$$

of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is

$$\frac{1}{T_c} = \frac{L}{T_d} \tag{3.27}$$

and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector

$$\underline{s}^{(k)} = \underline{d}^{(k)}\underline{c}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^{\mathrm{T}}. \tag{3.28}$$

The rate of the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread

spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d^{(k)}}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is

$$T_s' = T_g + N_c T_c. \quad (3.29)$$

The transmission of one data symbol per user per OFDM symbol requires

$$N_c = L \quad (3.30)$$

subcarriers. In this case, the OFDM symbol duration including the guard interval is

$$T_s' = T_g + T_d. \quad (3.31)$$

Kaiser-1998 at 39-40.

An MC-CDMA system designed for the transmission of one data symbol per user per OFDM symbol is referred to as a basic MC-CDMA system in the following. When applying orthogonal spreading codes $\underline{\boldsymbol{c}^{(k)}}$ like Walsh-Hadamard codes, the maximum number of active users $K_{\max}$ in the basic MC-CDMA system corresponds to the spreading code length L, i.e.,

$$K_{\max} = L. \quad (3.32)$$

Kaiser-1998 at 40.

• Frequency/time domain spreading code: Each MC-CDMA spreading code with a mapping on frequency slots can be transferred in a DS-CDMA spreading code with a mapping on time slots and vice versa by applying the Fourier transform [FBA94]. The key feature of the Fourier transform is that it preserves the correlation properties of the spreading code [Ach85]. Hence, an MC-CDMA system with a spreading code $\{\underline{C_l^{(k)}}\}, l = 1, \ldots, L,$

performs identically to a DS-CDMA system with a spreading code$\{\underline{c}_i^{(k)}\}, i = 1, \ldots, L$, when both spreading codes are related by the Fourier transform, i.e.,

$$\{\underline{C}_l^{(k)}\}, \quad l = 1, \ldots, L, \quad \bullet\!\!-\!\!\circ \quad \{\underline{c}_i^{(k)}\}, \quad i = 1, \ldots, L. \tag{3.84}$$

In (3.84), the symbol $\bullet\!\!-\!\!\circ$ denotes the discrete Fourier transformation. When, for instance, applying binary, real-valued, orthogonal MC-CDMA spreading codes, the equivalent DS-CDMA spreading codes are non-binary and complex-valued, but still orthogonal.

Kaiser-1998 at 62-63.

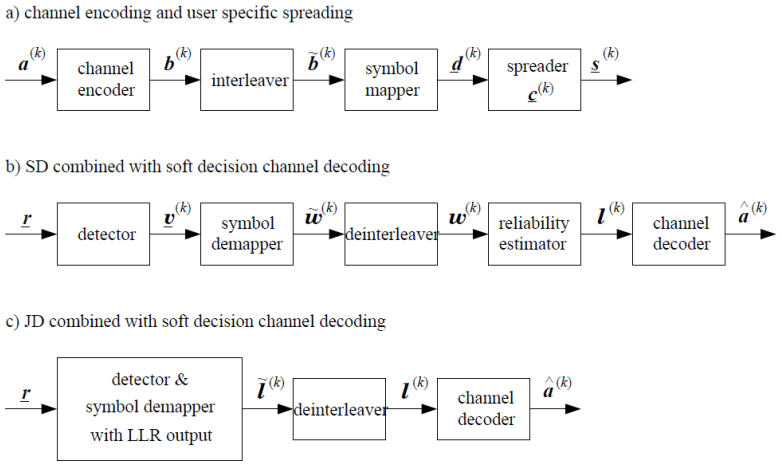


Figure 4.1: Concatenation of the spread spectrum technique with channel coding; a) channel encoding with subsequent data symbol spreading; b) SD and c) JD with optimum soft decision decoding

Kaiser-1998 at 65.

Performance and flexibility of mobile radio systems essentially depend on the choice of the multiple access scheme. The novel MC-CDMA scheme

	which is the topic of this thesis is a promising alternative to conventional FDMA, TDMA, and CDMA schemes. With MC-CDMA, each data modulated chip of the user specific spreading code is mapped onto a separate subcarrier, so that the chips of the spreading code and, hence, the data symbol is transmitted in parallel on multiple subcarriers. The application of OFDM enables one to avoid ISI and ICI in the detection process, resulting in simple SD and MD techniques. In MC-CDMA mobile radio systems, SD can be realized by equalizing each subcarrier individually, yielding only one complex-valued multiplication per subcarrier and OFDM symbol. Due to the M-, Q-, and M&Q-Modification of the MC-CDMA scheme, even the optimum JD techniques MLSSE and MLSE can be applied with reasonable complexity. Kaiser-1998 at 119. Brüninghaus-1997, which discloses: In this paper we will focus on Multi-Carrier CDMA (MC-CDMA). In contrast to a conventional OFDM system where every bit is assigned to a single subcarrier, the information is spread over several subcarriers using orthogonal codes. Since spreading is performed on information symbol level prior to subcarrier modulation, the resulting MC-CDMA signal is basically an OFDM signal. The advantage of this technique is a lower bit error rate in frequency-selective radio channels compared to a conventional OFDM system due to inherent frequency-diversity. The price to be paid is a higher computation complexity in the receiver since the frequency-selective radio channel leads to a loss of orthogonality of the spreading codes and interuser-interferences occur. A lot of research has been done to develop suitable detection or joint detection methods [4, 5, 6, 7] without considering the spreading matrix in detail. Brüninghaus-1997 at 187. In this paper we will discuss this item focussing on the special case that the spreading matrix equals the Fourier matrix. The two operations performed

in the transmitter, namely spreading and IFFT-processing, cancel each other resulting in a pure single-carrier system with blockwise processing. This special case was also mentioned in [8] but little was said about the consequences, which will be done in the following sections.

Brüninghaus-1997 at 188.

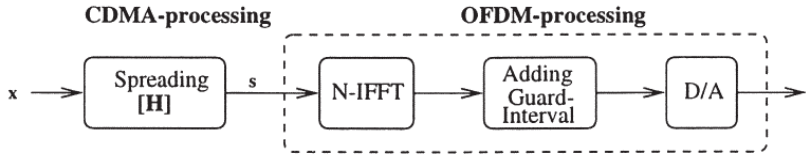


Figure 1: Block diagramm of a MC-CDMA transmitter (downlink)

Brüninghaus-1997 at 188.

The general block diagram of a MC-CDMA transmitter (only the downlink is considered in this paper) is depicted in Fig. 1. In a first step the complex data symbols $x_i, \quad 1 \leq i \leq M$, which can be elements of any arbitrary symbol set e.g. PSK or QAM, are spread over several subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation

$$s = [H] \cdot x \qquad (1)$$

where $x = (x_1, \ldots, x_M)^T$ is the vector of data symbols, $s = (s_1, \ldots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix. The M columns of the code matrix contain different spreading codes for every data symbol. To avoid interuser-interferences in AWGN the spreading codes should be mutually orthogonal. If the OFDM system consists of N subcarriers there are a maximum number of N orthogonal codes and $1 \leq M \leq N$ users can be supported every OFDM symbol. Apart from the described spreading procedure, the transmitter is identical to a conventional OFDM

transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard-interval is added) and D/A converted.

Brüninghaus-1997 at 188.

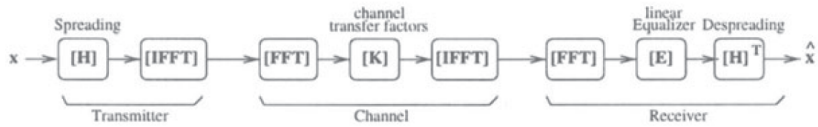


Figure 3: Model of a MC-CDMA transmission system with linear equalization

Brüninghaus-1997 at 190.

Both demands, i.e. minimal mean square error in frequency-selective fading channels and low dynamic range of the signal envelope, can also be met for the downlink if an FFT matrix is used as spreading matrix. In this case spreading and IFFT-processing cancel each other, see Fig. 3, and the transmission system degenerates into a single-carrier system, as depicted in Fig. 4. The main advantage of this step is that at this stage all knowledge about dynamic reduction of single carrier systems with linear modulation can be applied to create a time signal with low dynamic range.

Brüninghaus-1997 at 189.

The special choice of a FFT matrix as spreading matrix for Multi-Carrier CDMA leads to a single-carrier system with guard-interval. This way, the multi-carrier specific problems as high dynamic of the signal envelope, sensivity to phase noise and frequency/ clock synchronization errors can be avoided without losing the performance capacity of MC-CDMA. In case of linear equalization the receiver consists of a frequency domain equalizer with blockwise processing. Due to the guard-interval, this frequency domain equalizer outperforms the comparable time domain equalizer considerably and shows even in frequency-selective radio channels a

relatively good performance. Besides, the compuation complexity of such a receiver structure with blockwise processing in the frequency domain is lower than with processing in the time domain in case of highly dispersive channels.

Brüninghaus-1997 at 193.

Sorger-1997, which discloses:

The first $L_\Delta Q$ chips $c_l^{(i)}$, $l = 0, \ldots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by

$$T_\Delta = L_\Delta \cdot Q \cdot T_c, \tag{7}$$

where L_Δ has to be chosen to meet the condition of Eq. (2). The transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user dependent phase vector $s^{(i)}$ of dimension L_c having components

$$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \ldots, L_c - 1. \tag{8}$$

The user dependent phase $\Phi^{(i)}$ is chosen to be

$$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \tag{9}$$

The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures the user discrimination by assigning to each user i a different set of orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as

$$x^{(i)} = \left[c_0^{(i)}, c_1^{(i)} e^{-j\Phi^{(i)}}, c_2^{(i)} e^{-j2\Phi^{(i)}}, \ldots, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \tag{10}$$

Sorger-1997 at 113.

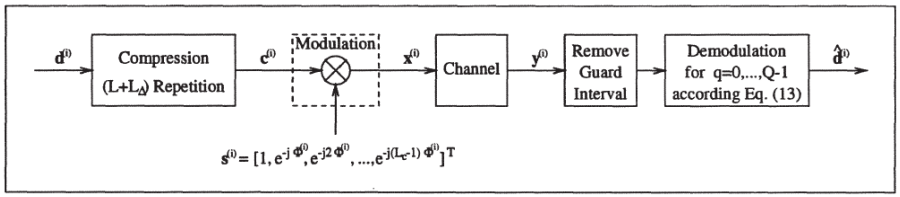


Figure 1: Block diagram of the proposed IFDMA system

Sorger-1997 at Fig. 1.

Brüninghaus-1998, which discloses:

> The combination of orthogonal frequency division multiplexing (OFDM) and code division multiplexing (CDM) has found great interest during the last few years. In contrast to a conventional OFDM system the information is spread over several subcarriers using orthogonal codes which leads to a diversity gain in frequency-selective channels. In this paper it is shown that such a system is technically equivalent to a single-carrier system with guard interval if the columns of a Fourier matrix are used as spreading codes. The pros and cons of such a system compared to an OFDM-CDM system with abritrary spreading matrix are described and discussed.

Brüninghaus-1998 at 2329.

> In the last years, multi-carrier transmission and especially OFDM (orthogonal frequency division multiplexing) have received much attention due to its ability of transmitting high data rates even in highly time dispersive radio channels with reasonable equalization effort. These systems are characterized by parallel data transmission over a number of generally narrowband subchannels. Recently, a combination of multi-carrier transmission and code division multiplexing (CDM) was proposed to improve the performance of multi-carrier systems [1], [2]. In this case every data symbol is spread over several subcarriers prior to subcarrier modulation and despread in the receiver, which is in fact a kind of

	frequency diversity. The same effect can be achieved with channel coding but it was shown in [3] that at least at code rates above 1/2 the combination of spreading and coding performs better than coding only. Brüninghaus-1998 at 2329. In the literature, Walsh-Hadamard codes are generally used as spreading codes but in principle every other orthogonal code matrix can be applied. In this paper we will focus on the special case that the Fourier matrix is used as orthogonal code matrix. Since the multi-carrier transmission signal is generated by an inverse Fourier-transform (IFFT), both operations - spreading and IFFT - cancel each other resulting in a pure single-carrier system with blockwise processing. This fact was already mentioned in [4] but without noticing that this kind of processing combines the advantages of single-carrier transmission, like constant signal envelope, simple clock and frequency synchronization, with the advantages of OFDM-CDM like high performance in frequency-selective channels. In the following sections, a brief review of OFDM-CDM is given, followed by a detailed discussion of the resultant transmission technique and its advantages. Brüninghaus-1998 at 2329. With OFDM-CDM the complex data symbols $x_i, \quad 1, \dots, M$, which can be elements of any arbitrary symbol set, e.g. PSK or QAM, are spread over N subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation $$s = [H] \cdot x \qquad (1)$$ where $x = (x_1, \dots, x_M)^T$ is the vector of data symbols, $s = (s_1, \dots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix of dimension$N \times M \quad (M \leq N)$. Apart from spreading, the transmitter is identical to a conventional OFDM transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard interval is

added) and D/A converted, see Fig. 1. In the receiver, the inverse processing is performed, see Fig. 2.

Brüninghaus-1998 at 2329.

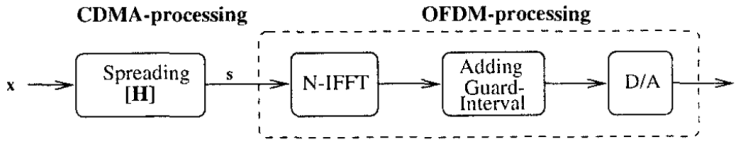


Fig. 1. Block diagram of a multi-carrier CDM transmitter

Brüninghaus-1998 at 2329.

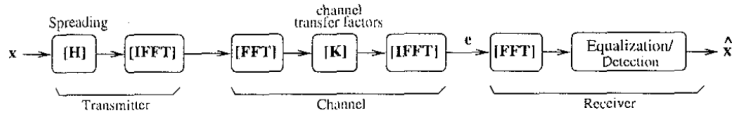


Fig. 3. Model of a multi-carrier CDM system

Brüninghaus-1998 at 2330.

The performance of the overall transmission system does not depend on the specific type of the orthogonal spreading matrix as long as every element of the matrix has the same magnitude which means that the energy is uniformly spread over all subcarriers [10]. Considering the case that all available orthogonal codes are used, i.e. the spreading matrix is a square matrix of dimension *N* x *N*, the matrix of the Fast Fourier transform meets the above mentioned demands as well as the often proposed Walsh-Hadamard matrix. If such an FFT-matrix is used spreading and OFDM processing cancel each and the transmission system degenerates into a linearly modulated single-carrier system with guard interval, i.e

$$s(t) = \sum_n x_n \cdot p(t - nT) \quad \text{where} \quad x_n = x_{n-N} \quad \text{if} \quad i(N + N_G) - N_G \leq n < i(N + N_G) \quad i \in Z \quad (2)$$

In Eq. (2), the parameter N_G describes the length of the guard interval in number of data symbols spaced by the symbol duration *T*.

Brüninghaus-1998 at 2330.

A. Dynamic of the signal envelope

It is well known that the envelope of an OFDM signal has a high dynamic which requires a linear power amplifier in the transmitter. A lot of studies have been performed with the aim to reduce the signal dynamic of multi-carrier systems but all methods known from literature [11] - [13] have certain drawbacks. These drawbacks are either high computation complexity, large memory requirements or signal distortions. At least in the case of absolute modulation (no differential encoding) these disadvantages can be overcome if the Fourier-matrix is used for spreading. Since the multi-carrier CDM system is thereby transformed into a single-carrier system with linear modulation the amplitude dynamic only depends on the pulse shape *p(t)*. In connection with second generation mobile systems this topic has been analyzed extensively and solutions are very well known: in case of binary transmission for example, MSK (minimum shift keying), which uses a sinusoidal pulse, can be applied leading to a constant envelope signal. Quaternary transmission can be realized with low amplitude dynamic using Offset-QPSK.

Brüninghaus-1998 at 2330.

Since the single-carrier system which results from an OFDM-CDM system with Fourier spreading matrix is a special case of an OFDM-CDM system, the same detection algorithms can be applied and the same performance can be expected.

	Brüninghaus-1998 at 2330. A general block diagram of an OFDM-CDM receiver with linear equalization [8] is depicted in Fig. 4. In case of a Fourier spreading matrix, despreading in the receiver is achieved by an inverse Fast-Fourier matrix, i.e. $[H]^H = [IFFT]$. The overall processing corresponds to a frequency domain equalization (FDE) since the received signal vector is first Fourier-transformed, multiplied by a diagonal equalization matrix and then transformed back into the time domain. Such an FDE was originally proposed in [17] to speed up the convergence of the equalizer coefficients in conjunction with the stochastic gradient method. In [18] the FDE was picked up again to compare single-carrier and multi-carrier (OFDM) transmission but without noticing that the considered single-carrier system is a special case of an OFDM-CDM system. Recently, the FDE was discussed for use in future mobile communication systems in combination with antenna diversity [20]. Brüninghaus-1998 at 2330. In contrast to a conventional single-carrier system, the single-carrier system resulting from OFDM-CDM with Fourier spreading matrix is characterized by a guard interval and the question arises why it should be advantageous to waste some part of the bandwidth. There are two reasons: the first one is the higher performance at the same number of equalizer coefficients in case of linear or decision feedback equalization. This results from the fact that the periodic extension of the data sequence in the transmitter in connection with the signal windowing the receiver leads to a cyclic convolution of the data sequence and the discrete-time channel impulse response. If the corresponding discrete-time channel transfer function contains no zeros, this cyclic convolution can be perfectly inverted in the receiver requiring not more than *N*(=length of data sequence) coefficients. To achieve the same effect with a conventional single-carrier system, generally an equalizer with an infinite number of taps is required,

	which cannot be implemented in a real system. Thus, an equalization error occurs, which limits the performance at high signal-to-noise-ratios. Brüninghaus-1998 at 2330-31. System parameters: • General - Bandwidth B = 2MHz - linear equalization based on MMSE criterion • OFDM-CDM with Fourier spreading matrix - blocklength: $T_N = 32\mu s$ - Guardlength: $T_G = 6.6\mu s$ - Number of symbols per block: $N = 64$ • Single-carrier system without guard interval - pulse with raised cosine spectral characteristic and rolloff' factor $\beta = 0.2$ - Symbol length: Ts = 600ns • Channel parameters: - Exponentially decreasing power delay profile from 0 to $5\mu s$ - Rayleigh channel - time invariant Brüninghaus-1998 at 2331. The special choice of an FFT matrix as spreading matrix for OFDM-CDM leads to a single-carrier system with guard interval. Such a single-carrier system has the same performance as the OFDM-CDM system but is less sensitive to nonlinear effects due to the reduced dynamic of the signal amplitude. In case of linear equalization, a single-carrier system with

guard-interval yields the same (low S/N) or even a better (high S/N) performance than the corresponding system without guard interval at the same number of equalizer coefficients and data rate. Besides, in highly time dispersive channels the computation complexity of such a receiver structure with blockwise processing is considerably lower than with continuous processing.

Brüninghaus-1998 at 2332.

Sorger-1998, which discloses:

The dimension of the IFDMA-symbol $c^{(i)}$ is $L_c = (L + L_\Delta)Q$ and the components $c_l^{(i)}$ can be written as

$$c_l^{(i)} = \frac{1}{L + L_\Delta} \cdot d_{l \bmod Q}^{(i)}, \quad l = 0, \dots, L_c - 1. \tag{6}$$

The first $L_\Delta Q$ chips $c_l^{(i)}, l = 0, \dots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by

$$T_\Delta = L_\Delta \cdot Q \cdot T_c. \tag{7}$$

where L_Δ has to be chosen to meet the condition of Equation (2). Finally, the transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user-dependent phase vector $s^{(i)}$ of dimension L_c having components

$$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \dots, L_c - 1. \tag{8}$$

The user-dependent phase $\Phi^{(i)}$ is chosen to be

$$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \tag{9}$$

The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures an orthogonal user discrimination by assigning to each user *i* a different set of

orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as

$$x^{(i)} = \left[c_0^{(i)},\, c_1^{(i)} e^{-j\Phi^{(i)}},\, c_2^{(i)} e^{-j2\Phi^{(i)}},\, \ldots,\, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \qquad (10)$$

Sorger-1998 at 1014.

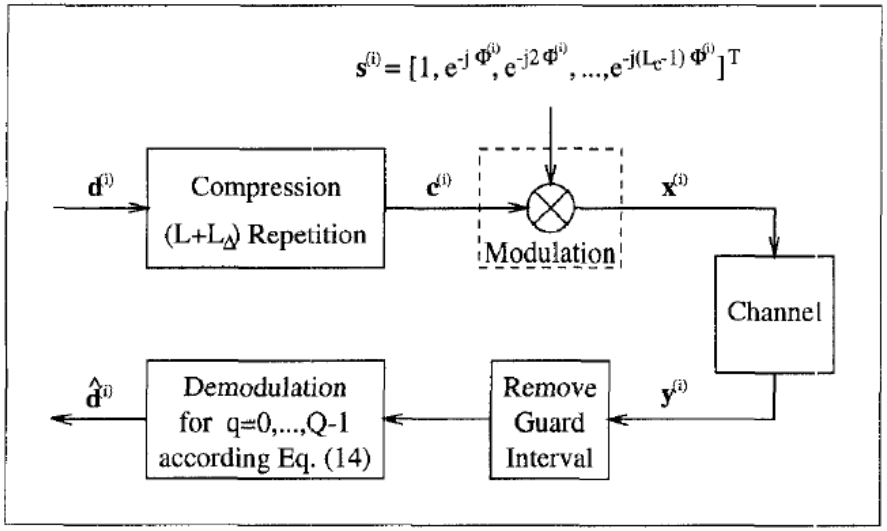


Figure 2: Block diagram of the proposed IFDMA system for a single user i

Sorger-1998 at Fig. 2.

Bury-1999, which discloses:

> We present a generalization and an extension of the block decision feedback equalizer described by Reinhardt in [1]. The original equalizer was derived for a class of transmission which is described by an orthogonal spreading over a group of non-interfering fading channels. We generalize

	this concept for block transmissions with arbitrary interference; the generalized description also includes reception with multiple antennas using joint diversity combining and equalization. In extension, we introduce soft feedback for all individual symbols, in contrast to the single soft value used in [1], offering an improved performance. We describe the proposed equalization method, provide examples for application, and illustrate the performance by simulation results. Bury-1999 at 345. In many practical cases it is convenient to transmit data in blocks which can be processed independently. Examples for block transmission methods are MC-CDM(A) on the basis of OFDM [3], Interleaved FDMA as described in [2], or serial transmission with termination to assure that there is no interference between blocks [4]. If there is interference within a block, the optimum detector performs a highly complex search of the most probable combination of transmit symbols. A less complex method is to employ equalization together with single symbol detection. Linear equalization allows simple implementation. The proposed decision feedback equalizer offers an improvement over linear equalization - however, at the cost of some complexity increase. Bury-1999 at 345-346. 6. SPREAD TRANSMISSION We now consider the special case of transmission over a set of interference free fading channels, where orthogonal symbol spreading is used to achieve a diversity gain. Figure 4 shows a model for this type of transmission.

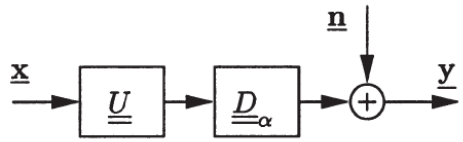


Figure 4 Transmission over non-interfering channels with orthogonal spreading

In this figure, $\underline{\underline{U}}$ is an orthogonal matrix for spreading, $\underline{\underline{D}}_\alpha$ is a diagonal matrix with the channel amplitudes on the main diagonal and zeros elsewhere, and we assume white noise with $\underline{\underline{\Phi}}_{nn} = \sigma_n^2 \cdot \underline{\underline{I}}$. The orthogonal spreading matrix has the property $\underline{\underline{U}}^H = \underline{\underline{U}}^{-1} = \underline{\underline{U}}$. For the cases of a Hadamard transform or a Fourier transform, multiplication with $\underline{\underline{U}}$ may be implemented as a fast algorithm (Fast Fourier Transform, FFT; Fast Hadamard Transform, FHT). By inserting $H = \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}}$ into equations (3), (4) and (5), we find

$$\underline{\underline{A}}_{\text{opt}}^{(0)} = \underline{\underline{U}}^H \cdot \underline{\underline{D}}_{\tilde{\alpha}} \quad \text{with} \quad \tilde{\alpha}_i = \frac{\alpha_i^*}{|\alpha_i|^2 + \frac{\sigma_n^2}{\sigma_x^2}} \tag{8}$$

$$\underline{\underline{A}}_{\text{opt}}^{(r)} = \underline{\underline{D}}_p^{(r)} \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)}, \tag{9}$$

$$\underline{\underline{B}}_{\text{opt}}^{(r)} = \underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)} - \text{diag}\left(\underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)}\right). \tag{10}$$

$$\underline{\underline{Q}}^{(r)} = \left(\underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \left(\underline{\underline{I}} - \underline{\underline{D}}_{|\varrho|^2}^{(r)}\right) \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H + \frac{\sigma_n^2}{\sigma_x^2} \cdot \underline{\underline{I}}\right)^{-1},$$

$$\frac{1}{p_i^{(r)}} = 1 + \underline{u}_i{}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{u}_i \cdot \left|\varrho_i^{(r)}\right|^2.$$

For the special case where for arbitrary i and fixed *r* the feedback values $\varrho_i^{(r)}$ are all identical, computation of the filter coefficients can be further

simplified, such that no matrix inversion is required; this has been derived in [1].

Bury-1999 at 350-51.

This model of spread transmission is applicable to, e.g., the following transmission schemes:

MC-SSMA (Multi-Carrier Spread Spectrum Multiple Access) as described in [3] uses a Hadamard transform to spread a vector of transmit symbols over a set of OFDM subchannels; each OFDM subchannel may be considered as a single Rayleigh fading channel. OFDM-CDMA is another name for essentially the same method.

IFDMA (Interleaved Frequency Division Multiple Access) as introduced in [2] can be described as an OFDM transmission where Fourier spreading is used to transmit over sets of equally spaced OFDM subchannels.

Serial block transmission over a multipath channel, using cyclic extension of transmitted blocks and corresponding extraction at the receiver, may be considered as an OFDM transmission with Fourier spreading over all subchannels. The equalizer can be implemented in the frequency domain by assuming a Fourier matrix for spreading. A linear equalizer for frequency domain equalization (FDE) has been presented in [4].

Bury-1999 at 351.

Bury-2000, which discloses:

Abstract - In this paper we investigate amplitude distributions of transmit signals for multi-carrier spread spectrum (MC-SS) transmission methods based on orthogonal frequency division multiplexing (OFDM), also called multi-carrier code division multiplexing (MC-CDM). In particular we compare Fourier spreading with the commonly used Walsh-Hadamard spreading. As a basis for the comparison we describe a general model. Both up- and downlink of multiple access transmission schemes employing

	either multi-carrier code division multiple access (MC-CDMA) or multi-carrier frequency division multiple access (MC-FDMA) are compared. Bury-2000 at 857. Multi-carrier code division multiplexing (MC-CDM) [1] is an interesting candidate for the physical layer in wireless high data rate local area networks. When compared to orthogonal frequency division multiplexing (OFDM), the additional spreading of MC-CDM produces a signal space diversity which improves power efficiency especially for high code rates [2]. A Hadamard transform is used for spreading in most MC-CDM system descriptions, e.g. [1]. However, further choices for orthogonal spreading are possible. With Fourier spreading [3], which can be implemented by a discrete Fourier transform (DFT) operation, it is clear that it can cancel the inverse discrete Fourier transform (IDFT) of an OFDM transmitter when spreading is done over all subcarriers, such that the result is a simple serial block transmission with cyclic extension [4]. This serial transmission can be regarded as a spread spectrum transmission, since the entire transmission bandwidth is covered by each transmitted symbol. The peak-to-average power ratio (PAPR) of a serial transmission is much lower than that of an OFDM transmission. The question that arises is: how is the situation when spreading is done not over all OFDM subcarriers but only over groups of carriers? Bury-2000 at 857. In [5] Golay complementary sequences have been used instead of Hadamard sequences for reducing the PAPR in MC-CDMA transmission, and a scrambling scheme was employed to further improve the amplitude distribution of the transmit signal. In this paper we suggest to employ a DFT for spreading, which can be implemented efficiently as a fast Fourier transform (FFT). Furthermore we extend our considerations to MC-FDMA, as introduced in [6] (named MC-SS-MA there).

Bury-2000 at 857.

> Subsequently we describe a model of a MC-CDM transmitter. In a multiple access context, this model is valid for both, MC-CDMA and MC-FDMA. We describe the methods used for computation of the amplitude distribution and the PAPR of the transmit signal. It is shown that, given the transmit symbol alphabet and the corresponding symbol probabilities, both amplitude distribution and PAPR are uniquely determined by a single matrix which describes the transmitters linear mapping from transmitted symbols to the transmit signal. Based on simulation results, we discuss the suitability of Hadamard and Fourier spreading for MC-CDM transmission methods.

Bury-2000 at 857.

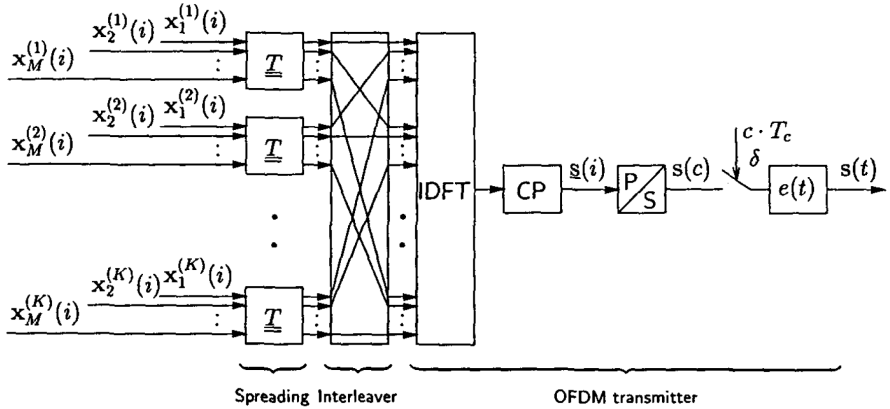


Fig. 1. Model of transmitter for OFDM-based MC-CDM.

Bury-2000 at 858.

> The model in Fig. 1 depicts a transmitter for MC-CDM based on OFDM. An OFDM transmitter is extended by an additional spreading, described by

	the transform matrices $\underline{\underline{T}}$, and by an interleaver. The OFDM transmitter consists of an IDFT, a cyclic prefix insertion CP, a parallel-to-serial conversion, and the conversion to continuous-time using an ideal Dirac sampler and a basic waveform $e(t)$, which is a Nyquist impulse. The delivered baseband transmit signal is $s(t)$. The number of OFDM subcarriers is N, the cyclic prefix has length L, transmit signal samples are indexed by c, and the Dirac sampler generates an impulse every T_c seconds. Bury-2000 at 857. Spreading is done by transforming a vector of M symbols through a matrix $\underline{\underline{T}}$. This square matrix is orthogonal, such that the condition $$\underline{\underline{T}}^H \underline{\underline{T}} = \underline{\underline{I}} \quad (1)$$ is fulfilled. Furthermore, to assure equal energy distribution, we consider only spreading matrices with the property that the absolute value of all matrix elements is constant $$\left|t_{i,k}\right| = \frac{1}{\sqrt{\underline{\underline{N}}}} \quad \forall\, i,k. \quad (2)$$ In literature usually a Hadamard transform is selected for $\underline{\underline{T}}$; however, further choices are possible, e.g. a DFT. Bury-2000 at 857-58. III. AMPLITUDE DISTRIBUTION OF THE TRANSMIT SIGNAL For a certain time instant t_0 the complex baseband transmit signal $s(t_0)$ is a random variable which is in general a linear combination of all random transmit symbols

$$s(t_0) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{K} \sum_{m=1}^{M} \alpha_{m,k,i}(t_0) x_m^{(k)}(i)\,. \qquad (3)$$

The coefficients $\alpha_{m,k,i}(t_0)$ are derived from $\underline{\underline{T}}$, $e(t)$, N, L, K, and M, as described subsequently. When the duration of the basic waveform $e(t)$ is finite, the infinite sum over i in this equation can be replaced by a finite sum. Then the probability density function (PDF) of the transmit signal at time $t_0, f_{s(t_0)}(x)$, is obtained from the PDFs of all contributing transmit symbols.

Bury-2000 at 858.

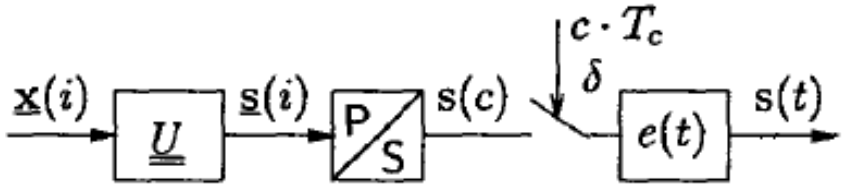


Fig. 2. Equivalent transmitter model.

Bury-2000 at 859.

Discrete-time computation

At discrete time we consider the signal $s(c)$ instead of $s(t)$. To obtain a simple description we join the spreading, interleaving, IDFT and cyclic extension of the transmitter in Fig. 1 into a single matrix $\underline{\underline{U}}$, see Fig. 2.

. . .

	The discrete-time transmit signal of a single OFDM block ($i = 0$) then represents the cyclo-stationary statistics of the transmit signal. We omit the block index i and write $$\underline{s} = \underline{\underline{U}} \cdot \underline{x}, \quad (6)$$ with vector elements $x_{(m+M(k-1))} = x_m^{(k)}(0)$ and $s_c = s(c)$. In equivalence to equation (3) we write $$s_c = \sum_{n=1}^{N} u_{c,n} x_n \,. \quad (7)$$ Hence, the PDF at a particular time instant c is related with a certain row in $\underline{\underline{U}}$. Bury-2000 at 859. From above equations we see that, given the transmit symbol alphabet and corresponding occurrence probabilities, the PDF of the discrete-time transmit signal, $f_{s(c)}(x)$, is determined by the transform matrix $\underline{\underline{U}}$. For the case of Fourier spreading, the matrix $\underline{\underline{U}}$ contains in most cases more zero elements than for Hadamard spreading. This already indicates a better amplitude distribution for Fourier spreading, because fewer random variables are summed. Bury-2000 at 859.

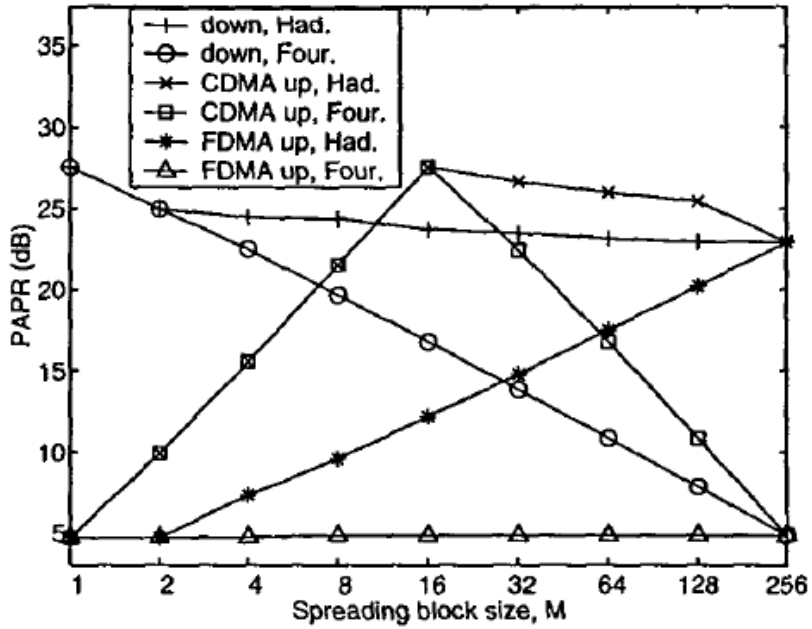


Fig. 3. PAPR as a function of the spreading block size. 4PSK, $N = 256$, $L = 32$, 'continuous' time.

Bury-2000 at 859.

Downlink

In the downlink, the PAPR is the same for both MC-CDMA and MC-FDMA. This is obvious because both systems are identical except for the assignment of transmitted symbols to users. For the trivial case of spreading over a single carrier and for the case of spreading over two carriers, both Hadamard and Fourier spreading deliver the same PAPR. In the latter case this happens because Hadamard and Fourier matrices are identical for spreading over two symbols. In the case of Hadamard spreading, when spreading is done over an increasing number of

	subcarriers, the PAPR remains nearly constant (with a slight decrease); for Fourier spreading, however, it decreases rapidly and reaches the PAPR of a single carrier transmission when spreading is done over all subcarriers. This means that for the downlink Fourier spreading clearly outperforms Hadamard spreading. The larger the spreading factor, the better the PAPR. Furthermore, assuming that a large number of users is desired, we consider the following: Since MC-FDMA requires (at least) one spreading block per user, the spreading blocks must be small in case of many users, resulting in a relatively large PAPR. For MC-CDMA, however, the larger the spreading block, the larger the possible number of users. Here the best choice with respect to PAPR is to use Fourier spreading over all carriers while assigning groups of input symbols for each user, resulting in the lowest possible PAPR. Bury-2000 at 859-60. Uplink In the uplink we distinguish between MC-CDMA and MC-FDMA. For MC-CDMA the PAPR of both Fourier and Hadamard spreading shows a strong increase for increasing spreading factors, reaching a maximum when the spreading factor equals the square root of the number of subcarriers. When the spreading factor is increased further, Hadamard spreading shows a slight decrease in PAPR while Fourier spreading shows a rapid decrease, reaching the PAPR of a serial transmission when spreading is done over all carriers. In contrast to MC-CDMA, MC-FDMA shows a much better behavior, with the PAPR being lower for the entire range of spreading factors, for the respective spreading methods. For Hadamard spreading, the PAPR increases for increasing spreading factors. For Fourier spreading, however, the PAPR remains nearly constant at a low level for all spreading factors. This shows that also in the uplink Fourier spreading outperforms Hadamard spreading in most cases. For the case of Fourier spreading in a

MC-FDMA uplink, the spreading factor may be selected arbitrarily, nearly without affecting the PAPR.

Bury-2000 at 860.

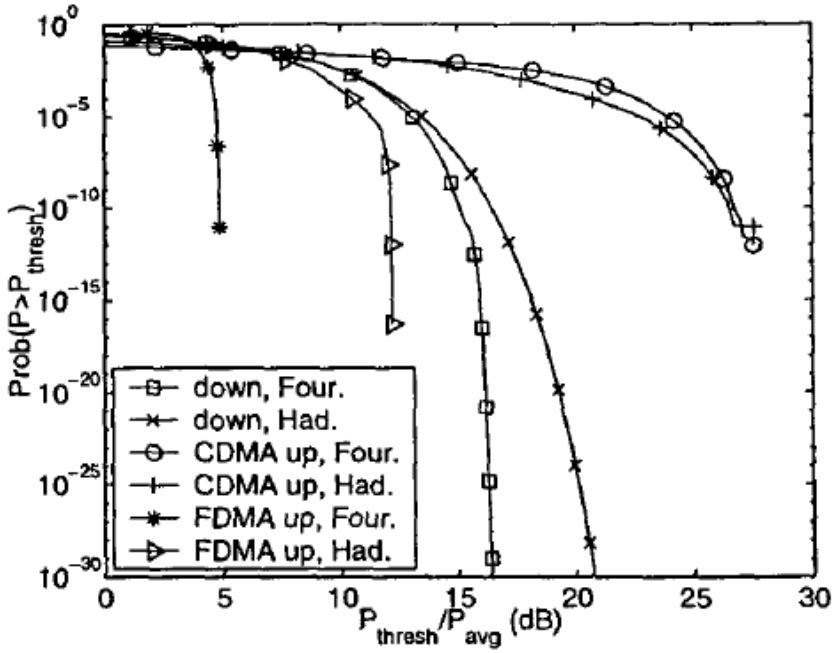
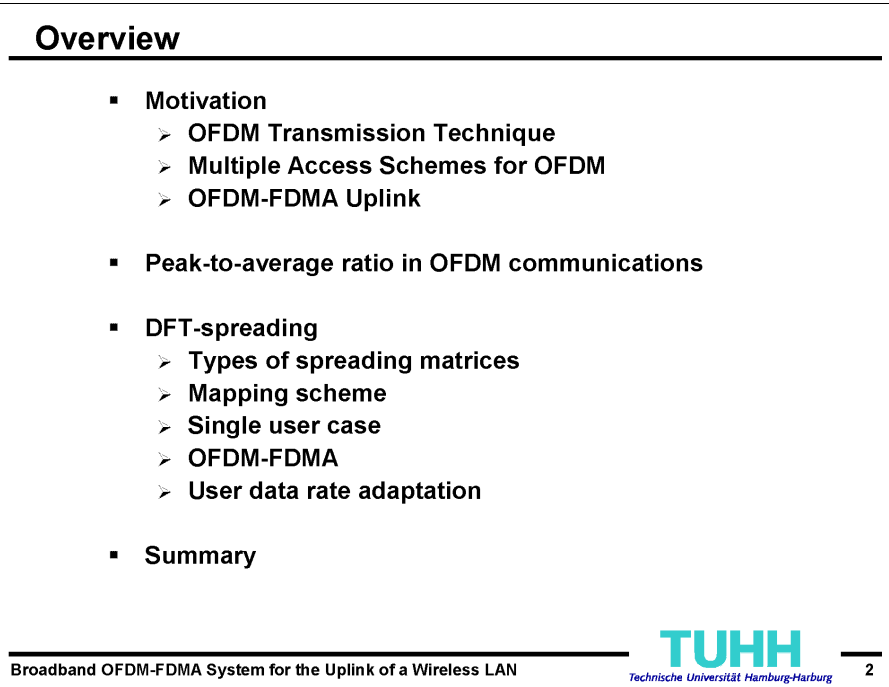


Fig. 4. Example for amplitude distribution.
4PSK, $N = 256$, $L = 32$, $M = 16$, 'continuous' time.

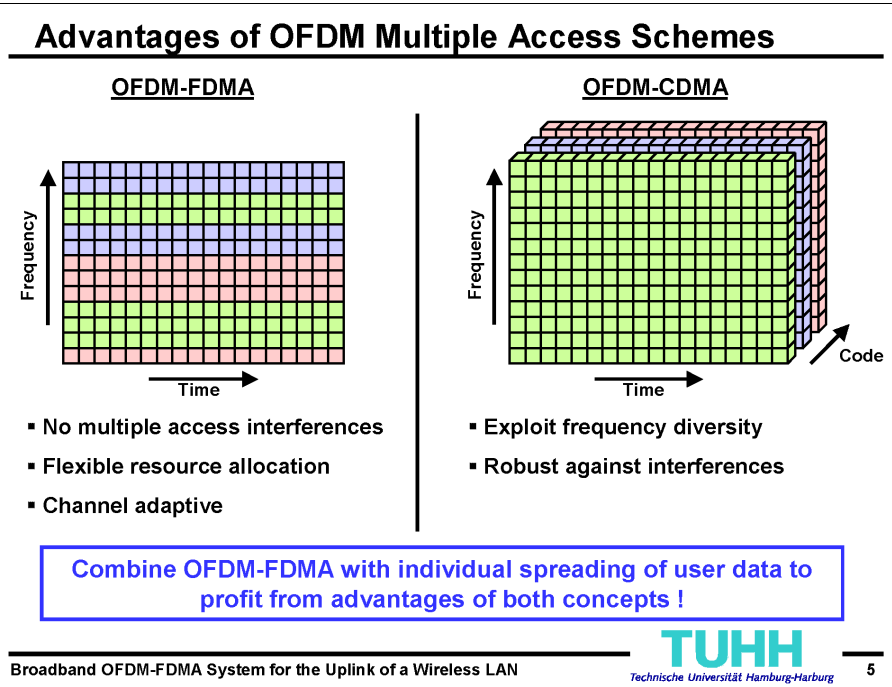
Bury-2000 at 860.

The graph shows that, in case of the downlink, Fourier spreading offers a more sharply limited amplitude distribution while Hadamard spreading produces continuously growing amplitudes at decreasing probabilities. Not only from the PAPR point of view, but also from the PDF of the amplitude

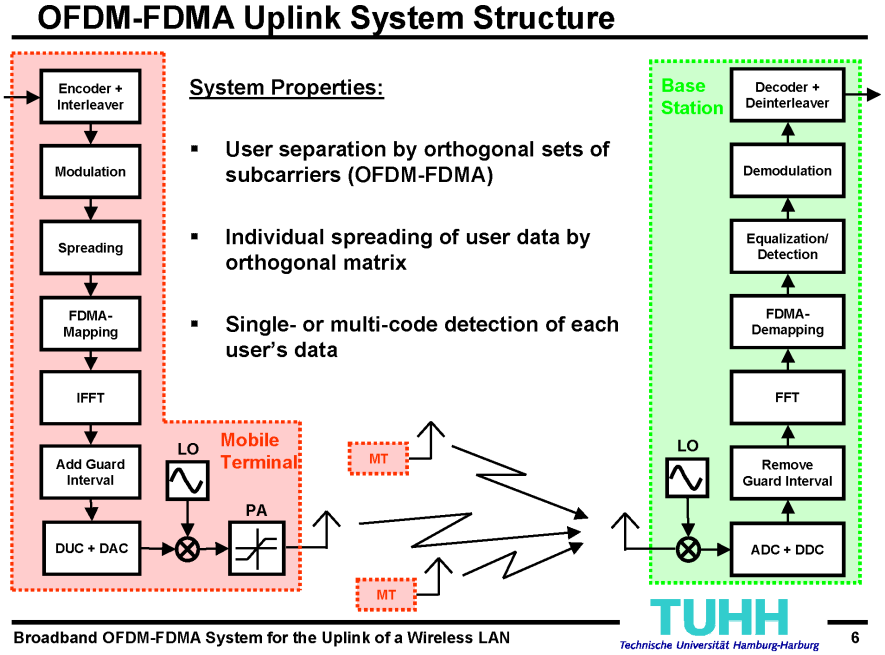
	it is clear that Fourier spreading is a better choice than Hadamard spreading. Bury-2000 at 860. Amplitude distributions of Hadamard spreading and Fourier spreading have been compared for OFDM based MC-CDM transmission methods, using a general matrix model. Comparison has been done for both up- and downlink in MC-CDMA and MC-FDMA multiple access scenarios, and for various spreading factors. For both up- and downlink Fourier spreading delivers a lower or equal PAPR. This superiority increases significantly for larger spreading factors. In the uplink, MC-FDMA delivers lower PAPRs than MC-CDMA. From the amplitude distribution point of view, the best choice is to employ Fourier spreading with MC-CDMA in the downlink and with MC-FDMA in the uplink. Bury-2000 at 860. Galda-2001, which discloses:



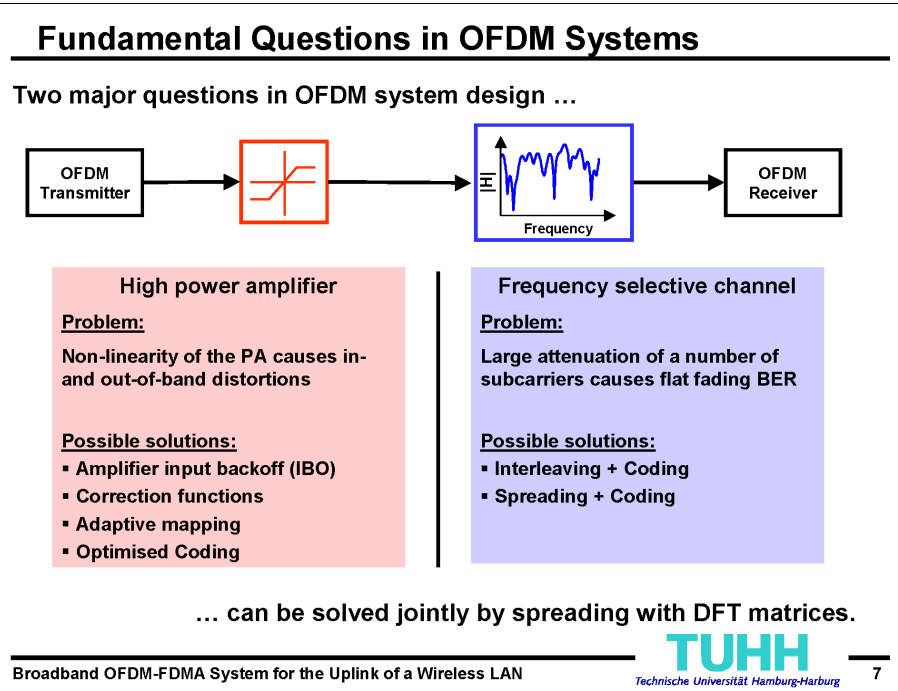
Galda-2001 at 2.



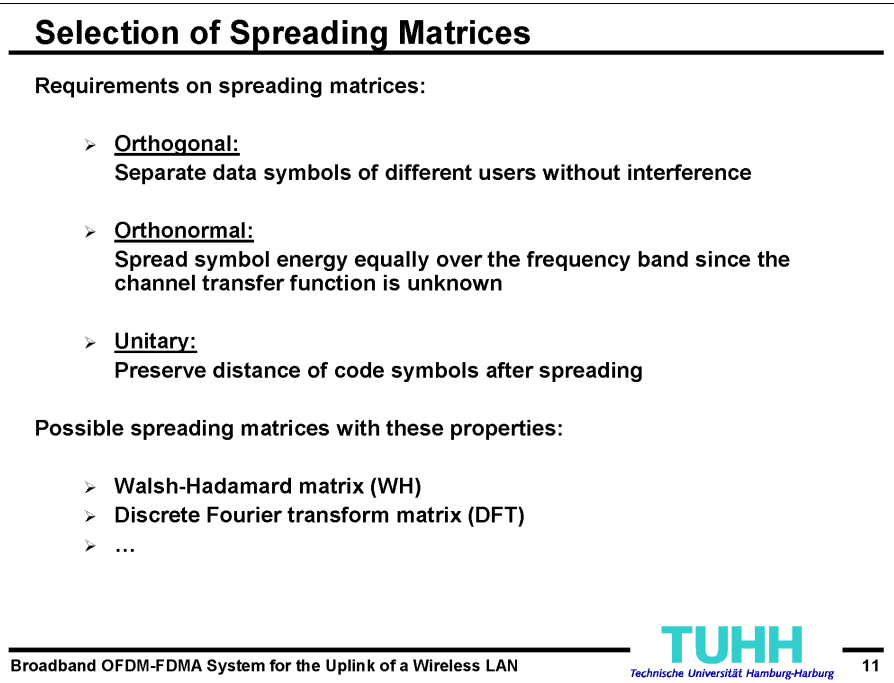
Galda-2001 at 5.



Galda-2001 at 6.



Galda-2001 at 7.



Selection of Spreading Matrices

Requirements on spreading matrices:

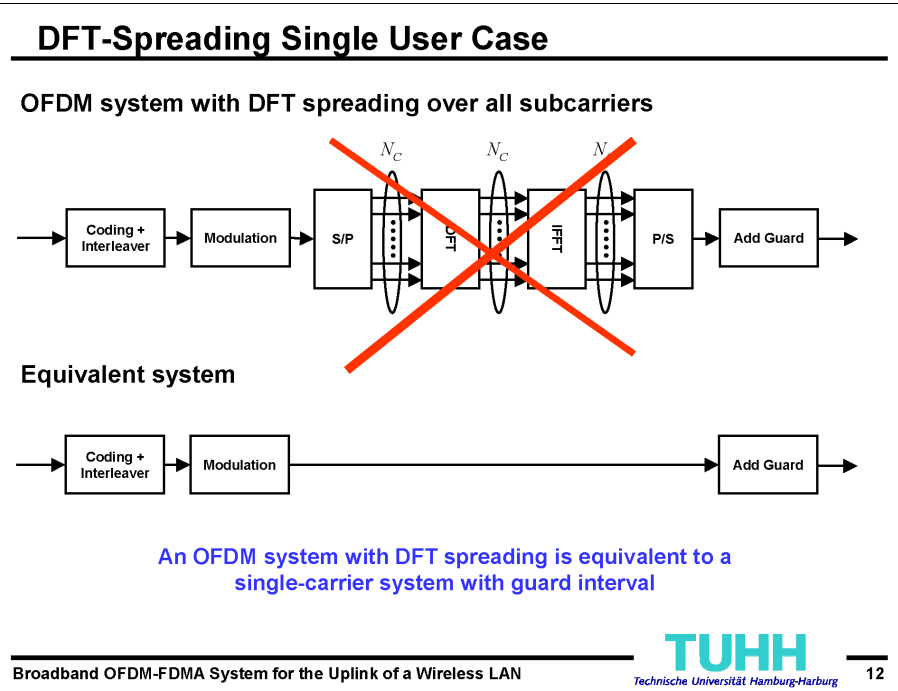
- Orthogonal:
  Separate data symbols of different users without interference
- Orthonormal:
  Spread symbol energy equally over the frequency band since the channel transfer function is unknown
- Unitary:
  Preserve distance of code symbols after spreading

Possible spreading matrices with these properties:

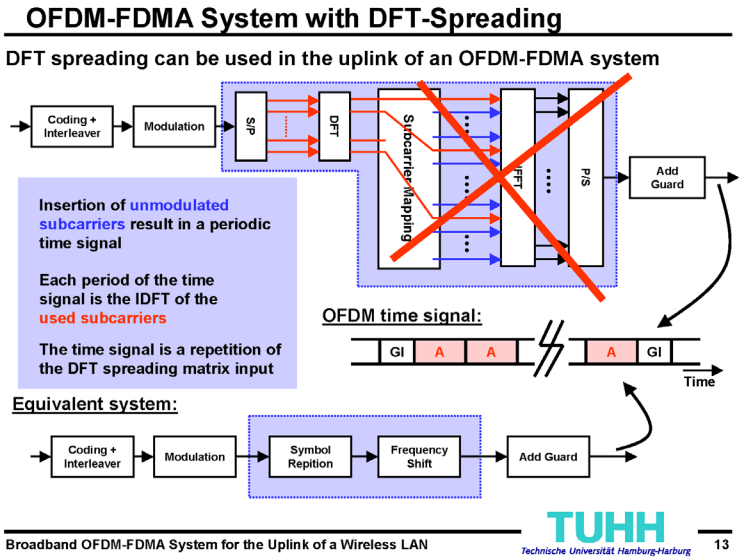
- Walsh-Hadamard matrix (WH)
- Discrete Fourier transform matrix (DFT)
- ...

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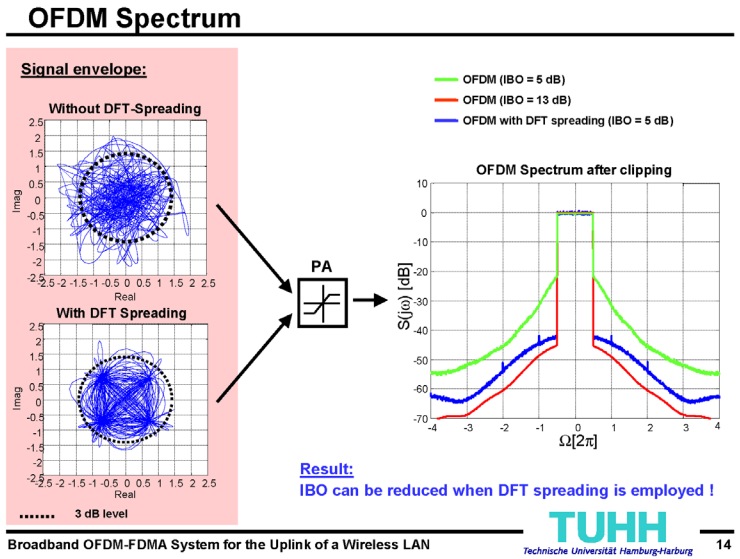
Galda-2001 at 11.



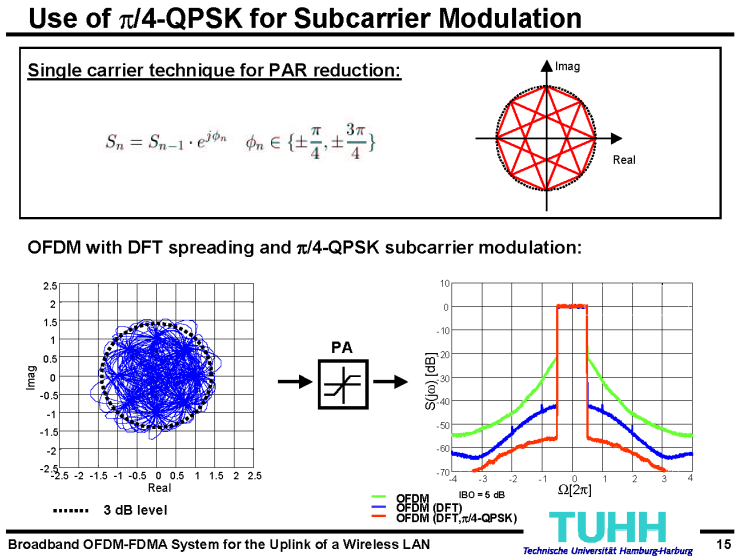
Galda-2001 at 12.



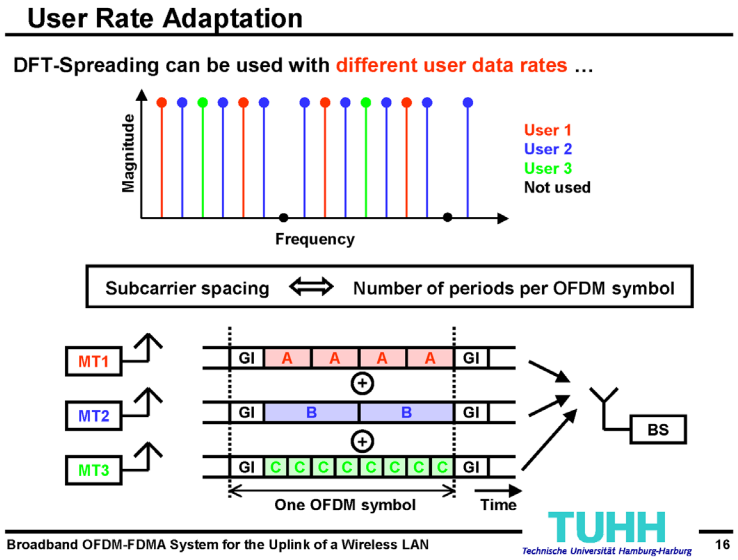
Galda-2001 at 13.



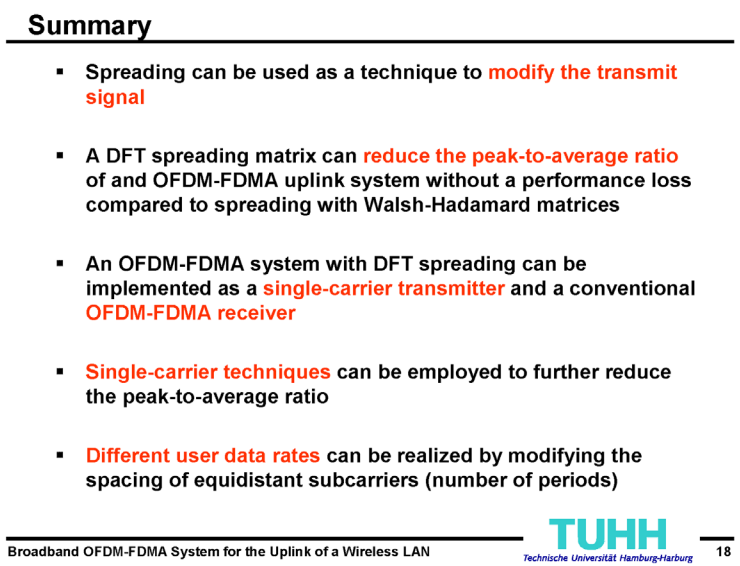
Galda-2001 at 14.



Galda-2001 at 15.



Galda-2001 at 16.



Galda-2001 at 18.

Galda-2002, which discloses:

> Abstract- The orthogonal frequency division multiplex (OFDM) transmission technique can efficiently deal with the effects of multi-path propagation in the broadband radio channel. It also has a high system inherent flexibility for designing a multiple access scheme by combining the conventional TDMA, FDMA and CDMA approaches with the OFDM modulation scheme. The FDMA multiple access scheme is especially interesting for an uplink of a communication system since it can completely avoid any multiple access interferences (MAI). Moreover, the peak-to-average ratio (PAR) of the uplink OFDM transmit signal can be greatly reduced if this OFDM-FDMA multiple access scheme is additionally combined with a data spreading technique based on a Discrete Fourier

	Transform (DFT) spreading matrix using only the user specific subcarriers. Since the DFT spreading operation and the IDFT operation used as a part of the OFDM modulation scheme cancel out each other the complexity of the transmitter structure for an OFDM-FDMA uplink can be greatly reduced. Galda-2002 at 1737. The subdivision of the transmission bandwidth into a set of orthogonal subcarriers can additionally be exploited by an OFDM-FDMA multiple access scheme. By allocating distinct sets of subcarriers to different users the available bandwidth can be flexibly shared between different mobile terminals while avoiding any multiple access interferences (MAI) between different users. The FDMA multiple access scheme offers not only a high flexibility for the radio resource management (RRM) but can also increase the bandwidth efficiency of the complete system by avoiding the use of highly attenuated subcarriers for specific users based on the knowledge of the channel transfer function [2]. Moreover, the OFDM-FDMA multiple access scheme can be adapted to the measured radio channel knowledge at the transmitter site using bit-loading techniques. If channel state information is not available the performance can be increased using an additional spreading over the subcarriers assigned to one user. The resulting computation complexity of the total system can by this means be adopted to the given system requirements which is especially of importance for the mobile terminal and in the uplink case. The alternative OFDM-FDMA multiple access scheme is therefore of importance for the uplink case and can be advantageous over OFDM-CDMA schemes because of its ability to avoid MAI if ideal carrier synchronization is assumed for all mobile terminals and the base station. Galda-2002 at 1737. Since the OFDM transmit signal results from the superposition of a large number of independent data symbols the envelope of the complex baseband

	time signal has in general a large peak-to-average ratio (PAR). The largest output power value of the amplifier will limit the maximum amplitude of the signal in the transmitter. Therefore, non-linear distortions due to clipping and amplification effects in the transmit signal will lead to both in-band and out-of-band emissions. In the past different techniques for reducing the PAR by changing the transmit signal independently from knowledge of other parts of the OFDM transmitter have been developed. But the PAR of the transmit signal envelope which employs an OFDM-FDMA multiple access scheme can significantly be reduced if additional spreading techniques are applied which spread the user data over the allocated subcarrier only. In this case an appropriate spreading technique must be designed reducing the PAR to a minimum value. It will be shown in this paper that using the Discrete Fourier Transform (DFT) matrix as an orthogonal spreading technique will reduce the PAR significantely [3]. Furthermore, the DFT based spreading operation and the IDFT based OFDM modulation technique cancel out each other which means that the transmitter structure can be simplified to a single carrier transmitter with an additional guard interval in this specific case which helps to reduce the computational complexity of the transmitter of the mobile terminal. Galda-2002 at 1737-38. This paper shows how an OFDM-FDMA uplink system can be combined with a user data spreading technique based on the DFT spreading matrix to reduce the PAR of the uplink signal without increasing the computational complexity of the transmitter. In Section II the structure of the analyzed OFDM-FDMA system combined with a DFT spreading matrix is described for the uplink application. In Section III the influence of a DFT matrix applied for data spreading is analyzed for an OFDM-TDMA multiple access scheme and is extended to an OFDM-FDMA system in a separate subsection. The general topic of non-linearities in an OFDM system is reviewed in Section IV. Quantitative results are given in Section V and Section VI summarizes the papers content.

Galda-2002 at 1738.

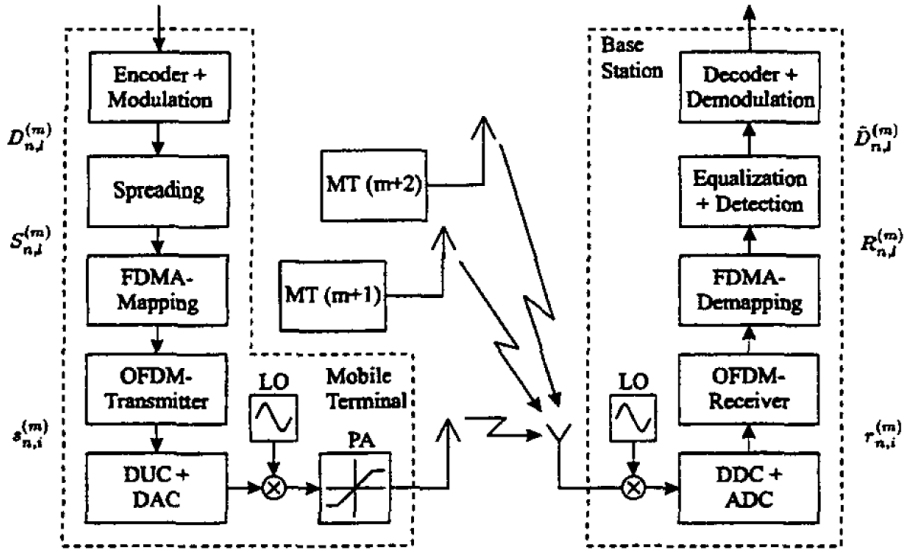


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

Galda-2002 at Fig. 1.

The baseband system model of an OFDM-FDMA uplink with individual spreading of user data is shown in Fig. 1. In this case M different users are considered and each user allocates L different subcarrier exclusively. The total number of subcarrier in the considered transmission system is $N_C = L \cdot M$. The input data stream for each mobile user $m, m = 0, \dots, M-1$, is convolutionally encoded in a first step. The bit sequence is then mapped onto L complex modulation symbols $D_l^{(m)}, l = 0, \dots, L-1$, of a coherent, higher-level modulation scheme. The L modulation symbols are spread over the L user specifically allocated subcarrier with an unitary spreading

matrix $[C]$ resulting in L complex transmit symbols $S_l^{(m)}$. The spreading operation can be denoted mathematically by the following simple matrix multiplication

$$\vec{S}^{(m)} = [C]\vec{D}^{(m)} \quad (1)$$

where each complex transmit symbol $S_l^{(m)}$ is calculated by the sum of L user modulation symbols $D_l^{(m)}$ weighted by L orthogonal code vectors $\widetilde{C_l} = \left(C_{l,0}, C_{l,1}, \dots, C_{l,l}\right)$ with $l = 0, \dots, L-1$

$$S_l^{(m)} = \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} \quad \text{for} \quad l = 0, \dots, L-1 \quad (2)$$

The transmit symbols $S_l(m)$ are then mapped onto L of the available N_C subcarrier which are exclusively allocated to user m. In principle, the set of subcarrier assigned to each user can be composed of any L out of N_C subcarrier that have not been assigned to another user.

Galda-2002 at 1738.

Independent of the considered spreading matrix C but assuming the equidistant allocation of subcarrier over the entire bandwidth the resulting OFDM time signal of user m can analytically be described as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \quad (3)$$

where N_G denotes the length of the guard interval which is inserted into the transmit time signal.

Galda-2002 at 1738.

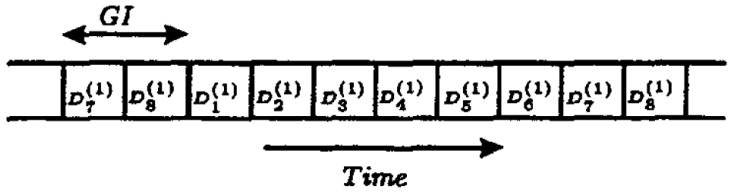


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

Galda-2002 at Fig. 3.

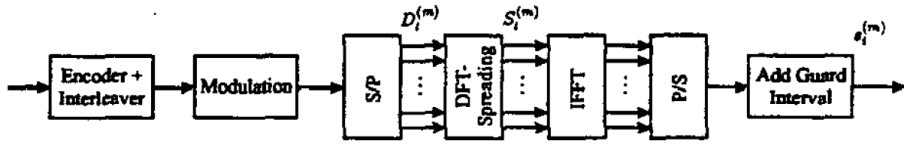
A. OFDM-TDMA with DFT Spreading

In [3] the Discrete Fourier Transformation (DFT) matrix has been used for spreading the vector $\vec{D}$ of length $L = N_C$ over all subcarriers of an OFDM system. If a single user is assumed in this OFDM system the spreading operation includes all subcarrier within the entire bandwidth. In this case the DFT spreading matrix and the IDFT operation in the OFDM modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore technically reduced to the serial sequence of complex transmit data symbols D_i to which a guard interval is added in the time domain as a cyclic prefix

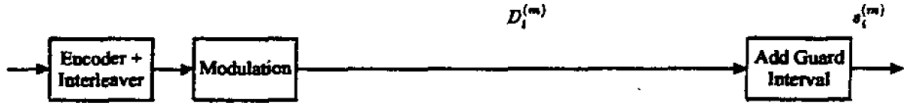
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \tag{5}$$

where mod denotes the modulo operation, as shown in Fig. 3.

Galda-2002 at 1739.



(a) OFDM transmitter including DFT spreading over all subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 4. In an OFDM system including a DFT spreading matrix and an IFFT for the OFDM modulation process both matrices cancel out each other.

Galda-2002 at Fig. 4.

> After calculating the FFT in the receiver which splits the received time signal into the orthogonal sub-channel the same single- or multi-code detection techniques can be applied which are well known from OFDM-CDMA receiver structures. The same bit error rate (BER) performance compared to a system using a Walsh-Hadamard spreading matrix can therefore be achieved if a DFT spreading matrix is considered instead. But in case of a DFT spreading matrix the resulting PAR is significantly reduced. The general structure of an OFDM transmitter including DFT spreading is shown in Fig. 4.

Galda-2002 at 1739.

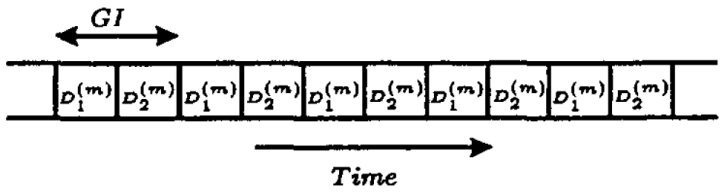


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

Galda-2002 at Fig. 5.

B. OFDM-FDMA with DFT Spreading

The advantage of a DFT spreading matrix can also be exploited in the uplink of an OFDM-FDMA system. If the user data is spread only over $L < N_C$ subcarriers then the DFT of length L used for spreading does not directly cancel out with the length N_C IDFT of the OFDM modulator in general. Only when the spreaded symbols $S_l^{(m)}$ are mapped onto equidistant located subcarriers with a spacing of $N_C/L = M$ the DFT spreading and the OFDM modulation can be removed in the transmitter structure. This can be seen by inserting Equation (2) into Equation (3) using the elements of the discrete Fourier matrix

$$C_{i,j} = \frac{1}{\sqrt{L}} \cdot e^{j2\pi ij/L} \qquad (6)$$

the transmit signal of user m can be written as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L}$$

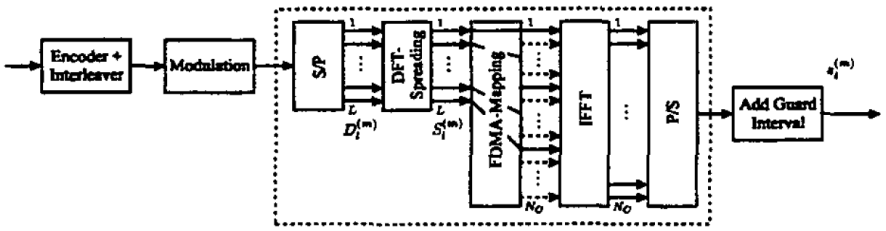
$$= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)}$$

$$= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu - i)$$

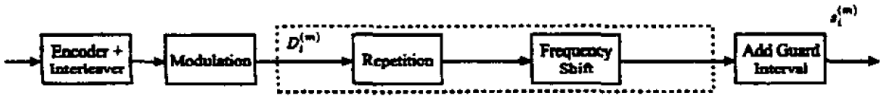
$$s_i^{(m)} = e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \quad (7)$$

for $i = -N_G, \ldots, 0, \ldots, N_C$ and the periodic dirac pulse sequence $\delta_L(\ \ )$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ sequence including an added guard interval as cyclic prefix, shown in Fig. 5. This periodic data sequence is multiplied by a user specific complex signal $e^{j2\pi im/N_C}$ due to the user individual frequency shift by m subcarriers of the complete allocated subcarrier set. The number of periods inside a single OFDM symbol is equal to the spacing M of the subcarriers allocated to user m.

Galda-2002 at 1739-40.



(a) OFDM-FDMA transmitter with DFT spreading over equidistant subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 6. In an OFDM-FDMA uplink system including DFT spreading matrix applied to a set of equidistant subcarriers the DFT spreading matrix and the OFDM IFFT transformation cancel out each other.

Galda-2002 at Fig. 6.

The structure of the OFDM transmitter can be simplified by this approach since both the DFT spreading operation and the IFFT calculation of the conventional OFDM transmitter cancel out and can be removed in the technical realization completely and will be replaced by a simple repetition process of the considered user data $D_l^{(m)}$. The simplified transmitter structure is depicted in Fig. 6. Any equidistant subcarrier allocation can be used with the proposed FDMA scheme since it only influences the number of periods of the transmit signal. Therefore the user data rate can be flexibly adjusted by assigning the required number of subcarriers to each user.

	Galda-2002 at 1740. In order to avoid non-linear distortions even in the case of a highly linear power amplifier a sufficient input-backoff (IBO) of the transmit signal to the amplifier has to be used. Even though the clipping probability of the OFDM signal can be reduced or even be avoided for an IBO larger than the PAR a system with large energy efficiency loss results. Alternatively, the effects which a non-linear device can have on the transmit power spectrum can be influenced by a reduction of the OFDM transmit signal PAR Different techniques have been developed which reduce the PAR of the OFDM signal by the means of a modified channel coding [5], an additive [6] or multiplicative [7] correction function or a selective mapping of modulation symbols to subcarriers [8]. A majority of these techniques has a high computational complexity due to the fact that they analyze the generated transmit signal and modify it either in the frequency or time domain to reduce its peak amplitudes. For a system employing coherent subcarrier modulation the PAR can also be reduced if the data symbols are spread by a Fourier matrix in frequency direction [3]. Galda-2002 at 1740. In this paper an OFDM-FDMA system concept for the uplink of a multi user communication system has been studied. It had be shown that if an OFDM-FDMA system with equidistant subcarrier allocation is combined with a user specific spreading using an discrete Fourier transform as a spreading matrix the transmitter structure can be greatly simplified without any performance degradation. Moreover, the peak-to-average ratio of the transmit signal is reduced to the PAR of the subcarrier modulation scheme which can limit the out-of-band and in-band emissions when the transmit signal is passed through a non-linear device. With the opportunity to independently adjust the user data rates the proposed technique offers an interesting alternative for reducing the complexity of the mobile terminal in the broadband radio uplink.

	Galda-2002 at 1741. Costa-193, which discloses: > The invention relates to a method and a communication system device for the generation of OFDM symbols, wherein data from one or more users or from one or more data sources (User 1–User M) are represented on a number of sub-carriers (Nc). According to the invention, in order to inhibit multiple-access interference (MAI) on application of the CDMA principle, the data are transformed in a data-source specific manner and only subsequently allocated to the sub-carriers, independently of the transformation. Costa-193 at abstract. > According to an alternative procedure, the user data can be spread over a specified number of sub-carriers and/or OFDM symbols by using orthogonal codes with the aid of an orthogonal matrix, as is the case with OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). In the OFDM-CDMA process, the data of all users is allocated to all available frequencies, wherein codes are used for separation. Without further measures, undesirable multiple access interferences occur in this case, in particular when considering a plurality of users or data sources whose data is received in parallel with one another. Costa-193 at 1:18-24. > To avoid this problem, the user data is thus spread over a plurality of sub-carriers only when sub-carriers are allocated to a plurality of users at the same time, which is referred to as OFDM-FDMA, with user-specific spreading of the reference data. Spreading and allocation of sub-carriers takes place in a common and comprehensive method step. So-called Walsh-Hadamard matrices of different sizes are mainly used for the spread, as described for example by M. Yee, J.-P. Linnartz: "Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading

	Channel," Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: "Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications," Kluwer Academic Publisher, 1996. Depending on the data rate required for transmission, different users are allocated a number between 1 and N of orthogonal codes, wherein N is the number of available sub-carriers. Costa-193 at 2:1-9. Furthermore, in K. Bruninghaus, H. Rohling: "Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission," Proc. IEEE VTC'98, Ottawa, Canada, 1998, a spread using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of the peak values to the average values (PAR: Peak-to-Average Ratios) is generally discussed, although multiple accesses are not considered. Costa-193 at 2:10-13. Advantageously, due to the data source-specific, i.e., exclusive, allocation of sub-carriers to the respective users or user data, to which the transformation result of an orthogonal transformation matrix or spread is transmitted, the undesirable multiple access interferences can be avoided, ideally completely, despite the application of the transformation. Advantageously, the choice of the orthogonal matrix is initially arbitrary. Furthermore, the transformation result can also be allocated to the exclusive sub-carriers of a user or a data source in any way. The separation of the spread of the user-specific data or data source-specific data and the allocation of the transformed or spread data to the sub-carriers of one or more OFDM symbols is particularly advantageous when a discrete Fourier transform (DFT) or fast Fourier transform (FFT) is used for the spread instead of, for example, the Walsh-Hadamard transform.

	In particular in combination with an equidistant arrangement of the sub-carriers on the carrier, in particular on the frequency axis, for the various user data or data sources, an OFDM-FDMA system then results in which the time signal or the OFDM symbols have a constant amplitude behind the usual inverse fast Fourier Transform (IFFT). This is a very significant advantage, because the various smoothing processes, which would currently have to be used, become unnecessary. Costa-193 at 3:1-13. In particular when combining a Fourier transform and an inverse Fourier transform, in a particularly preferred embodiment, a simplified generation of the OFDM symbols can also be carried out, because corresponding process steps can be omitted during their generation. In effect, the two successive Fourier transforms can cancel each other out, with the exception of, in particular, a frequency shift. Correspondingly, according to the invention, when communicating between, for example, a mobile user station and a base station in the uplink direction, it is possible to distribute/combine the incoming data from the individual data sources directly onto the corresponding OFDM symbol positions, if necessary after the usual encoding, interleaving, and modulation. This advantageously simplifies the structure of the transmitting communication station. The base station can expediently remain unchanged and continue to have the structure of an OFDM receiver, in order to be able to utilize the OFDM-specific advantages such as simple equalization of the received signal and separation of the user station data or users. Costa-193 at 4:1-10. FIG. [1] a scheme for a general multiple access, wherein the structure of an OFDM-FDMA system having user-specific spread of the data symbols is shown;

Costa-193 at 5:3-4.

> FIG. [2] schematically, a possible implementation of an OFDM-FDMA system having a particularly preferred FFT spread matrix and allocation of the user data to equidistant sub-carriers;

Costa-193 at 5:5-6.

> FIG. [3] schematically, an allocation of spread user data to equidistant sub-carriers, and

Costa-193 at 5:7.

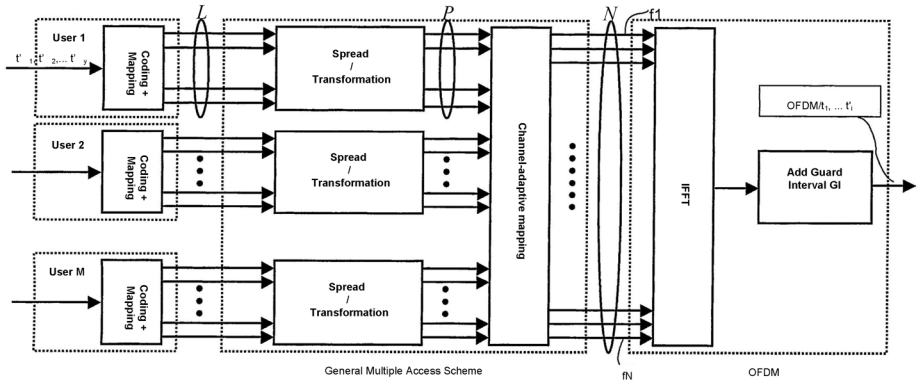


FIG. [1]

Costa-193 at Fig. 1.

> The following block shows the actual transformation or spread and the encoding of the data from different users onto the individual frequency sub-carriers.
>
> The data arriving on L data paths for each user is spread in a first step, i.e., distributed from a total of L data values onto P data values. This preferably serves to utilize the statistically independent propagation of the signals on

	different sub-carriers (frequency diversity). In the preferred exemplary embodiments, the number of individual data values or lines is not changed, although this is also possible, so that there are L complex data values per user before and after the spread. Analogous to the spread of the data with Walsh-Hadamard matrices as in OFDM-CDMA, L corresponds to the number of codes allocated to the user station and P to the number of available orthogonal code symbols. In this case, the spread corresponds to a full-load system. Costa-193 at 6:1-9. When describing the structure of the OFDM-FDMA system with the user-specific spread of the data symbols above, a conscious distinction is made between, on the one hand, spread/transformation and, on the other hand, mapping onto the sub-carriers. Costa-193 at 7:6-8. This separation is carried out in order to be able to transform or spread the data of the individual users, initially with the aid of an orthogonal matrix. In the subsequent step, the transformation result is then transferred onto sub-carriers, wherein sub-carriers are exclusively allocated to each of the individual users. In principle, the sub-carriers can be allocated in any way, wherein systems are preferred in which the first sub-carriers are allocated to the first user and the last sub-carriers to the last user. However, this is not absolutely necessary and is in particular undesirable in the case of a channel-adapted allocation, for example. However, systems in which the data of a user are mapped or transmitted onto sub-carriers that are distributed equidistantly across the frequency band are particularly preferred. Costa-193 at 7:9-15.

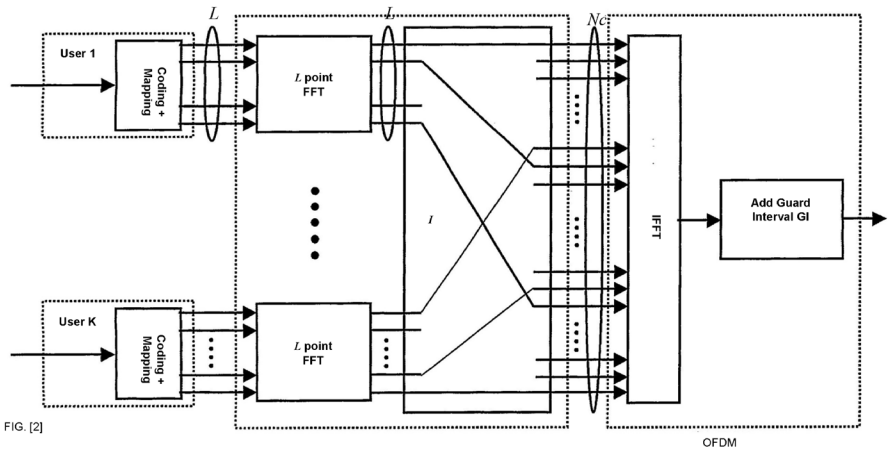


FIG. [2]

Costa-193 at Fig. 2.

> In principle, the selection of the orthogonal matrix is arbitrary. The Walsh-Hadamard transform, which is known per se, or especially a Fourier transform, in particular a discrete or fast Fourier transform, are preferred.
>
> The use of a fast Fourier transform FFT as a preferred form of transformation or spreading as well as the subsequent transfer to individual sub-carriers can be seen from FIG. [2], in an exemplary embodiment. The Fourier transforms FFT are carried out on a user-specific basis, i.e., the incoming data symbols of a user are fed in each case to their own Fourier transform.
>
> The data resulting from the individual user-specific Fourier transforms are then distributed to the individual frequency sub-carriers f1 ... fN, wherein the data of a user is preferably transmitted to sub-carriers that are not directly adjacent to one another. In principle, however, this distribution to the individual sub-carriers can take place in any manner.

Costa-193 at 8:7-15.

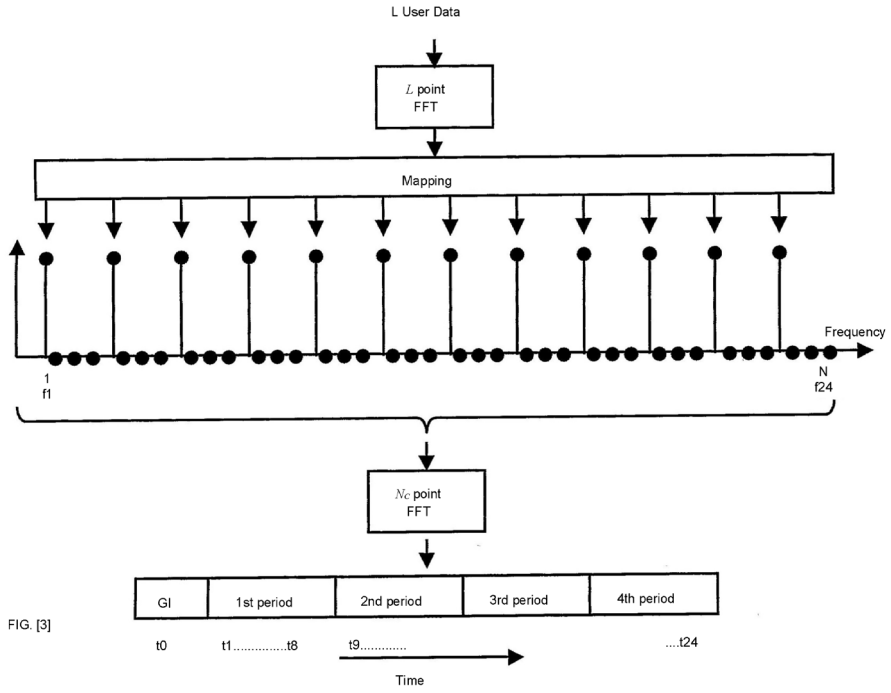
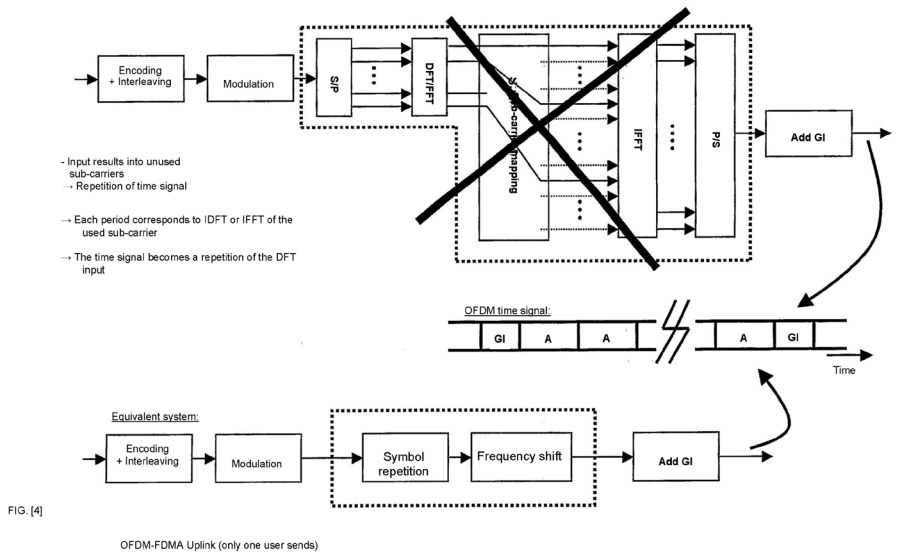


FIG. [3]

Costa-193 at Fig. 3.

> As can be seen from FIG. [3], a particularly preferred distribution of the individual data of the user-specific Fourier transforms takes place on an equidistant sequence of sub-carriers over the frequency axis. In the exemplary embodiment shown, L user data or data symbols having L data values of a user are introduced into the L-valued Fourier transform (L point FFT). According to the preferred exemplary embodiment, although not absolutely necessary, the Fourier transform in turn generates L data values which are mapped onto the N sub-carriers.

Costa-193 at 9:1-5.



Costa-193 at Fig. 4.

> Generalizing this with simple numbers, with a data symbol length L of the incoming user data and a mapping to L-valued transformation results, it requires a mapping to the sub-carriers f1...fN, wherein N sub-carriers are available. After the inverse Fourier transform, the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values are distributed equidistantly over N/L data periods, wherein the data periods can also be referred to as data blocks or data sections.

Costa-193 at 10:1-5.

> The particular advantage of combining a spread matrix formed by a Fourier transform FFT in combination with the equidistant distribution on the frequency axis is that, after the inverse Fourier transform, the result is a time signal having a constant amplitude in the uplink and a time signal having a peak value that is significantly reduced compared to a traditional

	OFDM system in the downlink. This constant amplitude results because the peak-to-average ratio (PAR) is significantly lower than other OFDM symbol generation methods. It corresponds precisely to the PAR of the modulation symbols before the transformation. If a PSK modulation were used here, then PAR=1. Costa-193 at 10:6-11. According to a further developed embodiment, if a Fourier transform is considered as a spread matrix and a subsequent inverse Fourier transform is considered for transmitting the individual frequency sub-carriers to a temporal data sequence, it can be determined that the two Fourier transforms then cancel each other out, purely theoretically, in terms of their effect. As a consequence, a particularly preferred embodiment for generating OFDM symbols can be implemented, as is shown in FIG. [4] for example for a transmission in the uplink from a user station to a network-side station, when only a single user transmits, wherein the transformations then cancel each other out. Due to the effect-cancelling transformation sequence of a Fourier transform FFT and after distribution to the individual sub-carriers f1...fN of an inverse Fourier transform IFFT, this block can be omitted during the implementation, or it can be replaced by repeating the symbol sequence according to the number of allocated, now fictitious, sub-carriers and subsequent frequency shift in the distribution of the input data onto the output data. Costa-193 at 11:1-10. 3. The method according to claim 1 or 2, in which, during the distribution of the input data onto the output data, the inputting of the data into the OFDM symbol is carried out by a repetition of the symbol sequence according to the number of allocated sub-carriers and a subsequent frequency shift.

	Costa-193, claim 3. 5. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using an orthogonal matrix. Costa-193, claim 5. 6. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using a Fourier transform (FFT). Costa-193, claim 6. Costa-782, which discloses: In accordance with an alternate procedure, by using orthogonal codes with the aid of an orthogonal matrix, the user data can be spread over a specified number of subcarriers and/or OFDM symbols, as with the methods known under OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). With the OFDM-CDMA method the data of all users is assigned to all available frequencies, in which case codes are used for separation. Without further measures, undesired multiple access interferences occur in this case and especially when considering a number of users or data sources for which the data enters in parallel. Costa-782 at 0005. To avoid this problem the user data is thus only spread over a number of subcarriers for simultaneous assignment of subcarriers to a number of users, which is referred to as OFDM-FDMA with user-specific spreading of payload data. Spreading and assignment of subcarriers is undertaken here in a common and comprehensive procedure step. What are known as Walsh-Hadamard Matrices of different sizes are predominantly used for spreading, as known for example from M. Yee, J.-P. Linnartz: Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading Channel,

	Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications, Kluwer Academic Publisher, 1996. In such systems different users, depending on the data rate required, are assigned a number between 1 and N of the orthogonal codes, with N being the number of available subcarriers. Costa-782 at 0006. Furthermore K. Bruninghaus, H. Rohling: Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission, Proc. IEEE VTC'98, Ottawa, channel, 1998, contains a general discussion of spreading using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of peak values to average values (PAR: Peak-to-Average-Ratios), in which case multiple accesses are not taken into account however. Costa-782 at 0007. The separation of spreading of user-specific data or data source-specific data and the assignment of the transformed or spread data to the subcarriers of one or more OFDM symbols is especially advantageous if a Discrete Fourier Transformation (DFT) or Fast Fourier Transformation (FFT) is used for the spreading instead of the Walsh-Hadamard Transformation for example. Costa-782 at 0011. Especially with the combination of a Fourier Transformation and an Inverse Fourier Transformation in an especially preferred embodiment a simplified generation of an OFDM symbol can be undertaken since the corresponding procedural steps can be omitted in its generation. The two successive Fourier Transformations can cancel each other out here in their effect except for especially one frequency shift. Correspondingly in

accordance with the invention it is possible in communication between for example a mobile user station and a base station in the uplink direction to distribute or to combine the incoming data of the individual data sources if necessary after normal encoding, interleaving and modulation directly onto the corresponding OFDM symbol positions. This advantageously simplifies the design of the sending communication station. Usefully the base can remain unchanged and continue to possess the structure of an OFDM receiver to enable it to exploit the OFDM-specific advantages such as simple equalization of the receive signal and separation of the user station data or the users.

Costa-782 at 0013.

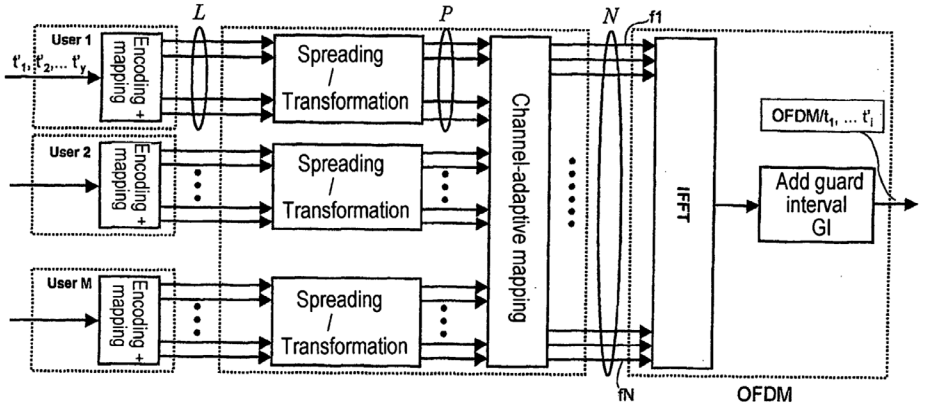


FIG 1

Costa-782 at Fig. 1.

The subsequent block shows the actual transformation or spreading and the encoding of the data of different users to the individual frequency subcarriers.

The data arriving in each case for a user on L data paths is spread in a first step, i.e. distributed from a total of L data values to P data values. This

preferably serves to exploit the statistically independent propagation of the signals on different subcarriers (frequency diversity). In the preferred exemplary embodiment the number of the individual data values or lines is not changed although this is also possible so that before and after the spreading L complex data values per user are available in each case In analogy to the spreading of the data with Walsh-Hadamard Matrices for OFDM-CDMA, L corresponds to the number of codes assigned to the user station and P the number of the available orthogonal code symbols. The spreading in this case corresponds to a full load system.

Costa-782 at 0022-23.

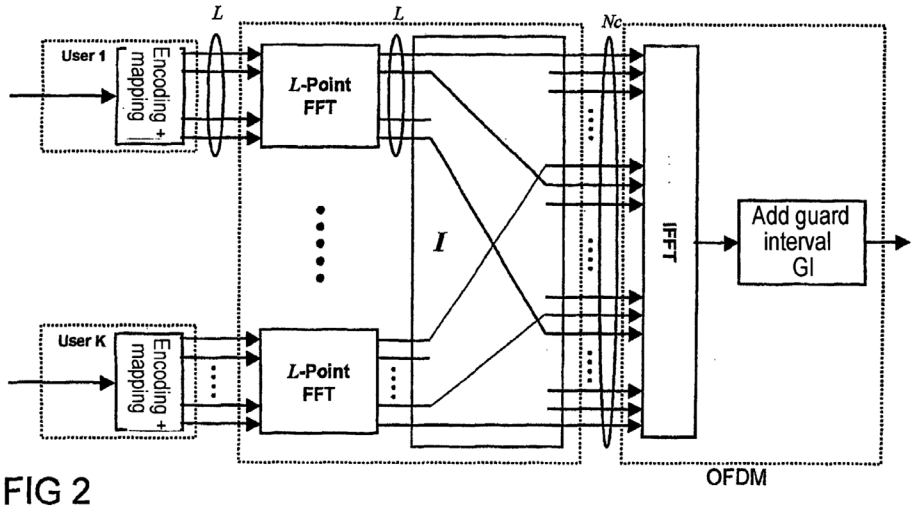


FIG 2

Costa-782 at Fig. 2.

In this case basically any orthogonal matrix can be chosen. Preferred is the Walsh-Hadamard Transformation known per se or especially a Fourier Transformation, especially a Discrete or Fast Fourier Transformation.

	The application of a Fast Fourier Transformation FFT, as preferred form of the transformation or spreading, as well as the subsequent transmission on individual subcarriers can be seen from FIG. 2 in a typical embodiment. The Fourier Transformations FFT are executed user-specifically here, i.e. the data symbols of a user arriving are fed to a separate Fourier Transformation in each case. The data produced from the individual user-specific Fourier transformations is then distributed to the individual frequency subcarriers f1 . . . fN, with the data of a user preferably not being transmitted on directly adjacent subcarriers. Purely in principle however this distribution can be undertaken in any way on the individual subcarriers. Costa-782 at 0030-32.

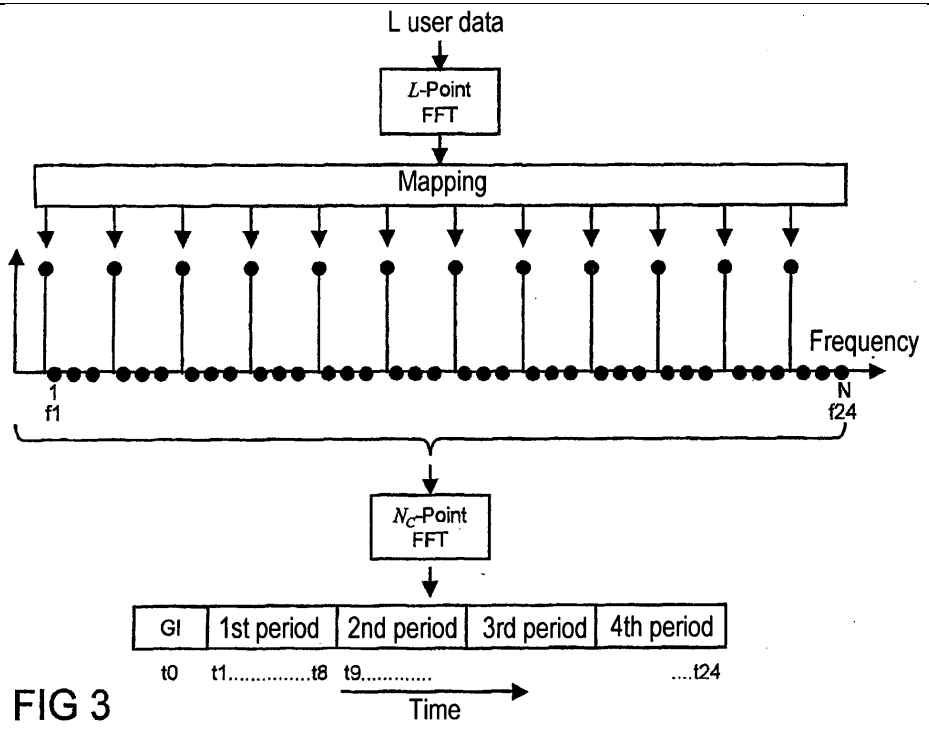


FIG 3

Costa-782 at Fig. 3.

> Put into simple generalized terms, with a data symbol length L of the user the data and a mapping to likewise L-point transformation results, this causes a mapping to subcarriers f1 . . . fN, with N subcarriers being available. After the inverse Fourier Transformation the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values here, with equidistantly distribution are distributed over N/L data periods, with the data periods also able to be referred to as data blocks or data sections.

Costa-782 at 0037.

	The particular advantage of the combination of a spread matrix formed by a Fourier Transformation FFT in combination with the equidistant distribution on the frequency axis lies in the fact that, after the inverse Fourier Transformation in the uplink a timing signal with a constant encapsulator and in the downlink a timing signal with a peak value which is much-reduced by contrast with a conventional OFDM system is produced. This constant encapsulator is produced since the peak to average value ratio (PAR) is far lower than with other generation methods for OFDM symbols. If a PSK modulation were to be used here, the PAR=1 Costa-782 at 0038. To assist understanding it is formally pointed out that a general linear transformation is involved here, that is even with the use of a Fourier Transformation to transform or spread the user-specific data no direct relationship of a frequency area to a period exists, as would be the case for normal considerations of Fourier Transformations. Costa-782 at 0039.

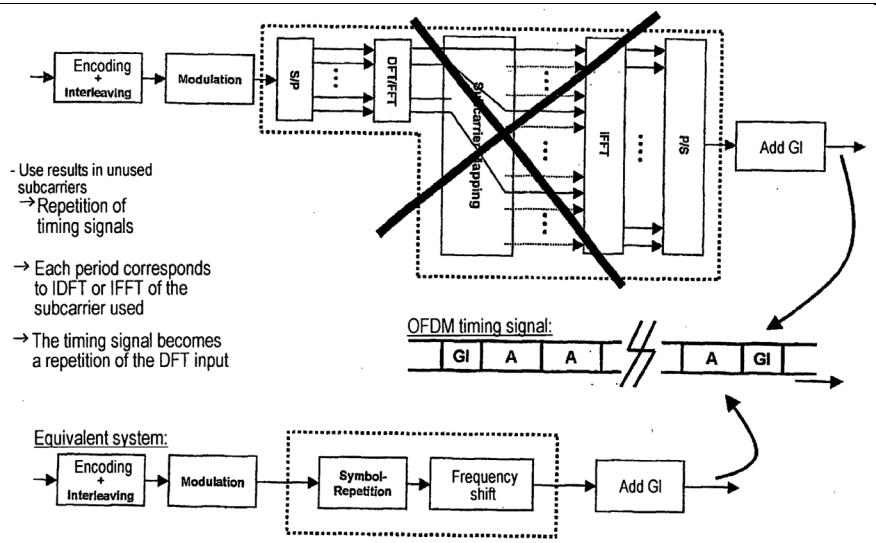


FIG 4: OFDM-FDMA Uplink (only one user sending)

Costa-782 at Fig. 4.

In accordance with a further developed embodiment, for the case of the consideration of a Fourier Transformation as spreading matrix and a subsequent Inverse Fourier Transformation to transmit the individual frequency subcarriers on a timing data sequence it can be established that purely theoretically the two Fourier Transformations cancel each other out. As a consequence a particularly preferred embodiment for generating OFDM symbols can be used, as is shown for example in FIG. 4 for example for a transmission in the uplink direction from a user station to a network-side station if only one single user is sending, in which case the transformations cancel each other out.

Through the canceling-out effect of the series of transformations of a Fourier Transformation FFT and after the distribution to the individual subcarriers f1 . . . fN of an Inverse Fourier Transformation IFFT this block can be omitted in the conversion or replaced by a repetition of the symbol

	sequence in accordance with the number of the assigned, now fictitious, subcarriers and subsequent frequency shifting for a distribution of the input data to the output data. A repeat of the timing signals is produced by the subcarriers which are not assigned to the user remaining unmodulated. Each individual period of the OFDM signal then corresponds in the final analysis to the inverse discrete Fourier Transformation of the subcarriers used. Thus, with ideal conversion and later error-free transmission over the interface the received OFDM then theoretically contains on the receiver side, behind the guard interval GI, a number of periods with the same data sequence in each case. The timing signals would thus correspond to a repeating sequence of the original inputs in the discrete Fourier Transformation which would be undertaken initially in accordance with the exemplary embodiment of FIG. 2. As can be seen from the bottom area of FIG. 4, this produces an equivalent system in which the blocks with the conversions of serial into parallel data, the subscriber-specific Fourier Transformations, the mapping or transmission on the subcarriers, the inverse Fourier Transformation and the conversion of parallel into serial data can be replaced by a series of repeating symbols and a corresponding frequency shift to be performed. Costa-782 at 0040-43. 12. A method for generating an OFDM symbol as a send signal in a communication system, comprising: mapping a complete data sequence from a data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 12.

	13. A method in accordance with claim 12, further comprising before said mapping encoding the complete data sequence from the data source to produce encoded data; and modulating the encoded data on the orthogonal subcarriers. Costa-782, claim 13. 15. A method for generating OFDM symbols for send signals in a communication system, comprising: mapping data from at least one data source to a plurality of orthogonal subcarriers, by transforming the data from the data sources; and assigning transformed data to the orthogonal subcarriers in a data source-specific manner independently of how the data is transformed. Costa-782, claim 15. 16. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by an orthogonal matrix. Costa-782, claim 16. 17. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by a Fourier Transformation. Costa-782, claim 17. 22. A communication device coupled to at least one data source, comprising: at least one interface receiving input data from the at least one data source;

	at least one of a memory device and at least one processing module temporary storing and processing, respectively, the input data from the at least one data source; and a control device controlling operation of said communication device and mapping a complete data sequence from each data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 22.
[11D] modulating the set of subcarrier values onto a set of Orthogonal Frequency Division Multiplexing (OFDM) subcarriers assigned for use by the user device, to produce a plurality of modulated subcarriers; and	StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality: For example, Kaiser-1998 discloses:

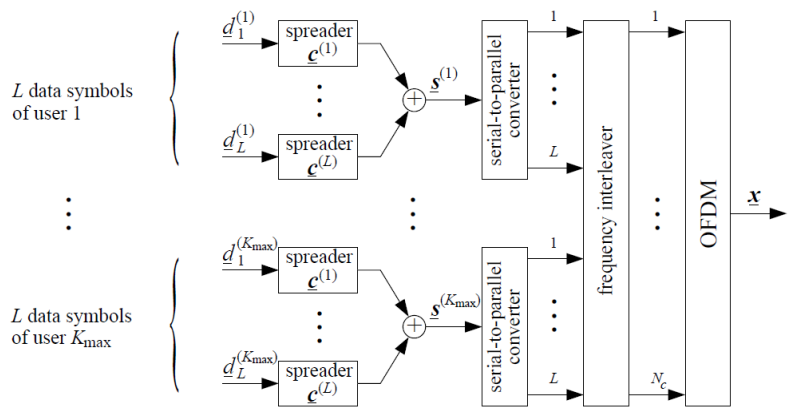


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be

observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users.

Kaiser-1998 at 130-131.

Between SS-MC-MA and MC-CDMA systems exist the following differences:

• In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme.

• MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user.

• In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

• In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are

spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity.

Kaiser-1998 at 131.

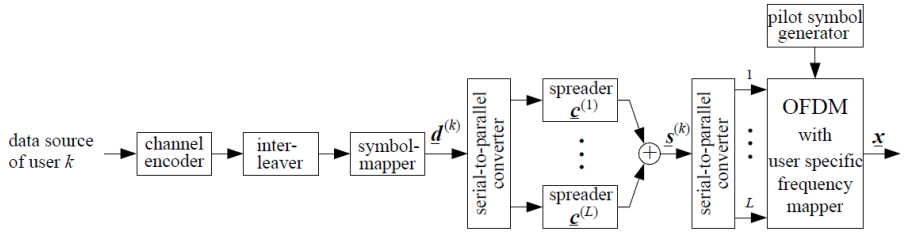


Figure B.2: SS-MC-MA transmitter of the kth user for the uplink

Kaiser-1998 at Fig. B.2.

SS-MC-MA Transmitter: Fig. B.2 shows an SS-MC-MA transmitter with channel coding for the data of the kth user, $k = 1 \ldots K$, for the uplink. The components channel encoding, interleaving, and symbol mapping are identical to those described in Chapter 4 for MC-CDMA systems. In SS-MC-MA systems, L subsequent complex-valued data symbols $\underline{d}_l^{(k)}, l = 1 \ldots L$, of user k are serial-to-parallel converted. The vector

$$\underline{\boldsymbol{d}}^{(\boldsymbol{k})} = \left(\underline{d}_1^{(k)}, \underline{d}_2^{(k)}, \ldots, \underline{d}_L^{(k)}\right)^T \qquad (B.1)$$

represents one block of L parallel converted data symbols of the kth user. Each of the L data symbols is multiplied with another orthogonal spreading code of length L. The $L \times L$ matrix

$$\underline{\boldsymbol{C}} = \left(\underline{\boldsymbol{c}}_1\, \underline{\boldsymbol{c}}_2\, \ldots\, \underline{\boldsymbol{c}}_L\right) = \begin{pmatrix} \underline{C}_{1,1} & \underline{C}_{2,1} & \cdots & \underline{C}_{L,1} \\ \underline{C}_{1,2} & \underline{C}_{2,2} & \cdots & \underline{C}_{L,2} \\ \vdots & \ddots & \cdots & \vdots \\ \underline{C}_{1,L} & \underline{C}_{2,L} & \cdots & \underline{C}_{L,L} \end{pmatrix} \qquad (B.2)$$

	represents the L different spreading codes $\underline{c_l}, l = 1, \dots, L$, used by user k. The matrix $\underline{C}$ is the same for all users. The modulated spreading codes are data symbol and, thus, chip synchronously added, resulting in the transmission vector $$\underline{\boldsymbol{s}}^{(\boldsymbol{k})} = \underline{\boldsymbol{C}}\,\underline{\boldsymbol{d}}^{(\boldsymbol{k})} = \left(\underline{\boldsymbol{S}}_{\boldsymbol{1}}^{(\boldsymbol{k})}, \underline{\boldsymbol{S}}_{\boldsymbol{2}}^{(\boldsymbol{k})}, \dots, \underline{\boldsymbol{S}}_{\boldsymbol{L}}^{(\boldsymbol{k})}\right)^{T} \quad (B.3)$$ consisting of L components. To increase the robustness of SS-MC-MA systems e.g. against inter cell interference, less than L data modulated spreading codes can be added to one transmission vector $\underline{s}^{(k)}$. Kaiser-1998 at 131-132. OFDM with guard interval is applied in SS-MC-MA systems in the same way as in MC-CDMA systems, cf. Section 3.1.1. In order to perform coherent data detection at the receiver and to guarantee robust time and frequency synchronization, pilot symbols are multiplexed in the transmitted data. Kaiser-1998 at 133.

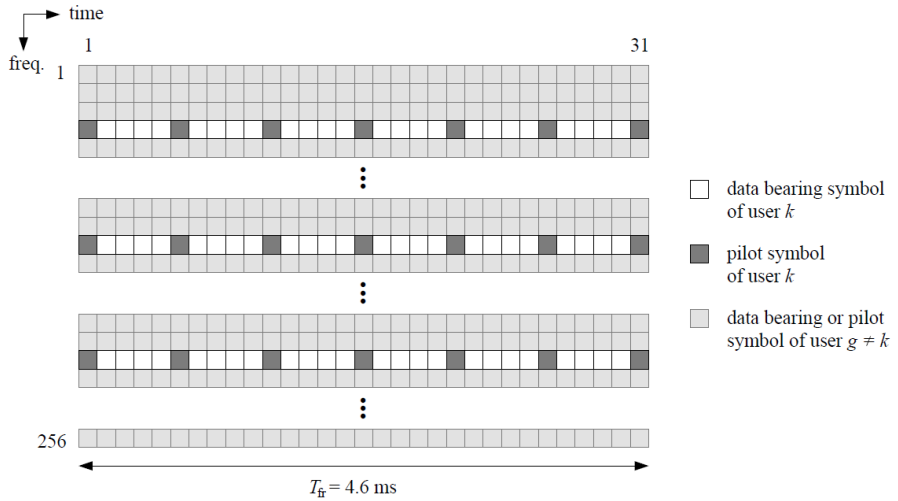


Figure B.4: OFDM frame of the proposed SS-MC-MA mobile radio system; $N_c = 256$; $N_s = 31$; $N_t = 5$; $N_{grid} = 1792$

Kaiser-1998 at Fig. B.4.

In the following, the performance of an SS-MC-MA mobile radio system in the uplink is presented. Table B.1 shows the SS-MC-MA system parameters used in the uplink. These parameters are chosen such that they correspond as far as possible with the MC-CDMA system parameters for the downlink presented in Table 6.1. The SS-MC-MA system parameters described in the following differ from those of the MC-CDMA system presented in Chapter 6. The SS-MC-MA system transmits only on 256 subcarriers. Since the channel estimation in the considered SS-MC-MA system is based on a 1-D filtering in time direction which should fulfill two-times oversampling of the time-variant fading process, the overhead due to pilot symbols can be reduced with decreasing OFDM symbol durations. However, it has to be taken into account that with decreasing OFDM symbol duration the loss in bandwidth efficiency due to the guard interval increases. The used TDMA frame structure consisting of 4 time

slots. A time slot corresponds to an OFDM frame consisting of 31 OFDM symbols as illustrated in Fig. B.4. Each user exclusively transmits on 8 subcarriers, where 3 of the 8 subcarriers used by the kth user are depicted. Hence, per user, a block of 8 serial data symbols is parallel converted and spread with orthogonal Walsh Hadamard codes of length L equal to 8, resulting after superposition in the transmission sequence $\underline{s}^{(k)}$, cf. (B.3). Note that in contrast to Fig. B.2, an additional interleaver is applied which scrambles 192 components of 24 transmission sequences $\underline{s}^{(k)}$ with the intention to increase the diversity potential of the system. Per OFDM symbol, 8 randomly interleaved components are mapped on 8 subcarriers exclusively used by the kth user. The 8 user specific subcarriers are distributed over the whole bandwidth. The receiver applies an MLSSE for data detection. The channel coding part is identical to that of the MC-CDMA system presented in Chapter 6.

Kaiser-1998 at 133-135.

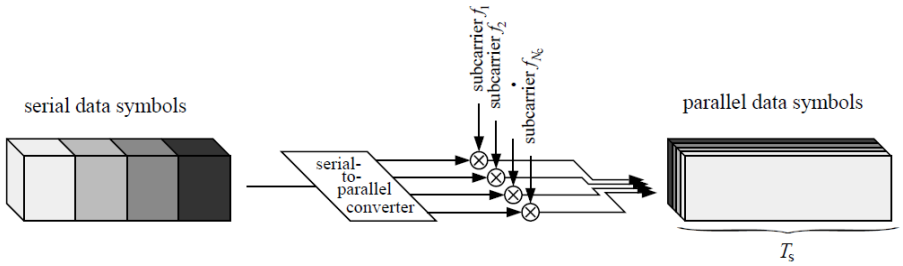


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

The progress in wireless communications entails a demand for higher data rates and, thus, shorter symbol durations. However, if the duration of the transmitted symbol becomes smaller than the time dispersion of the multipath channel, the performance of the wireless communication system suffers from ISI. This is a crucial problem since the receiver complexity is

	related to the amount of ISI. An approach to prevent ISI is offered by parallel data transmission [Cha66, Sal67, WeE71], referred to as MC communications. The principle of MC modulation, depicted in Fig. 1.3, is to convert a high rate data stream into N_c low-rate substreams, where N_c is the number of subcarriers used for data transmission. Each substream is modulated on its assigned subcarrier $f_n, n = 1, \ldots, N_c$. Thus, the available channel bandwidth is subdivided into N_c narrow subbands, which ideally appear frequency non-selective. The data symbol rate per subcarrier is reduced by a factor N_c and with that, the ISI is reduced. A common realization of MC communications is conventional frequency division multiplexing where the subbands are completely separated in the frequency domain. However, due to finite steepness of the filter roll-offs, the subchannel spacing has to be greater than the Nyquist bandwidth to avoid inter-subchannel interference (ICI). This inefficient use of the available spectrum can be overcome by permitting spectral overlap between adjacent subchannels [Cha66, Sal67]. ICI can be avoided by guaranteeing orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s, known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbolsof duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1/T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B. Kaiser-1998 at 5-6. The success of MC modulation in broadcast applications motivated many researchers to investigate the suitability of MC modulation for wireless mobile communications. First multiple access systems with MC modulation were published in 1993 and were based on DS-CDMA [FaP93, YLF93, Van93, KoM93, Faz93, DaS93, CBJ93]. Two different concepts

of combining DS-CDMA with MC modulation were introduced. Concept I is referred to as MC-CDMA, also known as OFDM-CDMA or MC-SSMA, and is the topic of this thesis. Concept II was proposed in two variants, the first one is referred to as MC-DS-CDMA, the second one as multi-tone (MT) CDMA. For both Concept I and Concept II, all users simultaneously share the available bandwidth where the separation of the users signals is carried out in the code domain comparable to DS-CDMA.

Kaiser-1998 at 6.

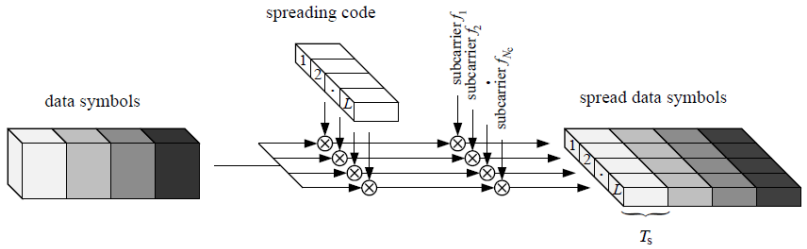


Figure 1.4: Principle of spreading of the data of a single user by MC-CDMA for the case $N_c = L$, i.e., $T_s = T_d$ and $T'_c = T_d$

Kaiser-1998 at Fig. 1.4.

Concept I: MC-CDMA is based on a serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, [FaP93, YLF93, CBJ93]. The high rate DS spread data stream is MC modulated in such a way, that the L chips of a spread data symbol are transmitted in parallel on different subcarriers. Thus, the assigned data symbol is simultaneously transmitted on L subcarriers. If the number of subcarriers N_c is equal to the spreading code length L, MCCDMA requires the total bandwidth for the transmission of a single data symbol comparable to DS-CDMA. When choosing L smaller than N_c and introducing an appropriate frequency interleaving, the flexibility of an MC-CDMA system can be increased and the complexity of the data detector can be reduced [FaP93, Faz93]. Fig. 1.4 shows the

	principle of an equivalent realization of the serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3. Each data symbol is copied onto L substreams before multiplication with one chip of the spreading code per substream. A chip of the MC-CDMA spreading code grouped in the frequency domain has the duration T_c', cf. Fig. 1.1, which is by a factor of N_c greater than the duration T_c of a chip of the DS-CDMA spreading code. The case of N_c equal to L is illustrated in Fig. 1.4, yielding that the data symbol duration T_d, the chip duration T_c', and the OFDM symbol duration T_s are identical. Fig. 1.4 reflects the fact that MC-CDMA has a spreading code grouped in the frequency domain. Comparing the spread data symbols of DS-CDMA, cf. Fig. 1.2, with those of MC-CDMA, cf. Fig. 1.4, it can be seen that MC-CDMA offers an additional flexibility in the frequency domain, which results in simple methods for signal reconstruction in the frequency domain. MC-CDMA was introduced with OFDM for optimum use of the available bandwidth [FaP93, YLF93, CBJ93]. Most MC-CDMA systems were proposed for the downlink from a base station (BS) to a mobile station (MS) where powerful mobile receivers with low complexity are required [FaP93, YLF93, CBJ93]. The time/frequency synchronism between the users in the downlink allows a simple realization of an efficient channel estimation required for coherent detection. Kaiser-1998 at 6-7. 3.1.1 Orthogonal Frequency Division Multiplexing The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and

forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible.

A communication system with MC modulation transmits a sequence $\{\underline{S}_n\}$ consisting of N_c complex-valued source symbols $\underline{S}_n, n = 1, \ldots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $\underline{S}_n, n = 1, \ldots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{\underline{S}_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{\underline{S}_n\}$ is valid since ISI and ICI can be avoided with OFDM.

The MC modulator maps a sequence $\{\underline{S}_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to

$$\frac{1}{T_s} = \frac{1}{N_c T}. \tag{3.1}$$

According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of

$$F_s = \frac{1}{T_s}. \tag{3.2}$$

	to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $\underline{S}_n, n = 1, \ldots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form $$x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} \underline{S}_n \ \mathrm{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$$ Kaiser-1998 at 31-32. The normalized energy density spectrum of an OFDM symbol with N_c equal to 16 subcarriers versus the normalized frequency fT is depicted as a solid curve in Fig. 3.1. The OFDM spectrum is shown for the case where the symbols $\underline{S}_n, n = 1, \ldots, N_c$, are transmitted with equal energy. The dotted curve illustrates the energy density spectrum of the first modulated subcarrier f_1 and indicates the construction of the overall energy density spectrum as the sum of N_c, each by $1/T_s$ shifted, individual energy density spectra. For large values of N_c, the energy density spectrum becomes more flat in the normalized frequency range of $fT \in [-0.5, 0.5]$ containing the subcarriers. Only subcarriers near the band edges contribute to the out-of-band power. Therefore, as N_c becomes large, the energy density spectrum approaches that of single carrier modulation with ideal Nyquist filtering. As a reference, the normalized energy density spectrum of binary phase shift keying (BPSK) [Pro95] is plotted as a dashed curve. Kaiser-1998 at 32.

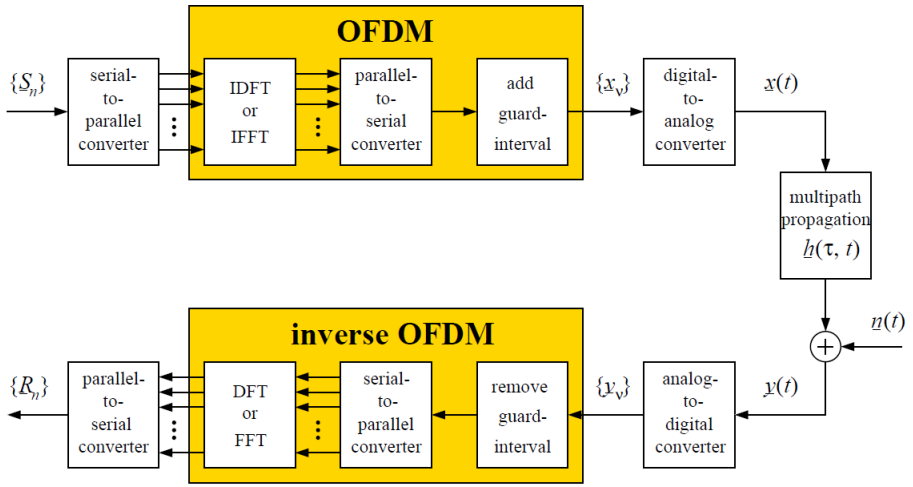


Figure 3.2: MC transmission system with OFDM

Kaiser-1998 at Fig. 3.2.

A key advantage of using OFDM is that the MC modulation can be implemented in the discrete domain by using an IDFT, or a more computationally efficient IFFT [WeE71]. When sampling the complex envelope $x(t)$ of an OFDM symbol at time instances t equal to $(\nu-1)T_s/N_c, \nu = 1, \ldots, N_c$, the samples are

$$x_\nu = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} \underline{S}_n e^{j2\pi(n-1)(\nu-1)/N_c}, \quad \nu = 1, \ldots, N_c, \tag{3.6}$$

and the sampling rate is N_c/T_s. The important result is that the sampled sequence $\{x_\nu\}, \nu = 1, \ldots, N_c$, is the IDFT of the source symbol sequence $\{\underline{S}_n\}, n = 1, \ldots, N_c$. The block diagram of an MC modulator employing OFDM based on an IDFT and MC demodulator employing inverse OFDM based on a DFT is illustrated in Fig. 3.2.

Kaiser-1998 at 32-33.

> • An OFDM symbol $\underline{x}(t)$ is the sum of many independently modulated sinewaves and its envelope has an almost Gaussian distribution. This yields high peak-to-average power ratios and high demands on linear amplifiers. Nonlinearities in the amplifiers may cause ICI and if the amplifiers are not adapted with proper output backoff, the clipping distortion may cause severe performance degradations [SSR95, BCF96]. Possible counter-measures are predistortion of the transmitted signal with a complementary nonlinearity [Bin90] or, when considering MC-CDMA systems, an approach is to design spreading codes resulting in reduced dynamic ranges [AuF96]. Within this thesis, the amplifiers in the MC-CDMA mobile radio system are assumed to be linear and adapted with appropriate output backoff.

Kaiser-1998 at 37.

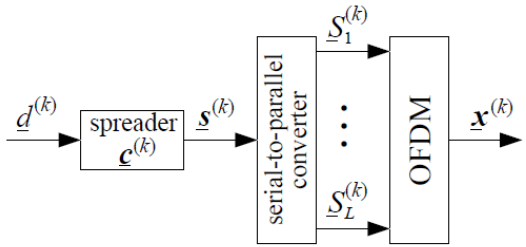


Figure 3.6: MC spread spectrum signal generation

Kaiser-1998 at Fig. 3.6.

> The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig.

	1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be transmitted over the radio channel is taken from the complex data symbol alphabet $$\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \quad (3.24)$$ of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code $$\underline{c}^{(k)} = \left(\underline{C}_1^{(k)}, \underline{C}_2^{(k)}, \dots, \underline{C}_L^{(k)}\right)^{\mathrm{T}} \quad (3.25)$$ of the kth user. The chips $\underline{C}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet $$\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \quad (3.26)$$ of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is $$\frac{1}{T_c} = \frac{L}{T_d} \quad (3.27)$$ and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector $$\underline{s}^{(k)} = \underline{d}^{(k)}\underline{c}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^{\mathrm{T}}. \quad (3.28)$$

The rate of the components $\underline{S}_l^{(k)}$, $l = 1, \ldots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{S}_l^{(k)}$, $l = 1, \ldots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{S}_l^{(k)}$, $l = 1, \ldots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is

$$T_s' = T_g + N_c T_c. \tag{3.29}$$

The transmission of one data symbol per user per OFDM symbol requires

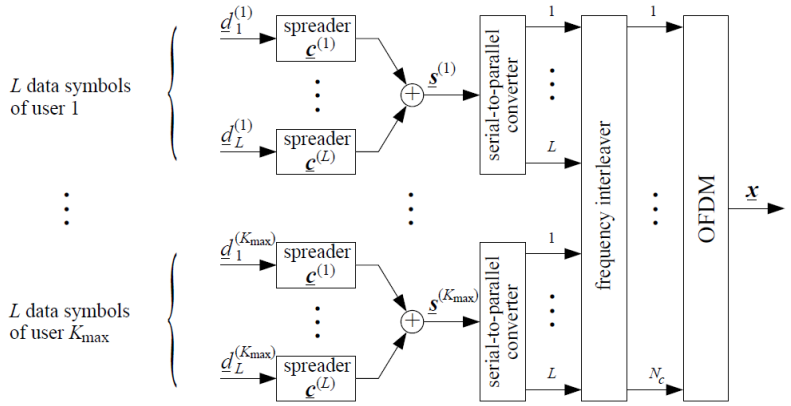
$$N_c = L \tag{3.30}$$

subcarriers. In this case, the OFDM symbol duration including the guard interval is

$$T_s' = T_g + T_d. \tag{3.31}$$

Kaiser-1998 at 39-40.

Performance and flexibility of mobile radio systems essentially depend on the choice of the multiple access scheme. The novel MC-CDMA scheme which is the topic of this thesis is a promising alternative to conventional FDMA, TDMA, and CDMA schemes. With MC-CDMA, each data modulated chip of the user specific spreading code is mapped onto a separate subcarrier, so that the chips of the spreading code and, hence, the data symbol is transmitted in parallel on multiple subcarriers. The application of OFDM enables one to avoid ISI and ICI in the detection process, resulting in simple SD and MD techniques. In MC-CDMA mobile radio systems, SD can be realized by equalizing each subcarrier individually, yielding only one complex-valued multiplication per subcarrier and OFDM symbol. Due to the M-, Q-, and M&Q-Modification

	of the MC-CDMA scheme, even the optimum JD techniques MLSSE and MLSE can be applied with reasonable complexity. Kaiser-1998 at 119.
[11E] producing a time-domain waveform that comprises a superposition of the plurality of modulated subcarriers, the time-domain waveform to be transmitted in the wireless network by the user device;	StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality: For example, Kaiser-1998 discloses:  Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

> This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users.

Kaiser-1998 at 130-131.

> Between SS-MC-MA and MC-CDMA systems exist the following differences:
>
> • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code

division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme.

• MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user.

• In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

• In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity.

Kaiser-1998 at 131.

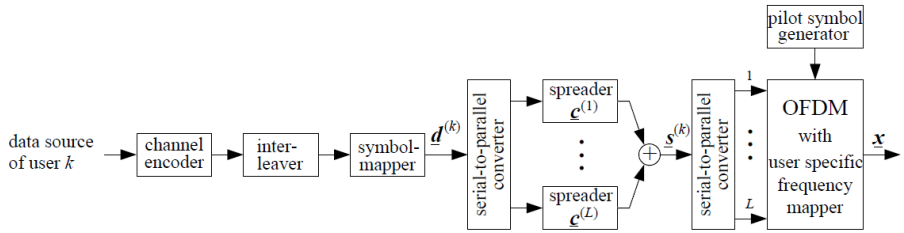


Figure B.2: SS-MC-MA transmitter of the kth user for the uplink

Kaiser-1998 at Fig. B.2.

SS-MC-MA Transmitter: Fig. B.2 shows an SS-MC-MA transmitter with channel coding for the data of the kth user, $k = 1 \ldots K$, for the uplink. The components channel encoding, interleaving, and symbol mapping are identical to those described in Chapter 4 for MC-CDMA systems. In SS-MC-MA systems, L subsequent complex-valued data symbols $\underline{d}_l^{(k)}, l = 1 \ldots L$, of user k are serial-to-parallel converted. The vector

$$\underline{\boldsymbol{d}}^{(\boldsymbol{k})} = \left(\underline{d}_1^{(k)}, \underline{d}_2^{(k)}, \ldots, \underline{d}_L^{(k)}\right)^T \qquad (B.1)$$

represents one block of L parallel converted data symbols of the kth user. Each of the L data symbols is multiplied with another orthogonal spreading code of length L. The $L \times L$ matrix

$$\underline{\boldsymbol{C}} = \left(\underline{\boldsymbol{c}}_{\boldsymbol{1}}\, \underline{\boldsymbol{c}}_{\boldsymbol{2}} \ \ldots\ \underline{\boldsymbol{c}}_{\boldsymbol{L}}\right) = \begin{pmatrix} \underline{C}_{1,1} & \underline{C}_{2,1} & \cdots & \underline{C}_{L,1} \\ \underline{C}_{1,2} & \underline{C}_{2,2} & \cdots & \underline{C}_{L,2} \\ \vdots & \ddots & \cdots & \vdots \\ \underline{C}_{1,L} & \underline{C}_{2,L} & \cdots & \underline{C}_{L,L} \end{pmatrix} \qquad (B.2)$$

represents the L different spreading codes $\underline{c}_l, l = 1, \ldots, L$, used by user k. The matrix $\underline{C}$ is the same for all users. The modulated spreading codes are data symbol and, thus, chip synchronously added, resulting in the transmission vector

$$\underline{\boldsymbol{s}}^{(\boldsymbol{k})} = \underline{\boldsymbol{C}}\, \underline{\boldsymbol{d}}^{(\boldsymbol{k})} = \left(\underline{\boldsymbol{S}}_{\boldsymbol{1}}^{(\boldsymbol{k})}, \underline{\boldsymbol{S}}_{\boldsymbol{2}}^{(\boldsymbol{k})}, \ldots, \underline{\boldsymbol{S}}_{\boldsymbol{L}}^{(\boldsymbol{k})}\right)^T \qquad (B.3)$$

consisting of L components. To increase the robustness of SS-MC-MA systems e.g. against inter cell interference, less than L data modulated spreading codes can be added to one transmission vector $\underline{s}^{(k)}$.

Kaiser-1998 at 131-132.

OFDM with guard interval is applied in SS-MC-MA systems in the same way as in MC-CDMA systems, cf. Section 3.1.1. In order to perform coherent data detection at the receiver and to guarantee robust time and frequency synchronization, pilot symbols are multiplexed in the transmitted data.

Kaiser-1998 at 133.

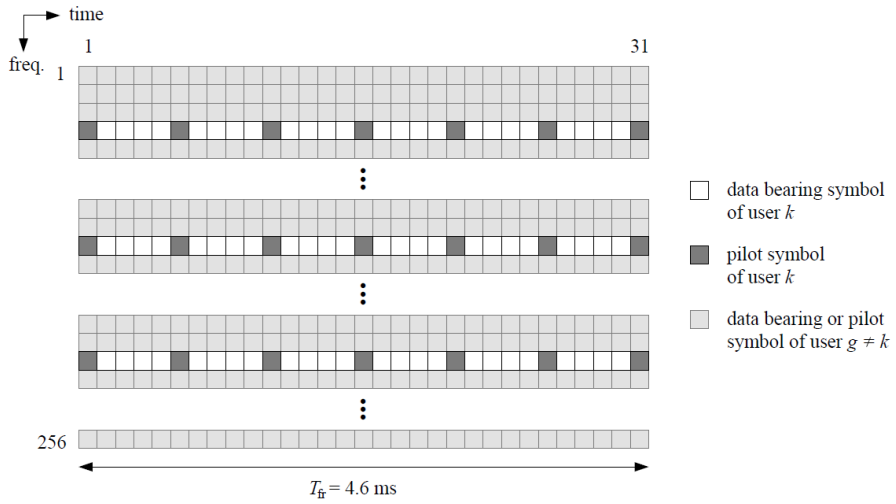


Figure B.4: OFDM frame of the proposed SS-MC-MA mobile radio system; $N_c = 256$; $N_s = 31$; $N_t = 5$; $N_{grid} = 1792$

Kaiser-1998 at Fig. B.4.

In the following, the performance of an SS-MC-MA mobile radio system in the uplink is presented. Table B.1 shows the SS-MC-MA system parameters used in the uplink. These parameters are chosen such that they correspond as far as possible with the MC-CDMA system parameters for the downlink presented in Table 6.1. The SS-MC-MA system parameters described in the following differ from those of the MC-CDMA system presented in Chapter 6. The SS-MC-MA system transmits only on 256

subcarriers. Since the channel estimation in the considered SS-MC-MA system is based on a 1-D filtering in time direction which should fulfill two-times oversampling of the time-variant fading process, the overhead due to pilot symbols can be reduced with decreasing OFDM symbol durations. However, it has to be taken into account that with decreasing OFDM symbol duration the loss in bandwidth efficiency due to the guard interval increases. The used TDMA frame structure consisting of 4 time slots. A time slot corresponds to an OFDM frame consisting of 31 OFDM symbols as illustrated in Fig. B.4. Each user exclusively transmits on 8 subcarriers, where 3 of the 8 subcarriers used by the kth user are depicted. Hence, per user, a block of 8 serial data symbols is parallel converted and spread with orthogonal Walsh Hadamard codes of length L equal to 8, resulting after superposition in the transmission sequence $\underline{s}^{(k)}$, cf. (B.3). Note that in contrast to Fig. B.2, an additional interleaver is applied which scrambles 192 components of 24 transmission sequences $\underline{s}^{(k)}$ with the intention to increase the diversity potential of the system. Per OFDM symbol, 8 randomly interleaved components are mapped on 8 subcarriers exclusively used by the kth user. The 8 user specific subcarriers are distributed over the whole bandwidth. The receiver applies an MLSSE for data detection. The channel coding part is identical to that of the MC-CDMA system presented in Chapter 6.

Kaiser-1998 at 133-135.

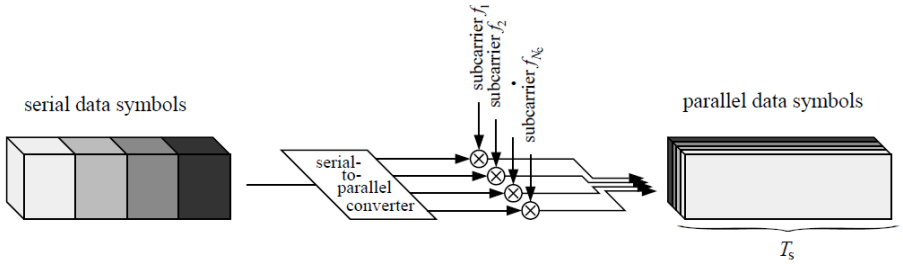


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

	Kaiser-1998 at Fig. 1.3. The progress in wireless communications entails a demand for higher data rates and, thus, shorter symbol durations. However, if the duration of the transmitted symbol becomes smaller than the time dispersion of the multipath channel, the performance of the wireless communication system suffers from ISI. This is a crucial problem since the receiver complexity is related to the amount of ISI. An approach to prevent ISI is offered by parallel data transmission [Cha66, Sal67, WeE71], referred to as MC communications. The principle of MC modulation, depicted in Fig. 1.3, is to convert a high rate data stream into N_c low-rate substreams, where N_c is the number of subcarriers used for data transmission. Each substream is modulated on its assigned subcarrier $f_n, n = 1, \ldots, N_c$. Thus, the available channel bandwidth is subdivided into N_c narrow subbands, which ideally appear frequency non-selective. The data symbol rate per subcarrier is reduced by a factor N_c and with that, the ISI is reduced. A common realization of MC communications is conventional frequency division multiplexing where the subbands are completely separated in the frequency domain. However, due to finite steepness of the filter roll-offs, the subchannel spacing has to be greater than the Nyquist bandwidth to avoid inter-subchannel interference (ICI). This inefficient use of the available spectrum can be overcome by permitting spectral overlap between adjacent subchannels [Cha66, Sal67]. ICI can be avoided by guaranteeing orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s, known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbolsof duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1/T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B.

Kaiser-1998 at 5-6.

> The success of MC modulation in broadcast applications motivated many researchers to investigate the suitability of MC modulation for wireless mobile communications. First multiple access systems with MC modulation were published in 1993 and were based on DS-CDMA [FaP93, YLF93, Van93, KoM93, Faz93, DaS93, CBJ93]. Two different concepts of combining DS-CDMA with MC modulation were introduced. Concept I is referred to as MC-CDMA, also known as OFDM-CDMA or MC-SSMA, and is the topic of this thesis. Concept II was proposed in two variants, the first one is referred to as MC-DS-CDMA, the second one as multi-tone (MT) CDMA. For both Concept I and Concept II, all users simultaneously share the available bandwidth where the separation of the users signals is carried out in the code domain comparable to DS-CDMA.

Kaiser-1998 at 6.

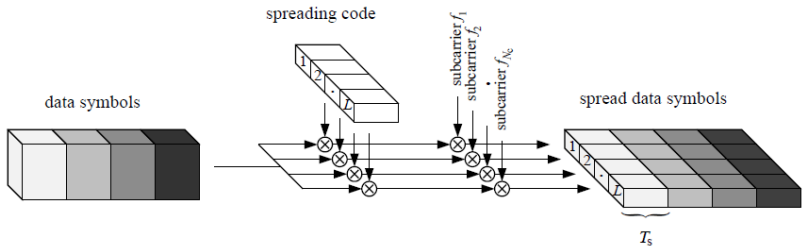


Figure 1.4: Principle of spreading of the data of a single user by MC-CDMA for the case $N_c = L$, i.e., $T_s = T_d$ and $T'_c = T_d$

Kaiser-1998 at Fig. 1.4.

> Concept I: MC-CDMA is based on a serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, [FaP93, YLF93, CBJ93]. The high rate DS spread data stream is MC modulated in such a way, that the *L* chips of a spread data symbol are transmitted in parallel on different

	subcarriers. Thus, the assigned data symbol is simultaneously transmitted on L subcarriers. If the number of subcarriers N_c is equal to the spreading code length L, MCCDMA requires the total bandwidth for the transmission of a single data symbol comparable to DS-CDMA. When choosing L smaller than N_c and introducing an appropriate frequency interleaving, the flexibility of an MC-CDMA system can be increased and the complexity of the data detector can be reduced [FaP93, Faz93]. Fig. 1.4 shows the principle of an equivalent realization of the serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3. Each data symbol is copied onto L substreams before multiplication with one chip of the spreading code per substream. A chip of the MC-CDMA spreading code grouped in the frequency domain has the duration T_c', cf. Fig. 1.1, which is by a factor of N_c greater than the duration T_c of a chip of the DS-CDMA spreading code. The case of N_c equal to L is illustrated in Fig. 1.4, yielding that the data symbol duration T_d, the chip duration T_c', and the OFDM symbol duration T_s are identical. Fig. 1.4 reflects the fact that MC-CDMA has a spreading code grouped in the frequency domain. Comparing the spread data symbols of DS-CDMA, cf. Fig. 1.2, with those of MC-CDMA, cf. Fig. 1.4, it can be seen that MC-CDMA offers an additional flexibility in the frequency domain, which results in simple methods for signal reconstruction in the frequency domain. MC-CDMA was introduced with OFDM for optimum use of the available bandwidth [FaP93, YLF93, CBJ93]. Most MC-CDMA systems were proposed for the downlink from a base station (BS) to a mobile station (MS) where powerful mobile receivers with low complexity are required [FaP93, YLF93, CBJ93]. The time/frequency synchronism between the users in the downlink allows a simple realization of an efficient channel estimation required for coherent detection. Kaiser-1998 at 6-7. 3.1.1 Orthogonal Frequency Division Multiplexing

	The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{\underline{S}_n\}$ consisting of N_c complex-valued source symbols $\underline{S}_n, n = 1, \ldots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $\underline{S}_n, n = 1, \ldots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{\underline{S}_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{\underline{S}_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{\underline{S}_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to

$$\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$$

According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of

$$F_s = \frac{1}{T_s}. \quad (3.2)$$

to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $\underline{S}_n, n = 1, \ldots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form

$$x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} \underline{S}_n \ \mathrm{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$$

Kaiser-1998 at 31-32.

The normalized energy density spectrum of an OFDM symbol with N_c equal to 16 subcarriers versus the normalized frequency fT is depicted as a solid curve in Fig. 3.1. The OFDM spectrum is shown for the case where the symbols $\underline{S}_n, n = 1, \ldots, N_c$, are transmitted with equal energy. The dotted curve illustrates the energy density spectrum of the first modulated subcarrier f_1 and indicates the construction of the overall energy density spectrum as the sum of N_c, each by $1/T_s$ shifted, individual energy density spectra. For large values of N_c, the energy density spectrum becomes more flat in the normalized frequency range of $fT \in [-0.5, 0.5]$ containing the subcarriers. Only subcarriers near the band edges contribute to the out-of-band power. Therefore, as N_c becomes large, the energy density spectrum approaches that of single carrier modulation with ideal Nyquist filtering.

As a reference, the normalized energy density spectrum of binary phase shift keying (BPSK) [Pro95] is plotted as a dashed curve.

Kaiser-1998 at 32.

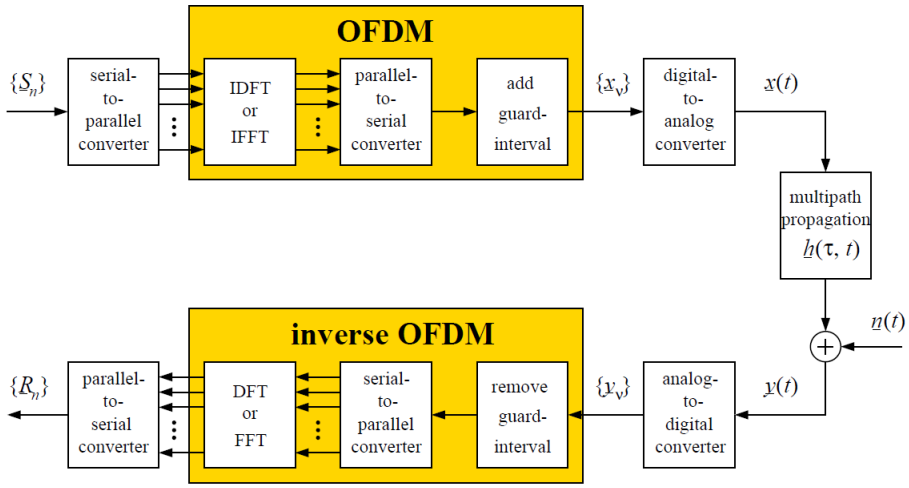


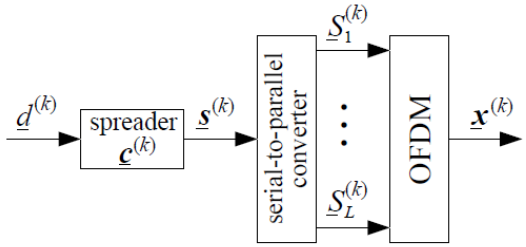
Figure 3.2: MC transmission system with OFDM

Kaiser-1998 at Fig. 3.2.

A key advantage of using OFDM is that the MC modulation can be implemented in the discrete domain by using an IDFT, or a more computationally efficient IFFT [WeE71]. When sampling the complex envelope $x(t)$ of an OFDM symbol at time instances t equal to $(\nu - 1)T_s/N_c, \nu = 1, \ldots, N_c$, the samples are

$$x_\nu = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} \underline{S}_n e^{j2\pi(n-1)(\nu-1)/N_c}, \quad \nu = 1, \ldots, N_c, \tag{3.6}$$

and the sampling rate is N_c/T_s. The important result is that the sampled sequence $\{x_\nu\}, \nu = 1, \ldots, N_c$, is the IDFT of the source symbol sequence

	$\{\underline{S}_n\}, n = 1, \ldots, N_c$. The block diagram of an MC modulator employing OFDM based on an IDFT and MC demodulator employing inverse OFDM based on a DFT is illustrated in Fig. 3.2. Kaiser-1998 at 32-33. • An OFDM symbol $\underline{x}(t)$ is the sum of many independently modulated sinewaves and its envelope has an almost Gaussian distribution. This yields high peak-to-average power ratios and high demands on linear amplifiers. Nonlinearities in the amplifiers may cause ICI and if the amplifiers are not adapted with proper output backoff, the clipping distortion may cause severe performance degradations [SSR95, BCF96]. Possible counter-measures are predistortion of the transmitted signal with a complementary nonlinearity [Bin90] or, when considering MC-CDMA systems, an approach is to design spreading codes resulting in reduced dynamic ranges [AuF96]. Within this thesis, the amplifiers in the MC-CDMA mobile radio system are assumed to be linear and adapted with appropriate output backoff. Kaiser-1998 at 37.  Figure 3.6: MC spread spectrum signal generation Kaiser-1998 at Fig. 3.6.

The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be transmitted over the radio channel is taken from the complex data symbol alphabet

$$\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \tag{3.24}$$

of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

$$\underline{c}^{(k)} = \left(\underline{C}_1^{(k)}, \underline{C}_2^{(k)}, \dots, \underline{C}_L^{(k)}\right)^{\mathrm{T}} \tag{3.25}$$

of the kth user. The chips $\underline{C}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet

$$\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \tag{3.26}$$

of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is

$$\frac{1}{T_c} = \frac{L}{T_d} \tag{3.27}$$

and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector

$$\underline{s}^{(k)} = \underline{d}^{(k)}\underline{c}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^{\mathrm{T}}. \quad (3.28)$$

The rate of the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is

$$T_s' = T_g + N_c T_c. \quad (3.29)$$

The transmission of one data symbol per user per OFDM symbol requires

$$N_c = L \quad (3.30)$$

subcarriers. In this case, the OFDM symbol duration including the guard interval is

$$T_s' = T_g + T_d. \quad (3.31)$$

Kaiser-1998 at 39-40.

Performance and flexibility of mobile radio systems essentially depend on the choice of the multiple access scheme. The novel MC-CDMA scheme which is the topic of this thesis is a promising alternative to conventional FDMA, TDMA, and CDMA schemes. With MC-CDMA, each data modulated chip of the user specific spreading code is mapped onto a separate subcarrier, so that the chips of the spreading code and, hence, the data symbol is transmitted in parallel on multiple subcarriers. The application of OFDM enables one to avoid ISI and ICI in the detection process, resulting in simple SD and MD techniques. In MC-CDMA mobile radio systems, SD can be realized by equalizing each subcarrier

	individually, yielding only one complex-valued multiplication per subcarrier and OFDM symbol. Due to the M-, Q-, and M&Q-Modification of the MC-CDMA scheme, even the optimum JD techniques MLSSE and MLSE can be applied with reasonable complexity. Kaiser-1998 at 119.
[11F] wherein the set of subcarrier values comprises a first polyphase code that encodes a first of the set of data symbols and at least a second polyphase code that encodes at least a second of the set of data symbols;	StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality: For example, Kaiser-1998 discloses:

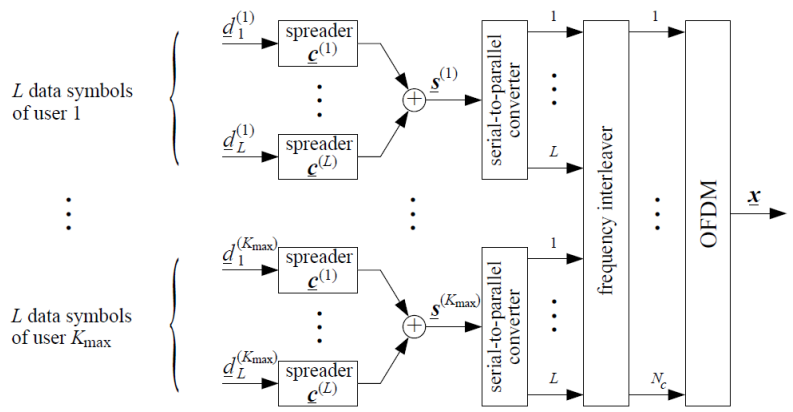
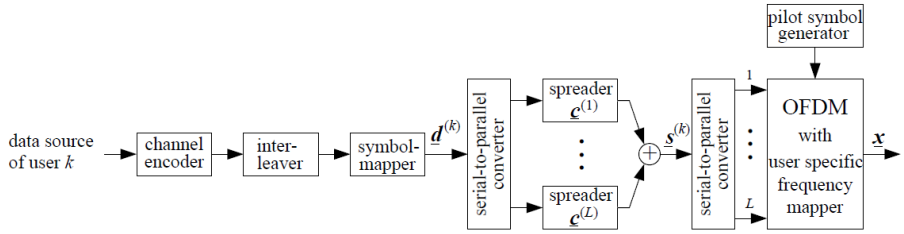


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be

	observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers. • Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques. Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme.

	• MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation. • In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity. Kaiser-1998 at 131.  Figure B.2: SS-MC-MA transmitter of the kth user for the uplink Kaiser-1998 at Fig. B.2. SS-MC-MA Transmitter: Fig. B.2 shows an SS-MC-MA transmitter with channel coding for the data of the kth user, $k = 1 \ldots K$, for the uplink. The components channel encoding, interleaving, and symbol mapping are identical to those described in Chapter 4 for MC-CDMA systems. In SS-

MC-MA systems, L subsequent complex-valued data symbols $\underline{d}_l^{(k)}, l = 1 \dots L$, of user k are serial-to-parallel converted. The vector

$$\underline{d}^{(k)} = \left(\underline{d}_1^{(k)}, \underline{d}_2^{(k)}, \dots, \underline{d}_L^{(k)}\right)^T \quad (B.1)$$

represents one block of L parallel converted data symbols of the kth user. Each of the L data symbols is multiplied with another orthogonal spreading code of length L. The $L \times L$ matrix

$$\underline{C} = \left(\underline{c}_1\ \underline{c}_2\ \dots\ \underline{c}_L\right) = \begin{pmatrix} \underline{C}_{1,1} & \underline{C}_{2,1} & \cdots & \underline{C}_{L,1} \\ \underline{C}_{1,2} & \underline{C}_{2,2} & \cdots & \underline{C}_{L,2} \\ \vdots & \ddots & \cdots & \vdots \\ \underline{C}_{1,L} & \underline{C}_{2,L} & \cdots & \underline{C}_{L,L} \end{pmatrix} \quad (B.2)$$

represents the L different spreading codes $\underline{c}_l, l = 1, \dots, L$, used by user k. The matrix $\underline{C}$ is the same for all users. The modulated spreading codes are data symbol and, thus, chip synchronously added, resulting in the transmission vector

$$\underline{s}^{(k)} = \underline{C}\,\underline{d}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^T \quad (B.3)$$

consisting of L components. To increase the robustness of SS-MC-MA systems e.g. against inter cell interference, less than L data modulated spreading codes can be added to one transmission vector $\underline{s}^{(k)}$.

Kaiser-1998 at 131-132.

In the following, the performance of an SS-MC-MA mobile radio system in the uplink is presented. Table B.1 shows the SS-MC-MA system parameters used in the uplink. These parameters are chosen such that they correspond as far as possible with the MC-CDMA system parameters for the downlink presented in Table 6.1. The SS-MC-MA system parameters described in the following differ from those of the MC-CDMA system presented in Chapter 6. The SS-MC-MA system transmits only on 256

	subcarriers. Since the channel estimation in the considered SS-MC-MA system is based on a 1-D filtering in time direction which should fulfill two-times oversampling of the time-variant fading process, the overhead due to pilot symbols can be reduced with decreasing OFDM symbol durations. However, it has to be taken into account that with decreasing OFDM symbol duration the loss in bandwidth efficiency due to the guard interval increases. The used TDMA frame structure consisting of 4 time slots. A time slot corresponds to an OFDM frame consisting of 31 OFDM symbols as illustrated in Fig. B.4. Each user exclusively transmits on 8 subcarriers, where 3 of the 8 subcarriers used by the kth user are depicted. Hence, per user, a block of 8 serial data symbols is parallel converted and spread with orthogonal Walsh Hadamard codes of length L equal to 8, resulting after superposition in the transmission sequence $\underline{s}^{(k)}$, cf. (B.3). Note that in contrast to Fig. B.2, an additional interleaver is applied which scrambles 192 components of 24 transmission sequences $\underline{s}^{(k)}$ with the intention to increase the diversity potential of the system. Per OFDM symbol, 8 randomly interleaved components are mapped on 8 subcarriers exclusively used by the kth user. The 8 user specific subcarriers are distributed over the whole bandwidth. The receiver applies an MLSSE for data detection. The channel coding part is identical to that of the MC-CDMA system presented in Chapter 6. Kaiser-1998 at 133-135.

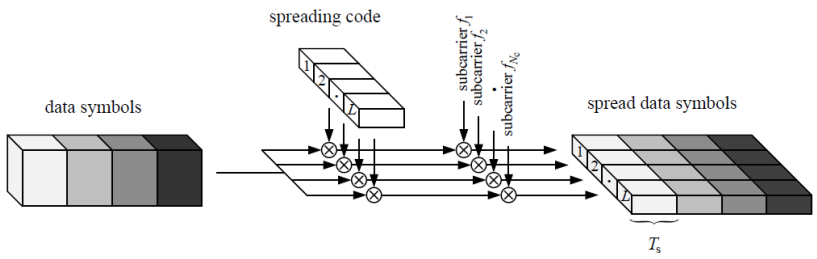
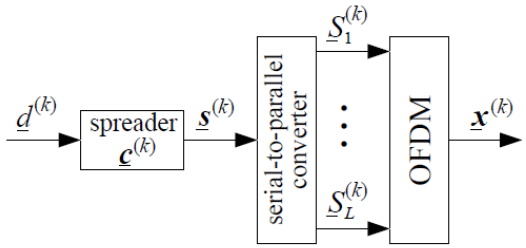


Figure 1.4: Principle of spreading of the data of a single user by MC-CDMA for the case $N_c = L$, i.e., $T_s = T_d$ and $T'_c = T_d$

Kaiser-1998 at Fig. 1.4.

Concept I: MC-CDMA is based on a serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, [FaP93, YLF93, CBJ93]. The high rate DS spread data stream is MC modulated in such a way, that the L chips of a spread data symbol are transmitted in parallel on different subcarriers. Thus, the assigned data symbol is simultaneously transmitted on L subcarriers. If the number of subcarriers N_c is equal to the spreading code length L, MC-CDMA requires the total bandwidth for the transmission of a single data symbol comparable to DS-CDMA. When choosing L smaller than N_c and introducing an appropriate frequency interleaving, the flexibility of an MC-CDMA system can be increased and the complexity of the data detector can be reduced [FaP93, Faz93]. Fig. 1.4 shows the principle of an equivalent realization of the serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3. Each data symbol is copied onto L substreams before multiplication with one chip of the spreading code per substream. A chip of the MC-CDMA spreading code grouped in the frequency domain has the duration T'_c, cf. Fig. 1.1, which is by a factor of N_c greater than the duration T_c of a chip of the DS-CDMA spreading code. The case of N_c equal to L is illustrated in Fig. 1.4, yielding that the data symbol duration T_d, the chip duration T'_c, and the OFDM symbol duration T_s are identical. Fig. 1.4 reflects the fact that MC-CDMA has a spreading code grouped in the frequency domain. Comparing

	the spread data symbols of DS-CDMA, cf. Fig. 1.2, with those of MC-CDMA, cf. Fig. 1.4, it can be seen that MC-CDMA offers an additional flexibility in the frequency domain, which results in simple methods for signal reconstruction in the frequency domain. MC-CDMA was introduced with OFDM for optimum use of the available bandwidth [FaP93, YLF93, CBJ93]. Most MC-CDMA systems were proposed for the downlink from a base station (BS) to a mobile station (MS) where powerful mobile receivers with low complexity are required [FaP93, YLF93, CBJ93]. The time/frequency synchronism between the users in the downlink allows a simple realization of an efficient channel estimation required for coherent detection. Kaiser-1998 at 6-7.  Figure 3.6: MC spread spectrum signal generation Kaiser-1998 at Fig. 3.6. The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be

transmitted over the radio channel is taken from the complex data symbol alphabet

$$\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \tag{3.24}$$

of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

$$\underline{c}^{(k)} = \left(\underline{C}_1^{(k)}, \underline{C}_2^{(k)}, \dots, \underline{C}_L^{(k)}\right)^{\mathrm{T}} \tag{3.25}$$

of the kth user. The chips $\underline{C}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet

$$\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \tag{3.26}$$

of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is

$$\frac{1}{T_c} = \frac{L}{T_d} \tag{3.27}$$

and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector

$$\underline{s}^{(k)} = \underline{d}^{(k)}\underline{c}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^{\mathrm{T}}. \tag{3.28}$$

The rate of the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread

spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d^{(k)}}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is

$$T_s' = T_g + N_c T_c. \quad (3.29)$$

The transmission of one data symbol per user per OFDM symbol requires

$$N_c = L \quad (3.30)$$

subcarriers. In this case, the OFDM symbol duration including the guard interval is

$$T_s' = T_g + T_d. \quad (3.31)$$

Kaiser-1998 at 39-40.

An MC-CDMA system designed for the transmission of one data symbol per user per OFDM symbol is referred to as a basic MC-CDMA system in the following. When applying orthogonal spreading codes $\underline{\boldsymbol{c}^{(k)}}$ like Walsh-Hadamard codes, the maximum number of active users $K_{\max}$ in the basic MC-CDMA system corresponds to the spreading code length L, i.e.,

$$K_{\max} = L. \quad (3.32)$$

Kaiser-1998 at 40.

• Frequency/time domain spreading code: Each MC-CDMA spreading code with a mapping on frequency slots can be transferred in a DS-CDMA spreading code with a mapping on time slots and vice versa by applying the Fourier transform [FBA94]. The key feature of the Fourier transform is that it preserves the correlation properties of the spreading code [Ach85]. Hence, an MC-CDMA system with a spreading code $\{\underline{C_l^{(k)}}\}, l = 1, \ldots, L,$

performs identically to a DS-CDMA system with a spreading code$\{\underline{c}_i^{(k)}\}, i = 1, \ldots, L$, when both spreading codes are related by the Fourier transform, i.e.,

$$\{\underline{C}_l^{(k)}\}, \quad l = 1, \ldots, L, \quad \bullet\!\!-\!\!\circ \quad \{\underline{c}_i^{(k)}\}, \quad i = 1, \ldots, L. \tag{3.84}$$

In (3.84), the symbol $\bullet\!\!-\!\!\circ$ denotes the discrete Fourier transformation. When, for instance, applying binary, real-valued, orthogonal MC-CDMA spreading codes, the equivalent DS-CDMA spreading codes are non-binary and complex-valued, but still orthogonal.

Kaiser-1998 at 62-63.

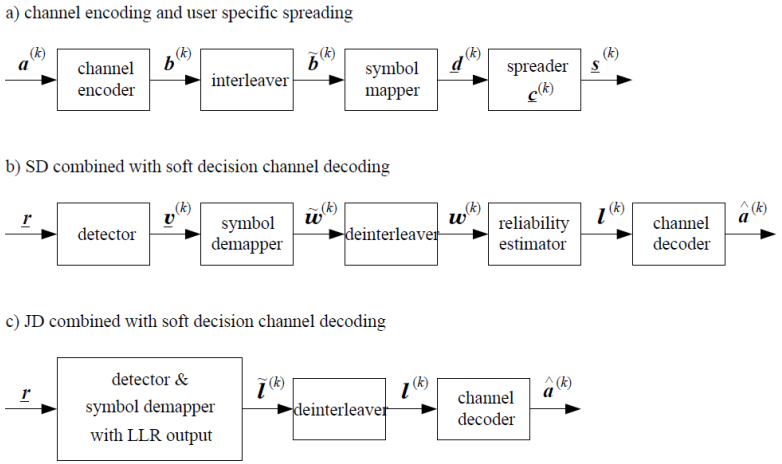


Figure 4.1: Concatenation of the spread spectrum technique with channel coding; a) channel encoding with subsequent data symbol spreading; b) SD and c) JD with optimum soft decision decoding

Kaiser-1998 at 65.

Performance and flexibility of mobile radio systems essentially depend on the choice of the multiple access scheme. The novel MC-CDMA scheme

	which is the topic of this thesis is a promising alternative to conventional FDMA, TDMA, and CDMA schemes. With MC-CDMA, each data modulated chip of the user specific spreading code is mapped onto a separate subcarrier, so that the chips of the spreading code and, hence, the data symbol is transmitted in parallel on multiple subcarriers. The application of OFDM enables one to avoid ISI and ICI in the detection process, resulting in simple SD and MD techniques. In MC-CDMA mobile radio systems, SD can be realized by equalizing each subcarrier individually, yielding only one complex-valued multiplication per subcarrier and OFDM symbol. Due to the M-, Q-, and M&Q-Modification of the MC-CDMA scheme, even the optimum JD techniques MLSSE and MLSE can be applied with reasonable complexity. Kaiser-1998 at 119. Brüninghaus-1997, which discloses: In this paper we will focus on Multi-Carrier CDMA (MC-CDMA). In contrast to a conventional OFDM system where every bit is assigned to a single subcarrier, the information is spread over several subcarriers using orthogonal codes. Since spreading is performed on information symbol level prior to subcarrier modulation, the resulting MC-CDMA signal is basically an OFDM signal. The advantage of this technique is a lower bit error rate in frequency-selective radio channels compared to a conventional OFDM system due to inherent frequency-diversity. The price to be paid is a higher computation complexity in the receiver since the frequency-selective radio channel leads to a loss of orthogonality of the spreading codes and interuser-interferences occur. A lot of research has been done to develop suitable detection or joint detection methods [4, 5, 6, 7] without considering the spreading matrix in detail. Brüninghaus-1997 at 187. In this paper we will discuss this item focussing on the special case that the spreading matrix equals the Fourier matrix. The two operations performed

in the transmitter, namely spreading and IFFT-processing, cancel each other resulting in a pure single-carrier system with blockwise processing. This special case was also mentioned in [8] but little was said about the consequences, which will be done in the following sections.

Brüninghaus-1997 at 188.

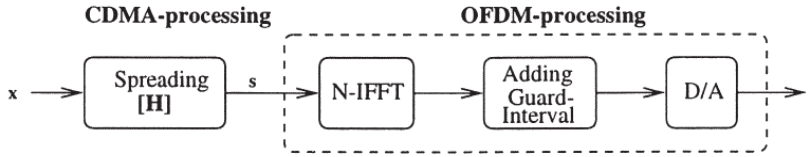


Figure 1: Block diagramm of a MC-CDMA transmitter (downlink)

Brüninghaus-1997 at 188.

The general block diagram of a MC-CDMA transmitter (only the downlink is considered in this paper) is depicted in Fig. 1. In a first step the complex data symbols $x_i, \quad 1 \leq i \leq M$, which can be elements of any arbitrary symbol set e.g. PSK or QAM, are spread over several subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation

$$s = [H] \cdot x \qquad (1)$$

where $x = (x_1, \ldots, x_M)^T$ is the vector of data symbols, $s = (s_1, \ldots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix. The M columns of the code matrix contain different spreading codes for every data symbol. To avoid interuser-interferences in AWGN the spreading codes should be mutually orthogonal. If the OFDM system consists of N subcarriers there are a maximum number of N orthogonal codes and $1 \leq M \leq N$ users can be supported every OFDM symbol. Apart from the described spreading procedure, the transmitter is identical to a conventional OFDM

transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard-interval is added) and D/A converted.

Brüninghaus-1997 at 188.

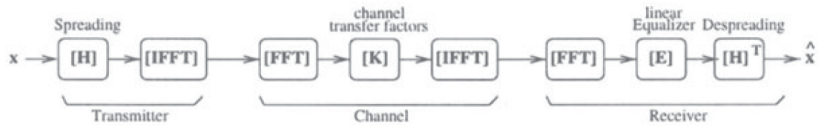


Figure 3: Model of a MC-CDMA transmission system with linear equalization

Brüninghaus-1997 at 190.

Both demands, i.e. minimal mean square error in frequency-selective fading channels and low dynamic range of the signal envelope, can also be met for the downlink if an FFT matrix is used as spreading matrix. In this case spreading and IFFT-processing cancel each other, see Fig. 3, and the transmission system degenerates into a single-carrier system, as depicted in Fig. 4. The main advantage of this step is that at this stage all knowledge about dynamic reduction of single carrier systems with linear modulation can be applied to create a time signal with low dynamic range.

Brüninghaus-1997 at 189.

The special choice of a FFT matrix as spreading matrix for Multi-Carrier CDMA leads to a single-carrier system with guard-interval. This way, the multi-carrier specific problems as high dynamic of the signal envelope, sensivity to phase noise and frequency/ clock synchronization errors can be avoided without losing the performance capacity of MC-CDMA. In case of linear equalization the receiver consists of a frequency domain equalizer with blockwise processing. Due to the guard-interval, this frequency domain equalizer outperforms the comparable time domain equalizer considerably and shows even in frequency-selective radio channels a

relatively good performance. Besides, the compuation complexity of such a receiver structure with blockwise processing in the frequency domain is lower than with processing in the time domain in case of highly dispersive channels.

Brüninghaus-1997 at 193.

Sorger-1997, which discloses:

> The first $L_\Delta Q$ chips $c_l^{(i)}$, $l = 0, \ldots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by
>
> $$T_\Delta = L_\Delta \cdot Q \cdot T_c, \quad (7)$$
>
> where L_Δ has to be chosen to meet the condition of Eq. (2). The transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user dependent phase vector $s^{(i)}$ of dimension L_c having components
>
> $$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \ldots, L_c - 1. \quad (8)$$
>
> The user dependent phase $\Phi^{(i)}$ is chosen to be
>
> $$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \quad (9)$$
>
> The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures the user discrimination by assigning to each user i a different set of orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as
>
> $$x^{(i)} = \left[c_0^{(i)}, c_1^{(i)} e^{-j\Phi^{(i)}}, c_2^{(i)} e^{-j2\Phi^{(i)}}, \ldots, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \quad (10)$$

Sorger-1997 at 113.

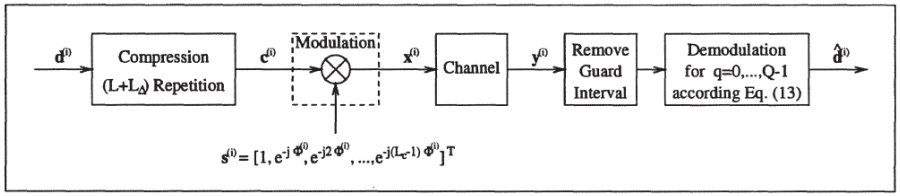


Figure 1: Block diagram of the proposed IFDMA system

Sorger-1997 at Fig. 1.

Brüninghaus-1998, which discloses:

> The combination of orthogonal frequency division multiplexing (OFDM) and code division multiplexing (CDM) has found great interest during the last few years. In contrast to a conventional OFDM system the information is spread over several subcarriers using orthogonal codes which leads to a diversity gain in frequency-selective channels. In this paper it is shown that such a system is technically equivalent to a single-carrier system with guard interval if the columns of a Fourier matrix are used as spreading codes. The pros and cons of such a system compared to an OFDM-CDM system with abritrary spreading matrix are described and discussed.

Brüninghaus-1998 at 2329.

> In the last years, multi-carrier transmission and especially OFDM (orthogonal frequency division multiplexing) have received much attention due to its ability of transmitting high data rates even in highly time dispersive radio channels with reasonable equalization effort. These systems are characterized by parallel data transmission over a number of generally narrowband subchannels. Recently, a combination of multi-carrier transmission and code division multiplexing (CDM) was proposed to improve the performance of multi-carrier systems [1], [2]. In this case every data symbol is spread over several subcarriers prior to subcarrier modulation and despread in the receiver, which is in fact a kind of

	frequency diversity. The same effect can be achieved with channel coding but it was shown in [3] that at least at code rates above 1/2 the combination of spreading and coding performs better than coding only. Brüninghaus-1998 at 2329. In the literature, Walsh-Hadamard codes are generally used as spreading codes but in principle every other orthogonal code matrix can be applied. In this paper we will focus on the special case that the Fourier matrix is used as orthogonal code matrix. Since the multi-carrier transmission signal is generated by an inverse Fourier-transform (IFFT), both operations - spreading and IFFT - cancel each other resulting in a pure single-carrier system with blockwise processing. This fact was already mentioned in [4] but without noticing that this kind of processing combines the advantages of single-carrier transmission, like constant signal envelope, simple clock and frequency synchronization, with the advantages of OFDM-CDM like high performance in frequency-selective channels. In the following sections, a brief review of OFDM-CDM is given, followed by a detailed discussion of the resultant transmission technique and its advantages. Brüninghaus-1998 at 2329. With OFDM-CDM the complex data symbols $x_i, \quad 1, \dots, M$, which can be elements of any arbitrary symbol set, e.g. PSK or QAM, are spread over *N* subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation $$s = [H] \cdot x \qquad (1)$$ where $x = (x_1, \dots, x_M)^T$ is the vector of data symbols, $s = (s_1, \dots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix of dimension$N \times M \quad (M \leq N)$. Apart from spreading, the transmitter is identical to a conventional OFDM transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard interval is

added) and D/A converted, see Fig. 1. In the receiver, the inverse processing is performed, see Fig. 2.

Brüninghaus-1998 at 2329.

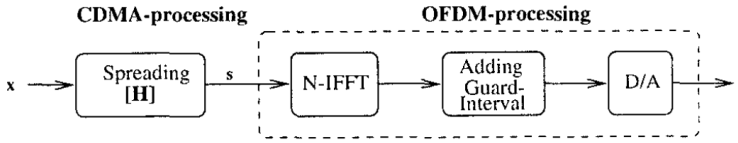


Fig. 1. Block diagram of a multi-carrier CDM transmitter

Brüninghaus-1998 at 2329.

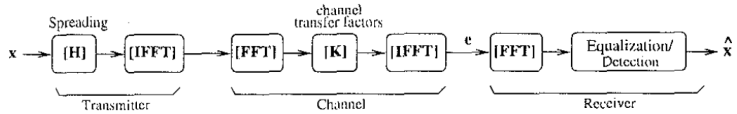


Fig. 3. Model of a multi-carrier CDM system

Brüninghaus-1998 at 2330.

The performance of the overall transmission system does not depend on the specific type of the orthogonal spreading matrix as long as every element of the matrix has the same magnitude which means that the energy is uniformly spread over all subcarriers [10]. Considering the case that all available orthogonal codes are used, i.e. the spreading matrix is a square matrix of dimension N x N, the matrix of the Fast Fourier transform meets the above mentioned demands as well as the often proposed Walsh-Hadamard matrix. If such an FFT-matrix is used spreading and OFDM processing cancel each and the transmission system degenerates into a linearly modulated single-carrier system with guard interval, i.e

$$s(t) = \sum_n x_n \cdot p(t - nT) \quad \text{where} \quad x_n = x_{n-N} \quad \text{if} \quad i(N + N_G) - N_G \leq n < i(N + N_G) \quad i \in Z \quad (2)$$

In Eq. (2), the parameter N_G describes the length of the guard interval in number of data symbols spaced by the symbol duration *T*.

Brüninghaus-1998 at 2330.

A. Dynamic of the signal envelope

It is well known that the envelope of an OFDM signal has a high dynamic which requires a linear power amplifier in the transmitter. A lot of studies have been performed with the aim to reduce the signal dynamic of multi-carrier systems but all methods known from literature [11] - [13] have certain drawbacks. These drawbacks are either high computation complexity, large memory requirements or signal distortions. At least in the case of absolute modulation (no differential encoding) these disadvantages can be overcome if the Fourier-matrix is used for spreading. Since the multi-carrier CDM system is thereby transformed into a single-carrier system with linear modulation the amplitude dynamic only depends on the pulse shape *p(t)*. In connection with second generation mobile systems this topic has been analyzed extensively and solutions are very well known: in case of binary transmission for example, MSK (minimum shift keying), which uses a sinusoidal pulse, can be applied leading to a constant envelope signal. Quaternary transmission can be realized with low amplitude dynamic using Offset-QPSK.

Brüninghaus-1998 at 2330.

Since the single-carrier system which results from an OFDM-CDM system with Fourier spreading matrix is a special case of an OFDM-CDM system, the same detection algorithms can be applied and the same performance can be expected.

	Brüninghaus-1998 at 2330. A general block diagram of an OFDM-CDM receiver with linear equalization [8] is depicted in Fig. 4. In case of a Fourier spreading matrix, despreading in the receiver is achieved by an inverse Fast-Fourier matrix, i.e. $[H]^H = [IFFT]$. The overall processing corresponds to a frequency domain equalization (FDE) since the received signal vector is first Fourier-transformed, multiplied by a diagonal equalization matrix and then transformed back into the time domain. Such an FDE was originally proposed in [17] to speed up the convergence of the equalizer coefficients in conjunction with the stochastic gradient method. In [18] the FDE was picked up again to compare single-carrier and multi-carrier (OFDM) transmission but without noticing that the considered single-carrier system is a special case of an OFDM-CDM system. Recently, the FDE was discussed for use in future mobile communication systems in combination with antenna diversity [20]. Brüninghaus-1998 at 2330. In contrast to a conventional single-carrier system, the single-carrier system resulting from OFDM-CDM with Fourier spreading matrix is characterized by a guard interval and the question arises why it should be advantageous to waste some part of the bandwidth. There are two reasons: the first one is the higher performance at the same number of equalizer coefficients in case of linear or decision feedback equalization. This results from the fact that the periodic extension of the data sequence in the transmitter in connection with the signal windowing the receiver leads to a cyclic convolution of the data sequence and the discrete-time channel impulse response. If the corresponding discrete-time channel transfer function contains no zeros, this cyclic convolution can be perfectly inverted in the receiver requiring not more than *N*(=length of data sequence) coefficients. To achieve the same effect with a conventional single-carrier system, generally an equalizer with an infinite number of taps is required,

	which cannot be implemented in a real system. Thus, an equalization error occurs, which limits the performance at high signal-to-noise-ratios. Brüninghaus-1998 at 2330-31. System parameters: • General - Bandwidth B = 2MHz - linear equalization based on MMSE criterion • OFDM-CDM with Fourier spreading matrix - blocklength: $T_N = 32\mu s$ - Guardlength: $T_G = 6.6\mu s$ - Number of symbols per block: $N = 64$ • Single-carrier system without guard interval - pulse with raised cosine spectral characteristic and rolloff' factor $\beta = 0.2$ - Symbol length: Ts = 600ns • Channel parameters: - Exponentially decreasing power delay profile from 0 to $5\mu s$ - Rayleigh channel - time invariant Brüninghaus-1998 at 2331. The special choice of an FFT matrix as spreading matrix for OFDM-CDM leads to a single-carrier system with guard interval. Such a single-carrier system has the same performance as the OFDM-CDM system but is less sensitive to nonlinear effects due to the reduced dynamic of the signal amplitude. In case of linear equalization, a single-carrier system with

guard-interval yields the same (low S/N) or even a better (high S/N) performance than the corresponding system without guard interval at the same number of equalizer coefficients and data rate. Besides, in highly time dispersive channels the computation complexity of such a receiver structure with blockwise processing is considerably lower than with continuous processing.

Brüninghaus-1998 at 2332.

Sorger-1998, which discloses:

The dimension of the IFDMA-symbol $c^{(i)}$ is $L_c = (L + L_\Delta)Q$ and the components $c_l^{(i)}$ can be written as

$$c_l^{(i)} = \frac{1}{L + L_\Delta} \cdot d_{l \bmod Q}^{(i)}, \quad l = 0, \dots, L_c - 1. \tag{6}$$

The first $L_\Delta Q$ chips $c_l^{(i)}, l = 0, \dots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by

$$T_\Delta = L_\Delta \cdot Q \cdot T_c. \tag{7}$$

where L_Δ has to be chosen to meet the condition of Equation (2). Finally, the transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user-dependent phase vector $s^{(i)}$ of dimension L_c having components

$$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \dots, L_c - 1. \tag{8}$$

The user-dependent phase $\Phi^{(i)}$ is chosen to be

$$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \tag{9}$$

The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures an orthogonal user discrimination by assigning to each user *i* a different set of

orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as

$$x^{(i)} = \left[c_0^{(i)},\, c_1^{(i)} e^{-j\Phi^{(i)}},\, c_2^{(i)} e^{-j2\Phi^{(i)}},\, \ldots,\, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \qquad (10)$$

Sorger-1998 at 1014.

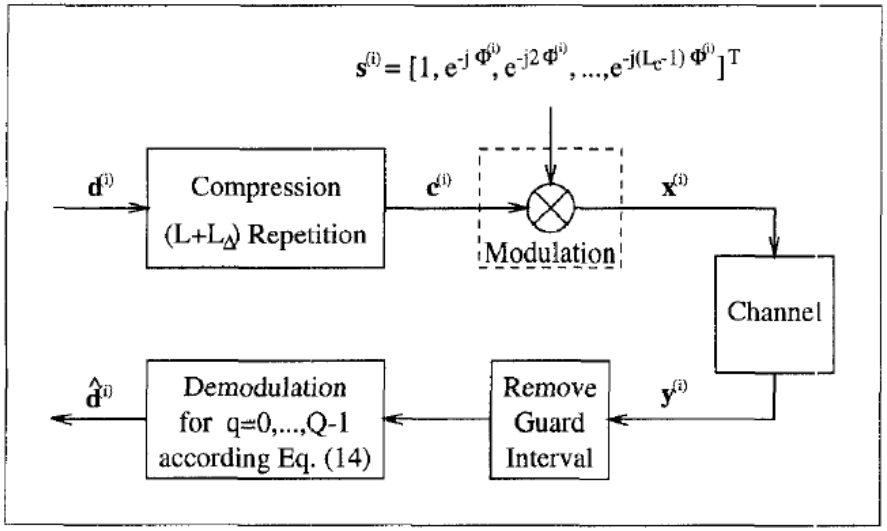


Figure 2: Block diagram of the proposed IFDMA system for a single user i

Sorger-1998 at Fig. 2.

Bury-1999, which discloses:

> We present a generalization and an extension of the block decision feedback equalizer described by Reinhardt in [1]. The original equalizer was derived for a class of transmission which is described by an orthogonal spreading over a group of non-interfering fading channels. We generalize

	this concept for block transmissions with arbitrary interference; the generalized description also includes reception with multiple antennas using joint diversity combining and equalization. In extension, we introduce soft feedback for all individual symbols, in contrast to the single soft value used in [1], offering an improved performance. We describe the proposed equalization method, provide examples for application, and illustrate the performance by simulation results. Bury-1999 at 345. In many practical cases it is convenient to transmit data in blocks which can be processed independently. Examples for block transmission methods are MC-CDM(A) on the basis of OFDM [3], Interleaved FDMA as described in [2], or serial transmission with termination to assure that there is no interference between blocks [4]. If there is interference within a block, the optimum detector performs a highly complex search of the most probable combination of transmit symbols. A less complex method is to employ equalization together with single symbol detection. Linear equalization allows simple implementation. The proposed decision feedback equalizer offers an improvement over linear equalization - however, at the cost of some complexity increase. Bury-1999 at 345-346. 6. SPREAD TRANSMISSION We now consider the special case of transmission over a set of interference free fading channels, where orthogonal symbol spreading is used to achieve a diversity gain. Figure 4 shows a model for this type of transmission.

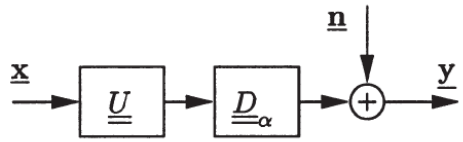


Figure 4 Transmission over non-interfering channels with orthogonal spreading

In this figure, $\underline{\underline{U}}$ is an orthogonal matrix for spreading, $\underline{\underline{D}}_\alpha$ is a diagonal matrix with the channel amplitudes on the main diagonal and zeros elsewhere, and we assume white noise with $\underline{\underline{\Phi}}_{nn} = \sigma_n^2 \cdot \underline{\underline{I}}$. The orthogonal spreading matrix has the property $\underline{\underline{U}}^H = \underline{\underline{U}}^{-1} = \underline{\underline{U}}$. For the cases of a Hadamard transform or a Fourier transform, multiplication with $\underline{\underline{U}}$ may be implemented as a fast algorithm (Fast Fourier Transform, FFT; Fast Hadamard Transform, FHT). By inserting $H = \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}}$ into equations (3), (4) and (5), we find

$$\underline{\underline{A}}_{\text{opt}}^{(0)} = \underline{\underline{U}}^H \cdot \underline{\underline{D}}_{\tilde{\alpha}} \quad \text{with} \quad \tilde{\alpha}_i = \frac{\alpha_i^*}{|\alpha_i|^2 + \frac{\sigma_n^2}{\sigma_x^2}} \tag{8}$$

$$\underline{\underline{A}}_{\text{opt}}^{(r)} = \underline{\underline{D}}_p^{(r)} \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)}, \tag{9}$$

$$\underline{\underline{B}}_{\text{opt}}^{(r)} = \underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)} - \text{diag}\left(\underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)}\right). \tag{10}$$

$$\underline{\underline{Q}}^{(r)} = \left(\underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \left(\underline{\underline{I}} - \underline{\underline{D}}_{|\varrho|^2}^{(r)}\right) \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H + \frac{\sigma_n^2}{\sigma_x^2} \cdot \underline{\underline{I}}\right)^{-1},$$

$$\frac{1}{p_i^{(r)}} = 1 + \underline{u}_i{}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{u}_i \cdot \left|\varrho_i^{(r)}\right|^2.$$

For the special case where for arbitrary i and fixed *r* the feedback values $\varrho_i^{(r)}$ are all identical, computation of the filter coefficients can be further

simplified, such that no matrix inversion is required; this has been derived in [1].

Bury-1999 at 350-51.

This model of spread transmission is applicable to, e.g., the following transmission schemes:

MC-SSMA (Multi-Carrier Spread Spectrum Multiple Access) as described in [3] uses a Hadamard transform to spread a vector of transmit symbols over a set of OFDM subchannels; each OFDM subchannel may be considered as a single Rayleigh fading channel. OFDM-CDMA is another name for essentially the same method.

IFDMA (Interleaved Frequency Division Multiple Access) as introduced in [2] can be described as an OFDM transmission where Fourier spreading is used to transmit over sets of equally spaced OFDM subchannels.

Serial block transmission over a multipath channel, using cyclic extension of transmitted blocks and corresponding extraction at the receiver, may be considered as an OFDM transmission with Fourier spreading over all subchannels. The equalizer can be implemented in the frequency domain by assuming a Fourier matrix for spreading. A linear equalizer for frequency domain equalization (FDE) has been presented in [4].

Bury-1999 at 351.

Bury-2000, which discloses:

Abstract - In this paper we investigate amplitude distributions of transmit signals for multi-carrier spread spectrum (MC-SS) transmission methods based on orthogonal frequency division multiplexing (OFDM), also called multi-carrier code division multiplexing (MC-CDM). In particular we compare Fourier spreading with the commonly used Walsh-Hadamard spreading. As a basis for the comparison we describe a general model. Both up- and downlink of multiple access transmission schemes employing

	either multi-carrier code division multiple access (MC-CDMA) or multi-carrier frequency division multiple access (MC-FDMA) are compared. Bury-2000 at 857. Multi-carrier code division multiplexing (MC-CDM) [1] is an interesting candidate for the physical layer in wireless high data rate local area networks. When compared to orthogonal frequency division multiplexing (OFDM), the additional spreading of MC-CDM produces a signal space diversity which improves power efficiency especially for high code rates [2]. A Hadamard transform is used for spreading in most MC-CDM system descriptions, e.g. [1]. However, further choices for orthogonal spreading are possible. With Fourier spreading [3], which can be implemented by a discrete Fourier transform (DFT) operation, it is clear that it can cancel the inverse discrete Fourier transform (IDFT) of an OFDM transmitter when spreading is done over all subcarriers, such that the result is a simple serial block transmission with cyclic extension [4]. This serial transmission can be regarded as a spread spectrum transmission, since the entire transmission bandwidth is covered by each transmitted symbol. The peak-to-average power ratio (PAPR) of a serial transmission is much lower than that of an OFDM transmission. The question that arises is: how is the situation when spreading is done not over all OFDM subcarriers but only over groups of carriers? Bury-2000 at 857. In [5] Golay complementary sequences have been used instead of Hadamard sequences for reducing the PAPR in MC-CDMA transmission, and a scrambling scheme was employed to further improve the amplitude distribution of the transmit signal. In this paper we suggest to employ a DFT for spreading, which can be implemented efficiently as a fast Fourier transform (FFT). Furthermore we extend our considerations to MC-FDMA, as introduced in [6] (named MC-SS-MA there).

Bury-2000 at 857.

> Subsequently we describe a model of a MC-CDM transmitter. In a multiple access context, this model is valid for both, MC-CDMA and MC-FDMA. We describe the methods used for computation of the amplitude distribution and the PAPR of the transmit signal. It is shown that, given the transmit symbol alphabet and the corresponding symbol probabilities, both amplitude distribution and PAPR are uniquely determined by a single matrix which describes the transmitters linear mapping from transmitted symbols to the transmit signal. Based on simulation results, we discuss the suitability of Hadamard and Fourier spreading for MC-CDM transmission methods.

Bury-2000 at 857.

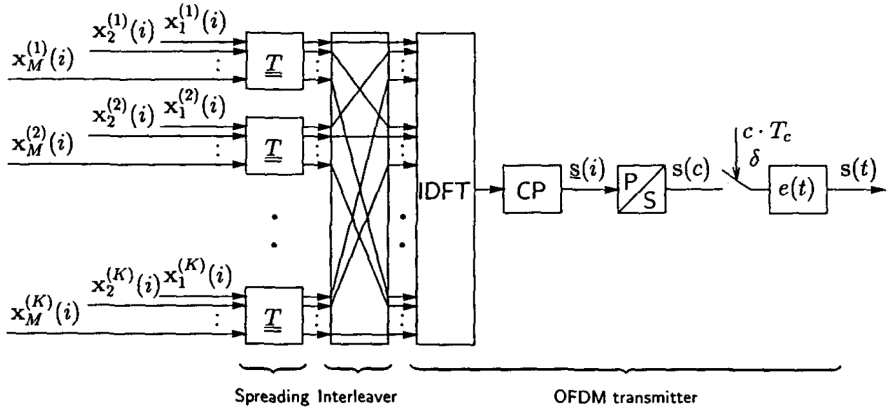


Fig. 1. Model of transmitter for OFDM-based MC-CDM.

Bury-2000 at 858.

> The model in Fig. 1 depicts a transmitter for MC-CDM based on OFDM. An OFDM transmitter is extended by an additional spreading, described by

	the transform matrices $\underline{\underline{T}}$, and by an interleaver. The OFDM transmitter consists of an IDFT, a cyclic prefix insertion CP, a parallel-to-serial conversion, and the conversion to continuous-time using an ideal Dirac sampler and a basic waveform $e(t)$, which is a Nyquist impulse. The delivered baseband transmit signal is $s(t)$. The number of OFDM subcarriers is N, the cyclic prefix has length L, transmit signal samples are indexed by c, and the Dirac sampler generates an impulse every T_c seconds. Bury-2000 at 857. Spreading is done by transforming a vector of M symbols through a matrix $\underline{\underline{T}}$. This square matrix is orthogonal, such that the condition $$\underline{\underline{T}}^H \underline{\underline{T}} = \underline{\underline{I}} \quad (1)$$ is fulfilled. Furthermore, to assure equal energy distribution, we consider only spreading matrices with the property that the absolute value of all matrix elements is constant $$\left|t_{i,k}\right| = \frac{1}{\sqrt{\underline{\underline{N}}}} \quad \forall\, i,k. \quad (2)$$ In literature usually a Hadamard transform is selected for $\underline{\underline{T}}$; however, further choices are possible, e.g. a DFT. Bury-2000 at 857-58. III. AMPLITUDE DISTRIBUTION OF THE TRANSMIT SIGNAL For a certain time instant t_0 the complex baseband transmit signal $s(t_0)$ is a random variable which is in general a linear combination of all random transmit symbols

$$s(t_0) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{K} \sum_{m=1}^{M} \alpha_{m,k,i}(t_0) x_m^{(k)}(i)\,. \qquad (3)$$

The coefficients $\alpha_{m,k,i}(t_0)$ are derived from $\underline{\underline{T}}$, $e(t)$, N, L, K, and M, as described subsequently. When the duration of the basic waveform $e(t)$ is finite, the infinite sum over i in this equation can be replaced by a finite sum. Then the probability density function (PDF) of the transmit signal at time $t_0, f_{s(t_0)}(x)$, is obtained from the PDFs of all contributing transmit symbols.

Bury-2000 at 858.

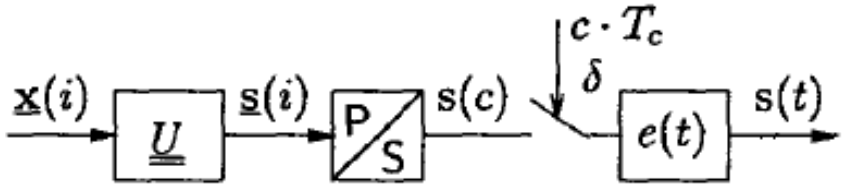


Fig. 2. Equivalent transmitter model.

Bury-2000 at 859.

Discrete-time computation

At discrete time we consider the signal $s(c)$ instead of $s(t)$. To obtain a simple description we join the spreading, interleaving, IDFT and cyclic extension of the transmitter in Fig. 1 into a single matrix $\underline{\underline{U}}$, see Fig. 2.

. . .

	The discrete-time transmit signal of a single OFDM block ($i = 0$) then represents the cyclo-stationary statistics of the transmit signal. We omit the block index i and write $$\underline{s} = \underline{\underline{U}} \cdot \underline{x}, \quad (6)$$ with vector elements $x_{(m+M(k-1))} = x_m^{(k)}(0)$ and $s_c = s(c)$. In equivalence to equation (3) we write $$s_c = \sum_{n=1}^{N} u_{c,n} x_n \,. \quad (7)$$ Hence, the PDF at a particular time instant c is related with a certain row in $\underline{\underline{U}}$. Bury-2000 at 859. From above equations we see that, given the transmit symbol alphabet and corresponding occurrence probabilities, the PDF of the discrete-time transmit signal, $f_{s(c)}(x)$, is determined by the transform matrix $\underline{\underline{U}}$. For the case of Fourier spreading, the matrix $\underline{\underline{U}}$ contains in most cases more zero elements than for Hadamard spreading. This already indicates a better amplitude distribution for Fourier spreading, because fewer random variables are summed. Bury-2000 at 859.

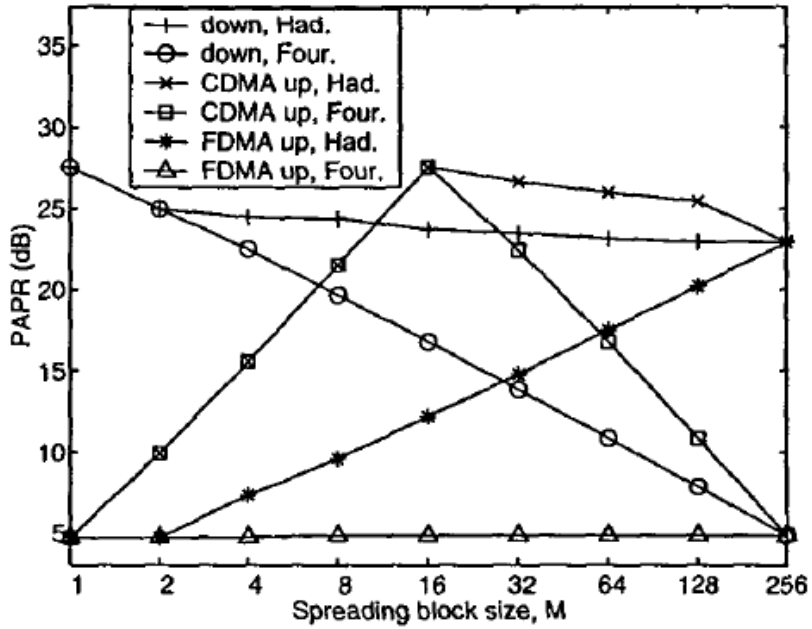


Fig. 3. PAPR as a function of the spreading block size. 4PSK, $N = 256$, $L = 32$, 'continuous' time.

Bury-2000 at 859.

Downlink

In the downlink, the PAPR is the same for both MC-CDMA and MC-FDMA. This is obvious because both systems are identical except for the assignment of transmitted symbols to users. For the trivial case of spreading over a single carrier and for the case of spreading over two carriers, both Hadamard and Fourier spreading deliver the same PAPR. In the latter case this happens because Hadamard and Fourier matrices are identical for spreading over two symbols. In the case of Hadamard spreading, when spreading is done over an increasing number of

	subcarriers, the PAPR remains nearly constant (with a slight decrease); for Fourier spreading, however, it decreases rapidly and reaches the PAPR of a single carrier transmission when spreading is done over all subcarriers. This means that for the downlink Fourier spreading clearly outperforms Hadamard spreading. The larger the spreading factor, the better the PAPR. Furthermore, assuming that a large number of users is desired, we consider the following: Since MC-FDMA requires (at least) one spreading block per user, the spreading blocks must be small in case of many users, resulting in a relatively large PAPR. For MC-CDMA, however, the larger the spreading block, the larger the possible number of users. Here the best choice with respect to PAPR is to use Fourier spreading over all carriers while assigning groups of input symbols for each user, resulting in the lowest possible PAPR. Bury-2000 at 859-60. Uplink In the uplink we distinguish between MC-CDMA and MC-FDMA. For MC-CDMA the PAPR of both Fourier and Hadamard spreading shows a strong increase for increasing spreading factors, reaching a maximum when the spreading factor equals the square root of the number of subcarriers. When the spreading factor is increased further, Hadamard spreading shows a slight decrease in PAPR while Fourier spreading shows a rapid decrease, reaching the PAPR of a serial transmission when spreading is done over all carriers. In contrast to MC-CDMA, MC-FDMA shows a much better behavior, with the PAPR being lower for the entire range of spreading factors, for the respective spreading methods. For Hadamard spreading, the PAPR increases for increasing spreading factors. For Fourier spreading, however, the PAPR remains nearly constant at a low level for all spreading factors. This shows that also in the uplink Fourier spreading outperforms Hadamard spreading in most cases. For the case of Fourier spreading in a

MC-FDMA uplink, the spreading factor may be selected arbitrarily, nearly without affecting the PAPR.

Bury-2000 at 860.

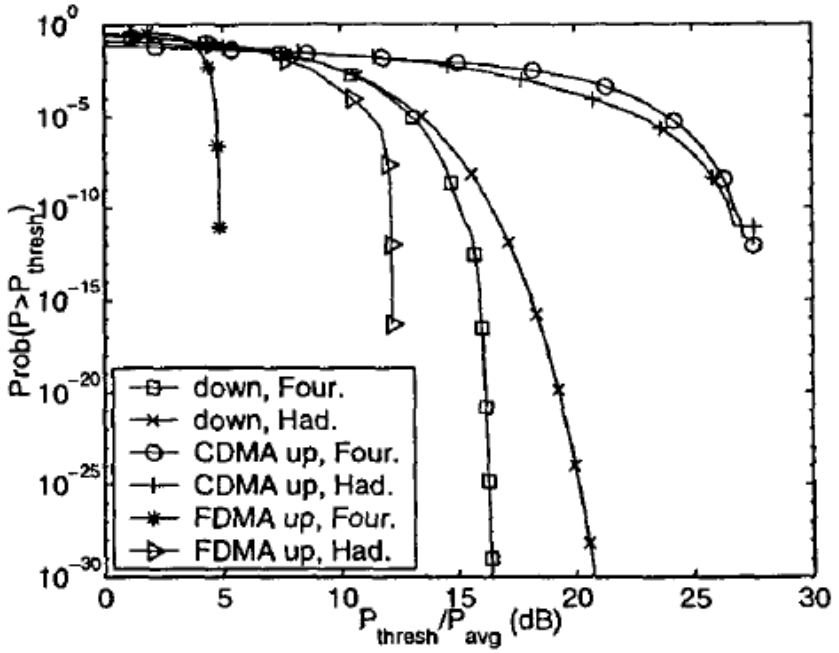
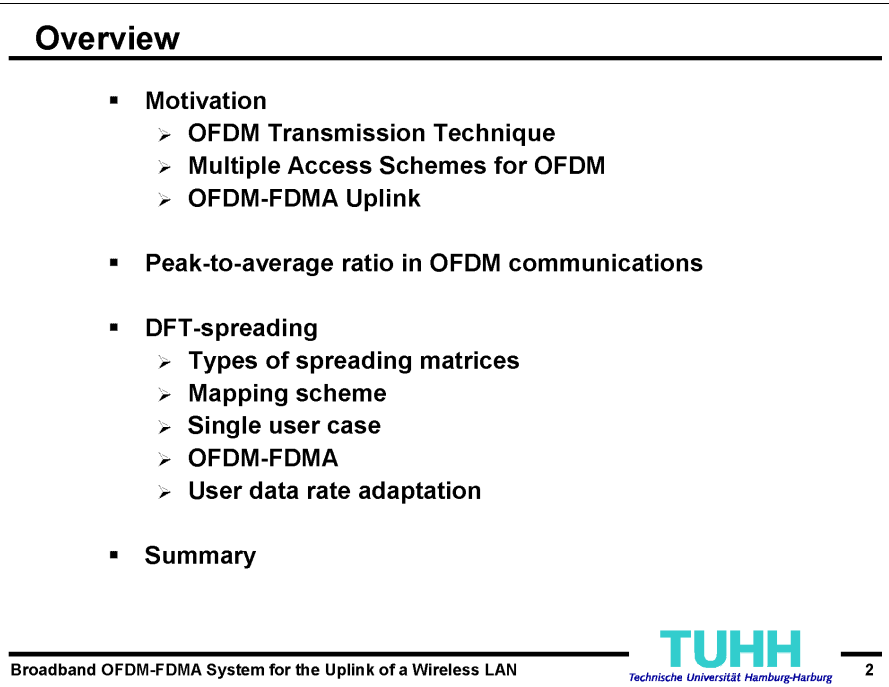


Fig. 4. Example for amplitude distribution.
4PSK, $N = 256$, $L = 32$, $M = 16$, 'continuous' time.

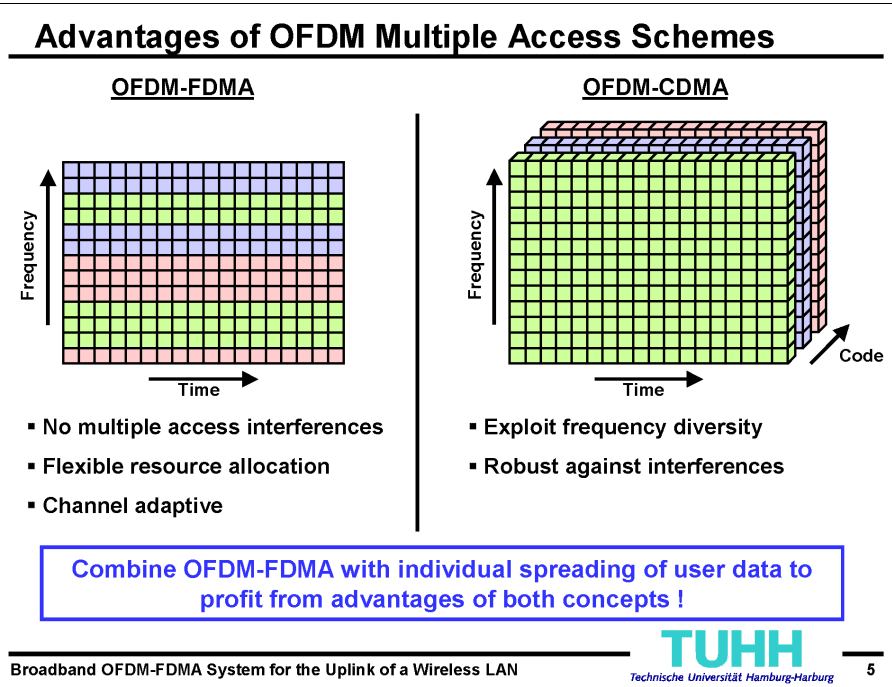
Bury-2000 at 860.

The graph shows that, in case of the downlink, Fourier spreading offers a more sharply limited amplitude distribution while Hadamard spreading produces continuously growing amplitudes at decreasing probabilities. Not only from the PAPR point of view, but also from the PDF of the amplitude

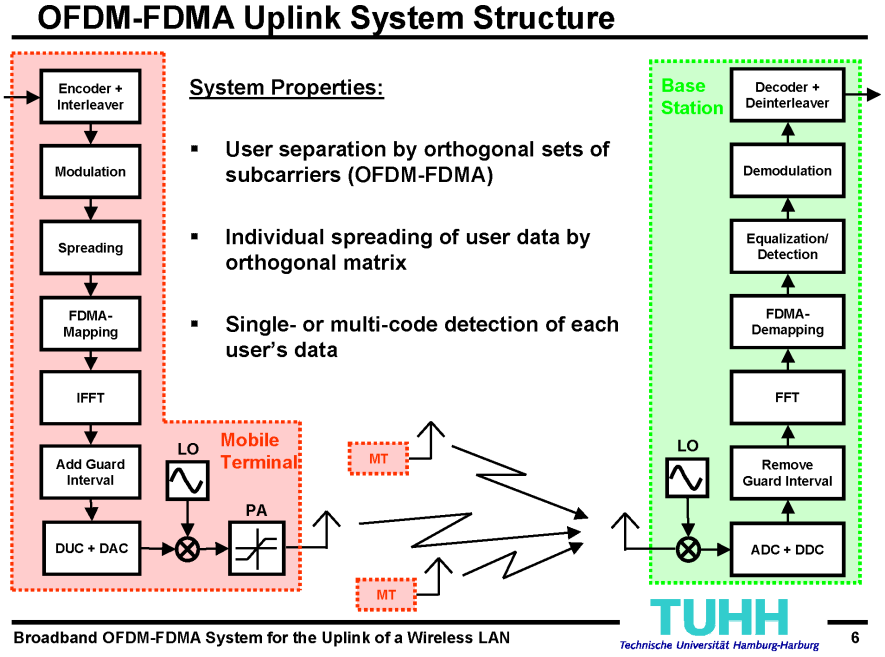
	it is clear that Fourier spreading is a better choice than Hadamard spreading. Bury-2000 at 860. Amplitude distributions of Hadamard spreading and Fourier spreading have been compared for OFDM based MC-CDM transmission methods, using a general matrix model. Comparison has been done for both up- and downlink in MC-CDMA and MC-FDMA multiple access scenarios, and for various spreading factors. For both up- and downlink Fourier spreading delivers a lower or equal PAPR. This superiority increases significantly for larger spreading factors. In the uplink, MC-FDMA delivers lower PAPRs than MC-CDMA. From the amplitude distribution point of view, the best choice is to employ Fourier spreading with MC-CDMA in the downlink and with MC-FDMA in the uplink. Bury-2000 at 860. Galda-2001, which discloses:



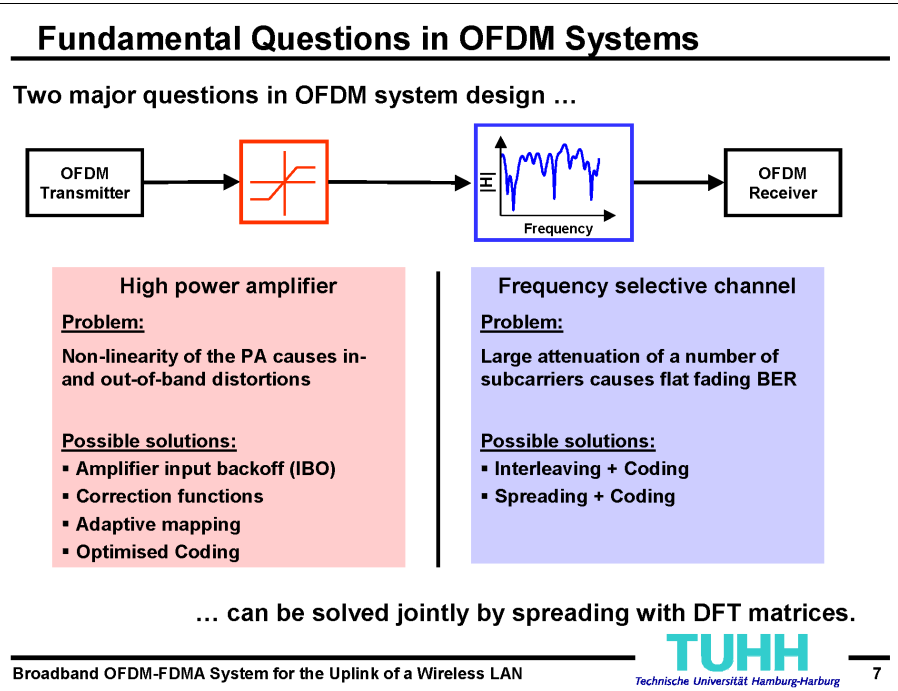
Galda-2001 at 2.



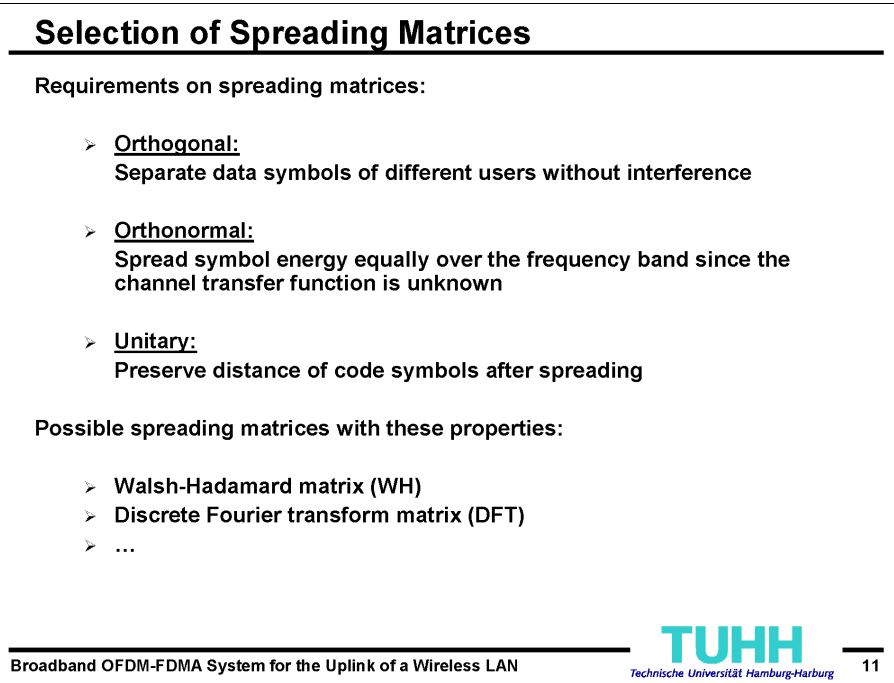
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Galda-2001 at 6.



Galda-2001 at 7.



Selection of Spreading Matrices

Requirements on spreading matrices:

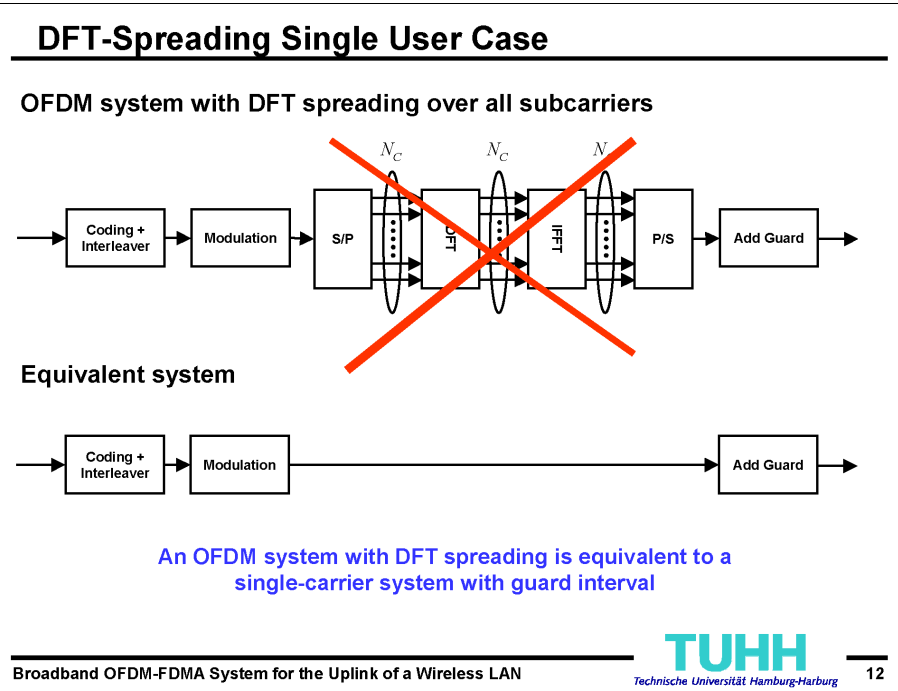
- Orthogonal:
  Separate data symbols of different users without interference
- Orthonormal:
  Spread symbol energy equally over the frequency band since the channel transfer function is unknown
- Unitary:
  Preserve distance of code symbols after spreading

Possible spreading matrices with these properties:

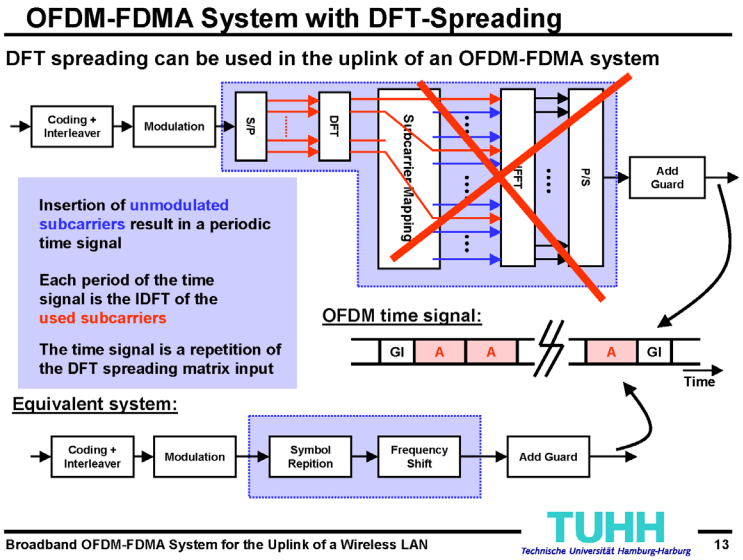
- Walsh-Hadamard matrix (WH)
- Discrete Fourier transform matrix (DFT)
- ...

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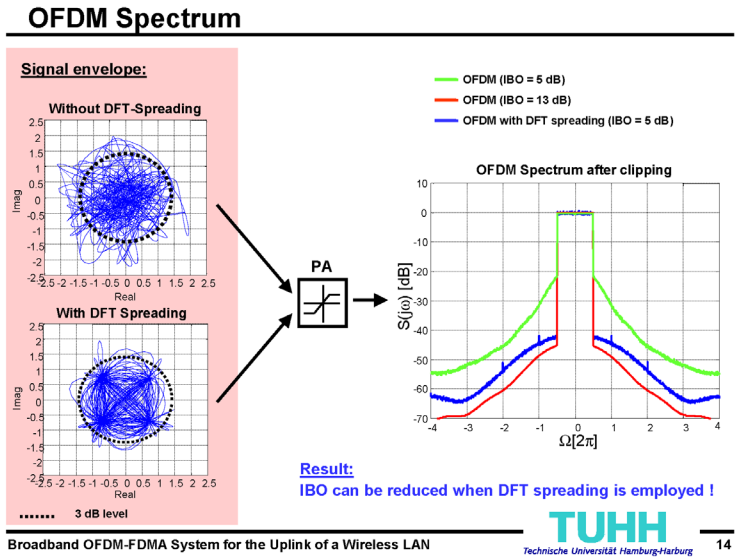
Galda-2001 at 11.



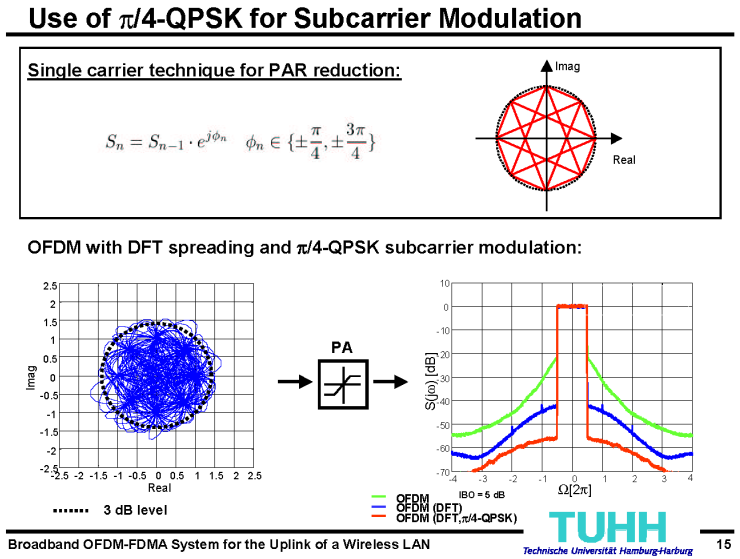
Galda-2001 at 12.



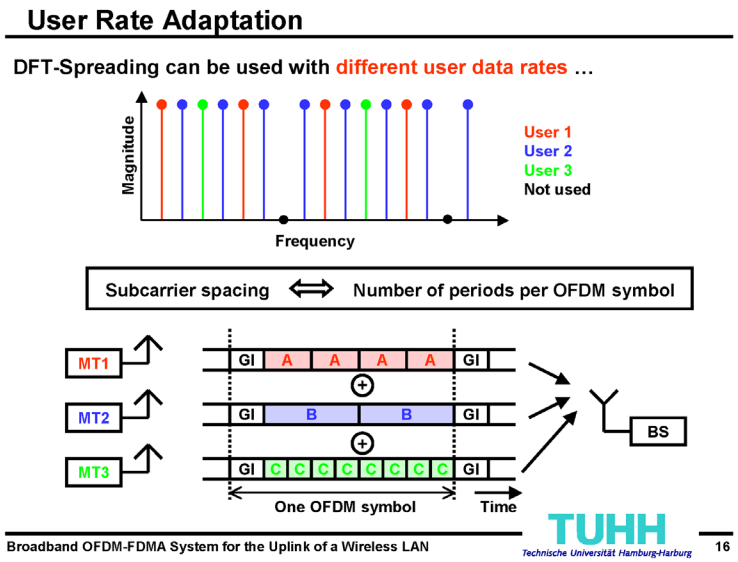
Galda-2001 at 13.



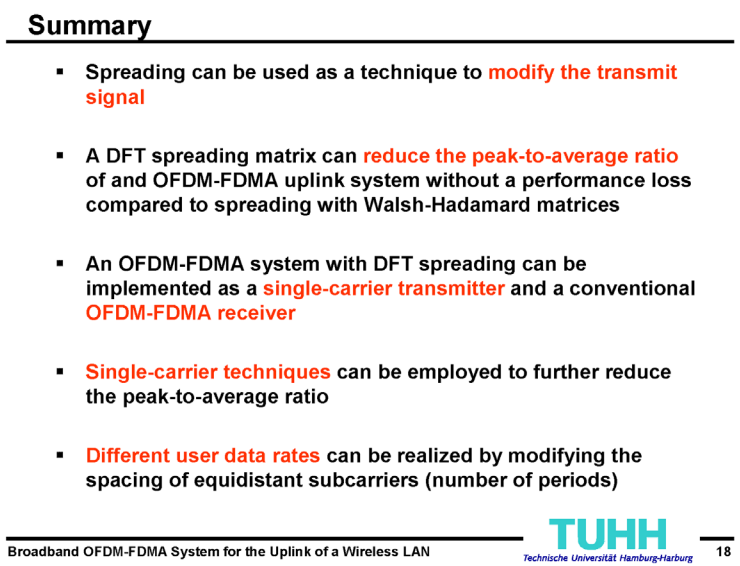
Galda-2001 at 14.



Galda-2001 at 15.



Galda-2001 at 16.



Galda-2001 at 18.

Galda-2002, which discloses:

> Abstract- The orthogonal frequency division multiplex (OFDM) transmission technique can efficiently deal with the effects of multi-path propagation in the broadband radio channel. It also has a high system inherent flexibility for designing a multiple access scheme by combining the conventional TDMA, FDMA and CDMA approaches with the OFDM modulation scheme. The FDMA multiple access scheme is especially interesting for an uplink of a communication system since it can completely avoid any multiple access interferences (MAI). Moreover, the peak-to-average ratio (PAR) of the uplink OFDM transmit signal can be greatly reduced if this OFDM-FDMA multiple access scheme is additionally combined with a data spreading technique based on a Discrete Fourier

	Transform (DFT) spreading matrix using only the user specific subcarriers. Since the DFT spreading operation and the IDFT operation used as a part of the OFDM modulation scheme cancel out each other the complexity of the transmitter structure for an OFDM-FDMA uplink can be greatly reduced. Galda-2002 at 1737. The subdivision of the transmission bandwidth into a set of orthogonal subcarriers can additionally be exploited by an OFDM-FDMA multiple access scheme. By allocating distinct sets of subcarriers to different users the available bandwidth can be flexibly shared between different mobile terminals while avoiding any multiple access interferences (MAI) between different users. The FDMA multiple access scheme offers not only a high flexibility for the radio resource management (RRM) but can also increase the bandwidth efficiency of the complete system by avoiding the use of highly attenuated subcarriers for specific users based on the knowledge of the channel transfer function [2]. Moreover, the OFDM-FDMA multiple access scheme can be adapted to the measured radio channel knowledge at the transmitter site using bit-loading techniques. If channel state information is not available the performance can be increased using an additional spreading over the subcarriers assigned to one user. The resulting computation complexity of the total system can by this means be adopted to the given system requirements which is especially of importance for the mobile terminal and in the uplink case. The alternative OFDM-FDMA multiple access scheme is therefore of importance for the uplink case and can be advantageous over OFDM-CDMA schemes because of its ability to avoid MAI if ideal carrier synchronization is assumed for all mobile terminals and the base station. Galda-2002 at 1737. Since the OFDM transmit signal results from the superposition of a large number of independent data symbols the envelope of the complex baseband

	time signal has in general a large peak-to-average ratio (PAR). The largest output power value of the amplifier will limit the maximum amplitude of the signal in the transmitter. Therefore, non-linear distortions due to clipping and amplification effects in the transmit signal will lead to both in-band and out-of-band emissions. In the past different techniques for reducing the PAR by changing the transmit signal independently from knowledge of other parts of the OFDM transmitter have been developed. But the PAR of the transmit signal envelope which employs an OFDM-FDMA multiple access scheme can significantly be reduced if additional spreading techniques are applied which spread the user data over the allocated subcarrier only. In this case an appropriate spreading technique must be designed reducing the PAR to a minimum value. It will be shown in this paper that using the Discrete Fourier Transform (DFT) matrix as an orthogonal spreading technique will reduce the PAR significantely [3]. Furthermore, the DFT based spreading operation and the IDFT based OFDM modulation technique cancel out each other which means that the transmitter structure can be simplified to a single carrier transmitter with an additional guard interval in this specific case which helps to reduce the computational complexity of the transmitter of the mobile terminal. Galda-2002 at 1737-38. This paper shows how an OFDM-FDMA uplink system can be combined with a user data spreading technique based on the DFT spreading matrix to reduce the PAR of the uplink signal without increasing the computational complexity of the transmitter. In Section II the structure of the analyzed OFDM-FDMA system combined with a DFT spreading matrix is described for the uplink application. In Section III the influence of a DFT matrix applied for data spreading is analyzed for an OFDM-TDMA multiple access scheme and is extended to an OFDM-FDMA system in a separate subsection. The general topic of non-linearities in an OFDM system is reviewed in Section IV. Quantitative results are given in Section V and Section VI summarizes the papers content.

Galda-2002 at 1738.

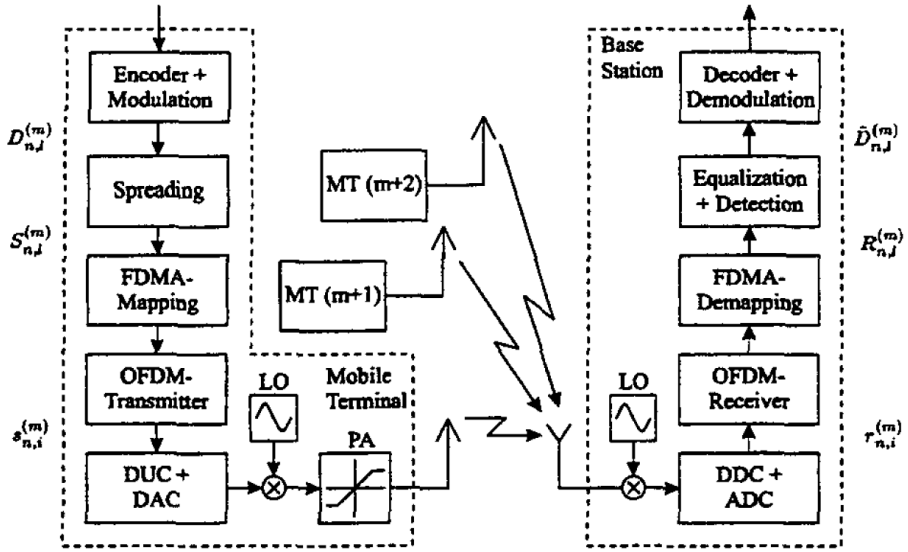


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

Galda-2002 at Fig. 1.

The baseband system model of an OFDM-FDMA uplink with individual spreading of user data is shown in Fig. 1. In this case M different users are considered and each user allocates L different subcarrier exclusively. The total number of subcarrier in the considered transmission system is $N_C = L \cdot M$. The input data stream for each mobile user $m, m = 0, \dots, M-1$, is convolutionally encoded in a first step. The bit sequence is then mapped onto L complex modulation symbols $D_l^{(m)}, l = 0, \dots, L-1$, of a coherent, higher-level modulation scheme. The L modulation symbols are spread over the L user specifically allocated subcarrier with an unitary spreading

matrix $[C]$ resulting in L complex transmit symbols $S_l^{(m)}$. The spreading operation can be denoted mathematically by the following simple matrix multiplication

$$\vec{S}^{(m)} = [C]\vec{D}^{(m)} \quad (1)$$

where each complex transmit symbol $S_l^{(m)}$ is calculated by the sum of L user modulation symbols $D_l^{(m)}$ weighted by L orthogonal code vectors $\widetilde{C_l} = \left(C_{l,0}, C_{l,1}, \dots, C_{l,l}\right)$ with $l = 0, \dots, L-1$

$$S_l^{(m)} = \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} \quad \text{for} \quad l = 0, \dots, L-1 \quad (2)$$

The transmit symbols $S_l(m)$ are then mapped onto L of the available N_C subcarrier which are exclusively allocated to user m. In principle, the set of subcarrier assigned to each user can be composed of any L out of N_C subcarrier that have not been assigned to another user.

Galda-2002 at 1738.

Independent of the considered spreading matrix C but assuming the equidistant allocation of subcarrier over the entire bandwidth the resulting OFDM time signal of user m can analytically be described as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \quad (3)$$

where N_G denotes the length of the guard interval which is inserted into the transmit time signal.

Galda-2002 at 1738.

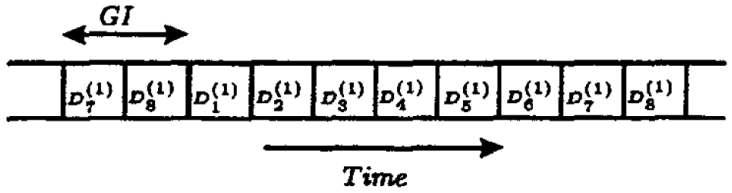


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

Galda-2002 at Fig. 3.

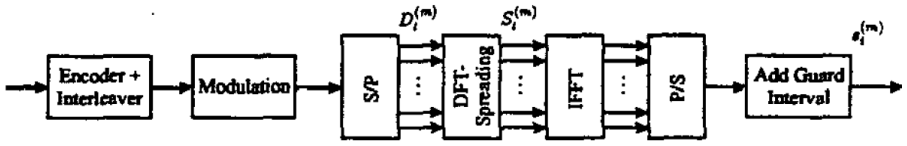
A. OFDM-TDMA with DFT Spreading

In [3] the Discrete Fourier Transformation (DFT) matrix has been used for spreading the vector $\vec{D}$ of length $L = N_C$ over all subcarriers of an OFDM system. If a single user is assumed in this OFDM system the spreading operation includes all subcarrier within the entire bandwidth. In this case the DFT spreading matrix and the IDFT operation in the OFDM modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore technically reduced to the serial sequence of complex transmit data symbols D_i to which a guard interval is added in the time domain as a cyclic prefix

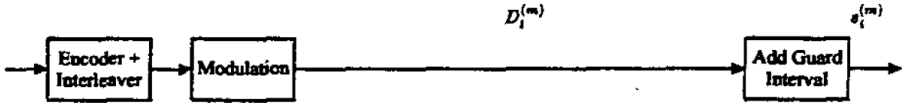
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \tag{5}$$

where mod denotes the modulo operation, as shown in Fig. 3.

Galda-2002 at 1739.



(a) OFDM transmitter including DFT spreading over all subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 4. In an OFDM system including a DFT spreading matrix and an IFFT for the OFDM modulation process both matrices cancel out each other.

Galda-2002 at Fig. 4.

> After calculating the FFT in the receiver which splits the received time signal into the orthogonal sub-channel the same single- or multi-code detection techniques can be applied which are well known from OFDM-CDMA receiver structures. The same bit error rate (BER) performance compared to a system using a Walsh-Hadamard spreading matrix can therefore be achieved if a DFT spreading matrix is considered instead. But in case of a DFT spreading matrix the resulting PAR is significantly reduced. The general structure of an OFDM transmitter including DFT spreading is shown in Fig. 4.

Galda-2002 at 1739.

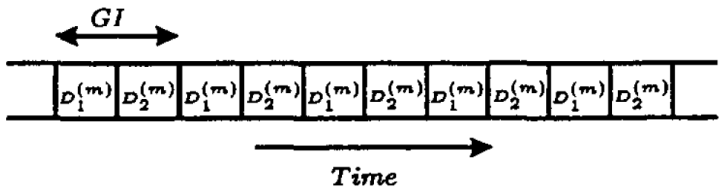


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

Galda-2002 at Fig. 5.

B. OFDM-FDMA with DFT Spreading

The advantage of a DFT spreading matrix can also be exploited in the uplink of an OFDM-FDMA system. If the user data is spread only over $L < N_C$ subcarriers then the DFT of length L used for spreading does not directly cancel out with the length N_C IDFT of the OFDM modulator in general. Only when the spreaded symbols $S_l^{(m)}$ are mapped onto equidistant located subcarriers with a spacing of $N_C/L = M$ the DFT spreading and the OFDM modulation can be removed in the transmitter structure. This can be seen by inserting Equation (2) into Equation (3) using the elements of the discrete Fourier matrix

$$C_{i,j} = \frac{1}{\sqrt{L}} \cdot e^{j2\pi ij/L} \tag{6}$$

the transmit signal of user m can be written as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L}$$

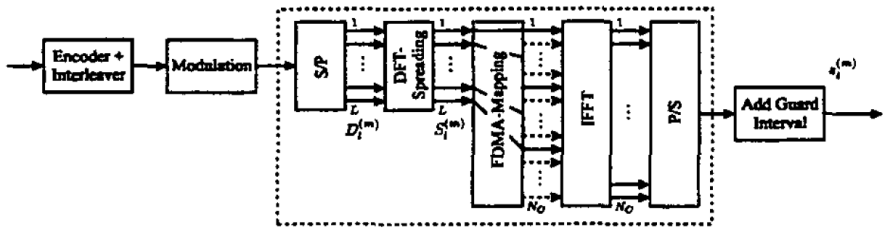
$$= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)}$$

$$= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu - i)$$

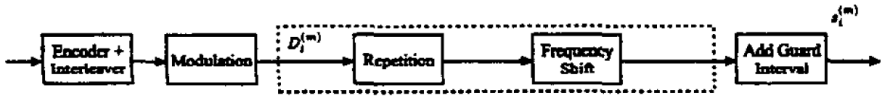
$$s_i^{(m)} = e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \quad (7)$$

for $i = -N_G, \ldots, 0, \ldots, N_C$ and the periodic dirac pulse sequence $\delta_L(\ \ )$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ sequence including an added guard interval as cyclic prefix, shown in Fig. 5. This periodic data sequence is multiplied by a user specific complex signal $e^{j2\pi im/N_C}$ due to the user individual frequency shift by m subcarriers of the complete allocated subcarrier set. The number of periods inside a single OFDM symbol is equal to the spacing M of the subcarriers allocated to user m.

Galda-2002 at 1739-40.



(a) OFDM-FDMA transmitter with DFT spreading over equidistant subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 6. In an OFDM-FDMA uplink system including DFT spreading matrix applied to a set of equidistant subcarriers the DFT spreading matrix and the OFDM IFFT transformation cancel out each other.

Galda-2002 at Fig. 6.

The structure of the OFDM transmitter can be simplified by this approach since both the DFT spreading operation and the IFFT calculation of the conventional OFDM transmitter cancel out and can be removed in the technical realization completely and will be replaced by a simple repetition process of the considered user data $D_l^{(m)}$. The simplified transmitter structure is depicted in Fig. 6. Any equidistant subcarrier allocation can be used with the proposed FDMA scheme since it only influences the number of periods of the transmit signal. Therefore the user data rate can be flexibly adjusted by assigning the required number of subcarriers to each user.

	Galda-2002 at 1740. In order to avoid non-linear distortions even in the case of a highly linear power amplifier a sufficient input-backoff (IBO) of the transmit signal to the amplifier has to be used. Even though the clipping probability of the OFDM signal can be reduced or even be avoided for an IBO larger than the PAR a system with large energy efficiency loss results. Alternatively, the effects which a non-linear device can have on the transmit power spectrum can be influenced by a reduction of the OFDM transmit signal PAR Different techniques have been developed which reduce the PAR of the OFDM signal by the means of a modified channel coding [5], an additive [6] or multiplicative [7] correction function or a selective mapping of modulation symbols to subcarriers [8]. A majority of these techniques has a high computational complexity due to the fact that they analyze the generated transmit signal and modify it either in the frequency or time domain to reduce its peak amplitudes. For a system employing coherent subcarrier modulation the PAR can also be reduced if the data symbols are spread by a Fourier matrix in frequency direction [3]. Galda-2002 at 1740. In this paper an OFDM-FDMA system concept for the uplink of a multi user communication system has been studied. It had be shown that if an OFDM-FDMA system with equidistant subcarrier allocation is combined with a user specific spreading using an discrete Fourier transform as a spreading matrix the transmitter structure can be greatly simplified without any performance degradation. Moreover, the peak-to-average ratio of the transmit signal is reduced to the PAR of the subcarrier modulation scheme which can limit the out-of-band and in-band emissions when the transmit signal is passed through a non-linear device. With the opportunity to independently adjust the user data rates the proposed technique offers an interesting alternative for reducing the complexity of the mobile terminal in the broadband radio uplink.

	Galda-2002 at 1741. Costa-193, which discloses: > The invention relates to a method and a communication system device for the generation of OFDM symbols, wherein data from one or more users or from one or more data sources (User 1–User M) are represented on a number of sub-carriers (Nc). According to the invention, in order to inhibit multiple-access interference (MAI) on application of the CDMA principle, the data are transformed in a data-source specific manner and only subsequently allocated to the sub-carriers, independently of the transformation. Costa-193 at abstract. > According to an alternative procedure, the user data can be spread over a specified number of sub-carriers and/or OFDM symbols by using orthogonal codes with the aid of an orthogonal matrix, as is the case with OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). In the OFDM-CDMA process, the data of all users is allocated to all available frequencies, wherein codes are used for separation. Without further measures, undesirable multiple access interferences occur in this case, in particular when considering a plurality of users or data sources whose data is received in parallel with one another. Costa-193 at 1:18-24. > To avoid this problem, the user data is thus spread over a plurality of sub-carriers only when sub-carriers are allocated to a plurality of users at the same time, which is referred to as OFDM-FDMA, with user-specific spreading of the reference data. Spreading and allocation of sub-carriers takes place in a common and comprehensive method step. So-called Walsh-Hadamard matrices of different sizes are mainly used for the spread, as described for example by M. Yee, J.-P. Linnartz: "Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading

	Channel," Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: "Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications," Kluwer Academic Publisher, 1996. Depending on the data rate required for transmission, different users are allocated a number between 1 and N of orthogonal codes, wherein N is the number of available sub-carriers. Costa-193 at 2:1-9. Furthermore, in K. Bruninghaus, H. Rohling: "Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission," Proc. IEEE VTC'98, Ottawa, Canada, 1998, a spread using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of the peak values to the average values (PAR: Peak-to-Average Ratios) is generally discussed, although multiple accesses are not considered. Costa-193 at 2:10-13. Advantageously, due to the data source-specific, i.e., exclusive, allocation of sub-carriers to the respective users or user data, to which the transformation result of an orthogonal transformation matrix or spread is transmitted, the undesirable multiple access interferences can be avoided, ideally completely, despite the application of the transformation. Advantageously, the choice of the orthogonal matrix is initially arbitrary. Furthermore, the transformation result can also be allocated to the exclusive sub-carriers of a user or a data source in any way. The separation of the spread of the user-specific data or data source-specific data and the allocation of the transformed or spread data to the sub-carriers of one or more OFDM symbols is particularly advantageous when a discrete Fourier transform (DFT) or fast Fourier transform (FFT) is used for the spread instead of, for example, the Walsh-Hadamard transform.

	In particular in combination with an equidistant arrangement of the sub-carriers on the carrier, in particular on the frequency axis, for the various user data or data sources, an OFDM-FDMA system then results in which the time signal or the OFDM symbols have a constant amplitude behind the usual inverse fast Fourier Transform (IFFT). This is a very significant advantage, because the various smoothing processes, which would currently have to be used, become unnecessary. Costa-193 at 3:1-13. In particular when combining a Fourier transform and an inverse Fourier transform, in a particularly preferred embodiment, a simplified generation of the OFDM symbols can also be carried out, because corresponding process steps can be omitted during their generation. In effect, the two successive Fourier transforms can cancel each other out, with the exception of, in particular, a frequency shift. Correspondingly, according to the invention, when communicating between, for example, a mobile user station and a base station in the uplink direction, it is possible to distribute/combine the incoming data from the individual data sources directly onto the corresponding OFDM symbol positions, if necessary after the usual encoding, interleaving, and modulation. This advantageously simplifies the structure of the transmitting communication station. The base station can expediently remain unchanged and continue to have the structure of an OFDM receiver, in order to be able to utilize the OFDM-specific advantages such as simple equalization of the received signal and separation of the user station data or users. Costa-193 at 4:1-10. FIG. [1] a scheme for a general multiple access, wherein the structure of an OFDM-FDMA system having user-specific spread of the data symbols is shown;

Costa-193 at 5:3-4.

> FIG. [2] schematically, a possible implementation of an OFDM-FDMA system having a particularly preferred FFT spread matrix and allocation of the user data to equidistant sub-carriers;

Costa-193 at 5:5-6.

> FIG. [3] schematically, an allocation of spread user data to equidistant sub-carriers, and

Costa-193 at 5:7.

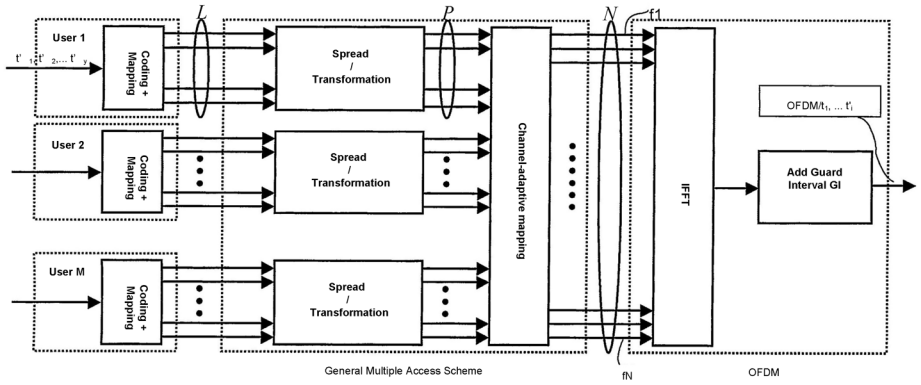


FIG. [1]

Costa-193 at Fig. 1.

> The following block shows the actual transformation or spread and the encoding of the data from different users onto the individual frequency sub-carriers.
>
> The data arriving on L data paths for each user is spread in a first step, i.e., distributed from a total of L data values onto P data values. This preferably serves to utilize the statistically independent propagation of the signals on

	different sub-carriers (frequency diversity). In the preferred exemplary embodiments, the number of individual data values or lines is not changed, although this is also possible, so that there are L complex data values per user before and after the spread. Analogous to the spread of the data with Walsh-Hadamard matrices as in OFDM-CDMA, L corresponds to the number of codes allocated to the user station and P to the number of available orthogonal code symbols. In this case, the spread corresponds to a full-load system. Costa-193 at 6:1-9. When describing the structure of the OFDM-FDMA system with the user-specific spread of the data symbols above, a conscious distinction is made between, on the one hand, spread/transformation and, on the other hand, mapping onto the sub-carriers. Costa-193 at 7:6-8. This separation is carried out in order to be able to transform or spread the data of the individual users, initially with the aid of an orthogonal matrix. In the subsequent step, the transformation result is then transferred onto sub-carriers, wherein sub-carriers are exclusively allocated to each of the individual users. In principle, the sub-carriers can be allocated in any way, wherein systems are preferred in which the first sub-carriers are allocated to the first user and the last sub-carriers to the last user. However, this is not absolutely necessary and is in particular undesirable in the case of a channel-adapted allocation, for example. However, systems in which the data of a user are mapped or transmitted onto sub-carriers that are distributed equidistantly across the frequency band are particularly preferred. Costa-193 at 7:9-15.

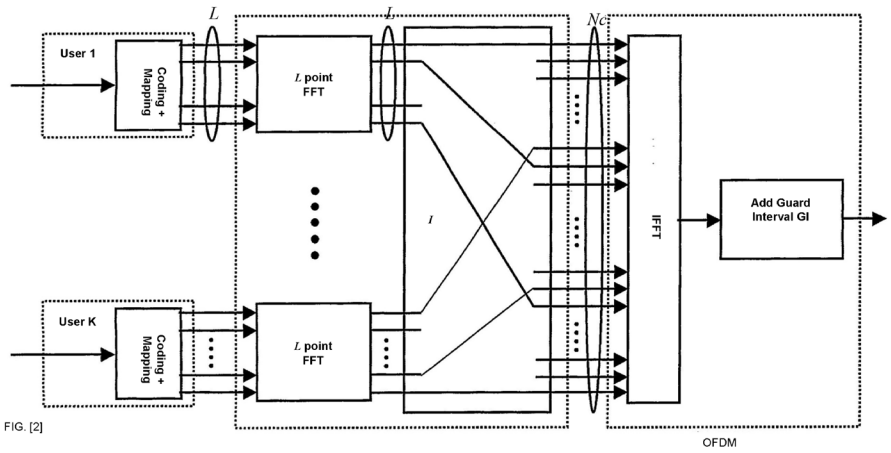


FIG. [2]

Costa-193 at Fig. 2.

> In principle, the selection of the orthogonal matrix is arbitrary. The Walsh-Hadamard transform, which is known per se, or especially a Fourier transform, in particular a discrete or fast Fourier transform, are preferred.
>
> The use of a fast Fourier transform FFT as a preferred form of transformation or spreading as well as the subsequent transfer to individual sub-carriers can be seen from FIG. [2], in an exemplary embodiment. The Fourier transforms FFT are carried out on a user-specific basis, i.e., the incoming data symbols of a user are fed in each case to their own Fourier transform.
>
> The data resulting from the individual user-specific Fourier transforms are then distributed to the individual frequency sub-carriers f1 ... fN, wherein the data of a user is preferably transmitted to sub-carriers that are not directly adjacent to one another. In principle, however, this distribution to the individual sub-carriers can take place in any manner.

Costa-193 at 8:7-15.

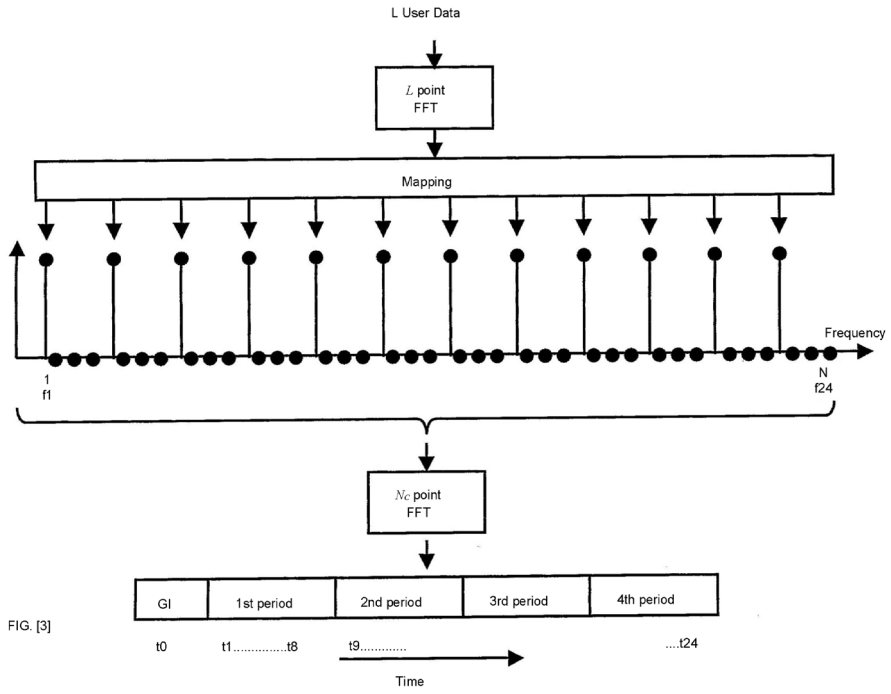
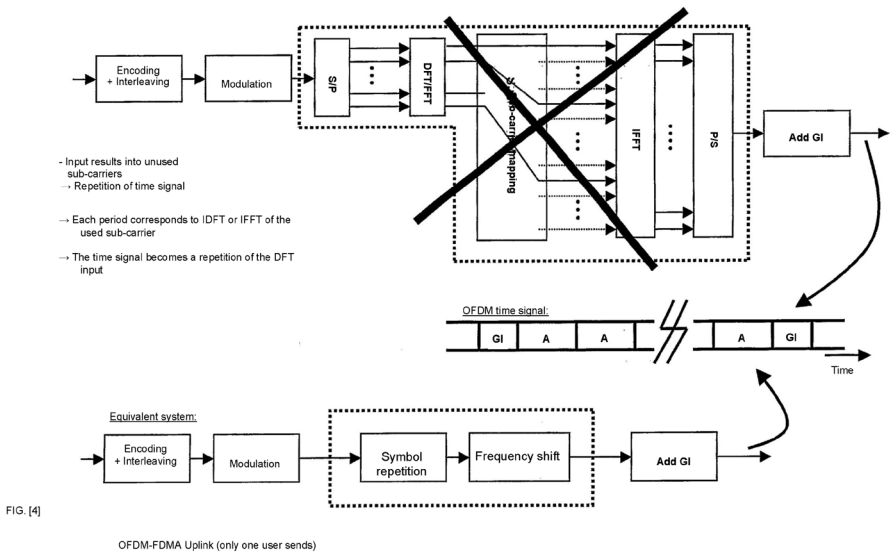


FIG. [3]

Costa-193 at Fig. 3.

> As can be seen from FIG. [3], a particularly preferred distribution of the individual data of the user-specific Fourier transforms takes place on an equidistant sequence of sub-carriers over the frequency axis. In the exemplary embodiment shown, L user data or data symbols having L data values of a user are introduced into the L-valued Fourier transform (L point FFT). According to the preferred exemplary embodiment, although not absolutely necessary, the Fourier transform in turn generates L data values which are mapped onto the N sub-carriers.

Costa-193 at 9:1-5.



Costa-193 at Fig. 4.

> Generalizing this with simple numbers, with a data symbol length L of the incoming user data and a mapping to L-valued transformation results, it requires a mapping to the sub-carriers f1...fN, wherein N sub-carriers are available. After the inverse Fourier transform, the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values are distributed equidistantly over N/L data periods, wherein the data periods can also be referred to as data blocks or data sections.

Costa-193 at 10:1-5.

> The particular advantage of combining a spread matrix formed by a Fourier transform FFT in combination with the equidistant distribution on the frequency axis is that, after the inverse Fourier transform, the result is a time signal having a constant amplitude in the uplink and a time signal having a peak value that is significantly reduced compared to a traditional

	OFDM system in the downlink. This constant amplitude results because the peak-to-average ratio (PAR) is significantly lower than other OFDM symbol generation methods. It corresponds precisely to the PAR of the modulation symbols before the transformation. If a PSK modulation were used here, then PAR=1. Costa-193 at 10:6-11. According to a further developed embodiment, if a Fourier transform is considered as a spread matrix and a subsequent inverse Fourier transform is considered for transmitting the individual frequency sub-carriers to a temporal data sequence, it can be determined that the two Fourier transforms then cancel each other out, purely theoretically, in terms of their effect. As a consequence, a particularly preferred embodiment for generating OFDM symbols can be implemented, as is shown in FIG. [4] for example for a transmission in the uplink from a user station to a network-side station, when only a single user transmits, wherein the transformations then cancel each other out. Due to the effect-cancelling transformation sequence of a Fourier transform FFT and after distribution to the individual sub-carriers f1...fN of an inverse Fourier transform IFFT, this block can be omitted during the implementation, or it can be replaced by repeating the symbol sequence according to the number of allocated, now fictitious, sub-carriers and subsequent frequency shift in the distribution of the input data onto the output data. Costa-193 at 11:1-10. 3. The method according to claim 1 or 2, in which, during the distribution of the input data onto the output data, the inputting of the data into the OFDM symbol is carried out by a repetition of the symbol sequence according to the number of allocated sub-carriers and a subsequent frequency shift.

	Costa-193, claim 3. 5. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using an orthogonal matrix. Costa-193, claim 5. 6. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using a Fourier transform (FFT). Costa-193, claim 6. Costa-782, which discloses: In accordance with an alternate procedure, by using orthogonal codes with the aid of an orthogonal matrix, the user data can be spread over a specified number of subcarriers and/or OFDM symbols, as with the methods known under OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). With the OFDM-CDMA method the data of all users is assigned to all available frequencies, in which case codes are used for separation. Without further measures, undesired multiple access interferences occur in this case and especially when considering a number of users or data sources for which the data enters in parallel. Costa-782 at 0005. To avoid this problem the user data is thus only spread over a number of subcarriers for simultaneous assignment of subcarriers to a number of users, which is referred to as OFDM-FDMA with user-specific spreading of payload data. Spreading and assignment of subcarriers is undertaken here in a common and comprehensive procedure step. What are known as Walsh-Hadamard Matrices of different sizes are predominantly used for spreading, as known for example from M. Yee, J.-P. Linnartz: Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading Channel,

	Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications, Kluwer Academic Publisher, 1996. In such systems different users, depending on the data rate required, are assigned a number between 1 and N of the orthogonal codes, with N being the number of available subcarriers. Costa-782 at 0006. Furthermore K. Bruninghaus, H. Rohling: Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission, Proc. IEEE VTC'98, Ottawa, channel, 1998, contains a general discussion of spreading using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of peak values to average values (PAR: Peak-to-Average-Ratios), in which case multiple accesses are not taken into account however. Costa-782 at 0007. The separation of spreading of user-specific data or data source-specific data and the assignment of the transformed or spread data to the subcarriers of one or more OFDM symbols is especially advantageous if a Discrete Fourier Transformation (DFT) or Fast Fourier Transformation (FFT) is used for the spreading instead of the Walsh-Hadamard Transformation for example. Costa-782 at 0011. Especially with the combination of a Fourier Transformation and an Inverse Fourier Transformation in an especially preferred embodiment a simplified generation of an OFDM symbol can be undertaken since the corresponding procedural steps can be omitted in its generation. The two successive Fourier Transformations can cancel each other out here in their effect except for especially one frequency shift. Correspondingly in

accordance with the invention it is possible in communication between for example a mobile user station and a base station in the uplink direction to distribute or to combine the incoming data of the individual data sources if necessary after normal encoding, interleaving and modulation directly onto the corresponding OFDM symbol positions. This advantageously simplifies the design of the sending communication station. Usefully the base can remain unchanged and continue to possess the structure of an OFDM receiver to enable it to exploit the OFDM-specific advantages such as simple equalization of the receive signal and separation of the user station data or the users.

Costa-782 at 0013.

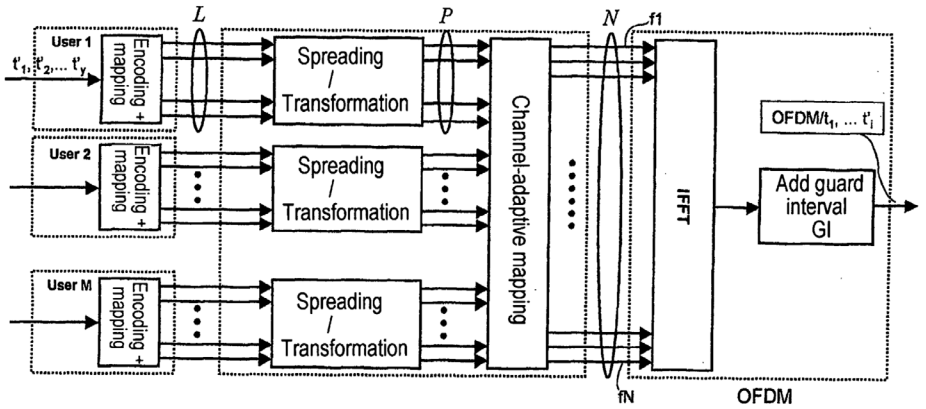
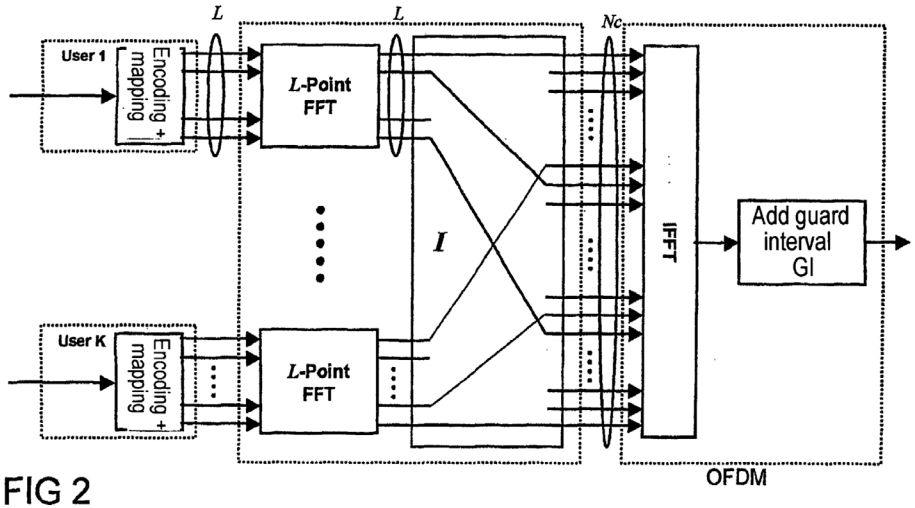


FIG 1

Costa-782 at Fig. 1.

The subsequent block shows the actual transformation or spreading and the encoding of the data of different users to the individual frequency subcarriers.

The data arriving in each case for a user on L data paths is spread in a first step, i.e. distributed from a total of L data values to P data values. This

	preferably serves to exploit the statistically independent propagation of the signals on different subcarriers (frequency diversity). In the preferred exemplary embodiment the number of the individual data values or lines is not changed although this is also possible so that before and after the spreading L complex data values per user are available in each case In analogy to the spreading of the data with Walsh-Hadamard Matrices for OFDM-CDMA, L corresponds to the number of codes assigned to the user station and P the number of the available orthogonal code symbols. The spreading in this case corresponds to a full load system. Costa-782 at 0022-23.  FIG 2 Costa-782 at Fig. 2. In this case basically any orthogonal matrix can be chosen. Preferred is the Walsh-Hadamard Transformation known per se or especially a Fourier Transformation, especially a Discrete or Fast Fourier Transformation.

	The application of a Fast Fourier Transformation FFT, as preferred form of the transformation or spreading, as well as the subsequent transmission on individual subcarriers can be seen from FIG. 2 in a typical embodiment. The Fourier Transformations FFT are executed user-specifically here, i.e. the data symbols of a user arriving are fed to a separate Fourier Transformation in each case. The data produced from the individual user-specific Fourier transformations is then distributed to the individual frequency subcarriers f1 . . . fN, with the data of a user preferably not being transmitted on directly adjacent subcarriers. Purely in principle however this distribution can be undertaken in any way on the individual subcarriers. Costa-782 at 0030-32.

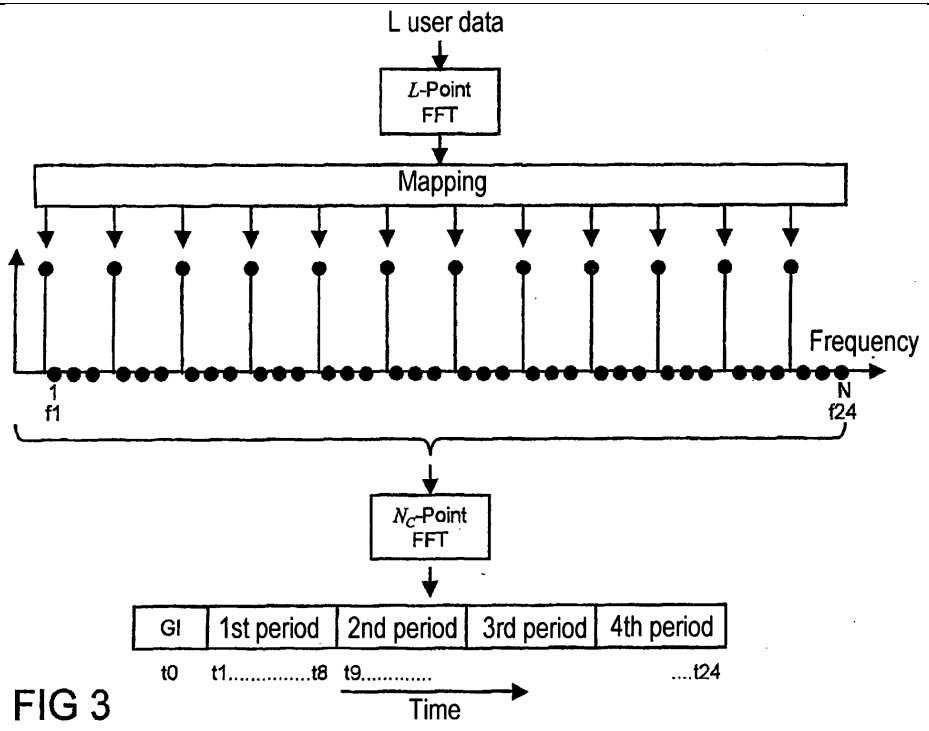


FIG 3

Costa-782 at Fig. 3.

> Put into simple generalized terms, with a data symbol length L of the user the data and a mapping to likewise L-point transformation results, this causes a mapping to subcarriers f1 . . . fN, with N subcarriers being available. After the inverse Fourier Transformation the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values here, with equidistantly distribution are distributed over N/L data periods, with the data periods also able to be referred to as data blocks or data sections.

Costa-782 at 0037.

	The particular advantage of the combination of a spread matrix formed by a Fourier Transformation FFT in combination with the equidistant distribution on the frequency axis lies in the fact that, after the inverse Fourier Transformation in the uplink a timing signal with a constant encapsulator and in the downlink a timing signal with a peak value which is much-reduced by contrast with a conventional OFDM system is produced. This constant encapsulator is produced since the peak to average value ratio (PAR) is far lower than with other generation methods for OFDM symbols. If a PSK modulation were to be used here, the PAR=1 Costa-782 at 0038. To assist understanding it is formally pointed out that a general linear transformation is involved here, that is even with the use of a Fourier Transformation to transform or spread the user-specific data no direct relationship of a frequency area to a period exists, as would be the case for normal considerations of Fourier Transformations. Costa-782 at 0039.

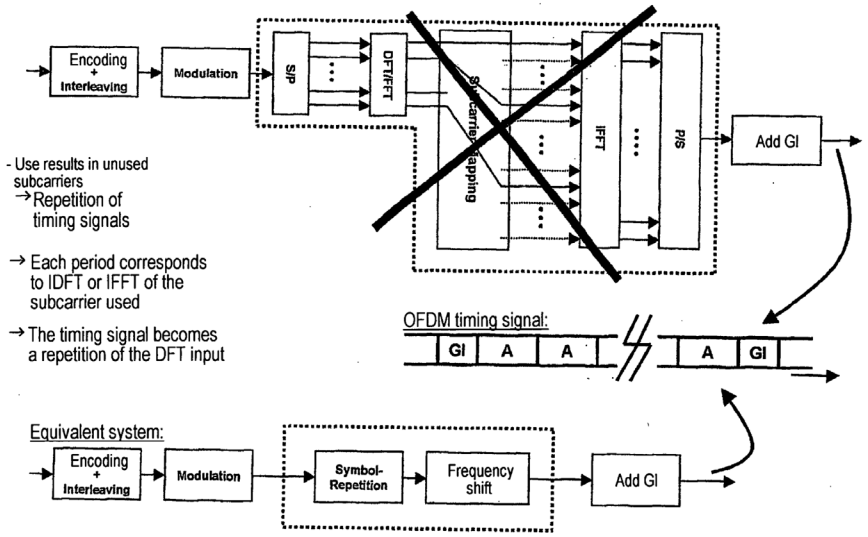


FIG 4: OFDM-FDMA Uplink (only one user sending)

Costa-782 at Fig. 4.

In accordance with a further developed embodiment, for the case of the consideration of a Fourier Transformation as spreading matrix and a subsequent Inverse Fourier Transformation to transmit the individual frequency subcarriers on a timing data sequence it can be established that purely theoretically the two Fourier Transformations cancel each other out. As a consequence a particularly preferred embodiment for generating OFDM symbols can be used, as is shown for example in FIG. 4 for example for a transmission in the uplink direction from a user station to a network-side station if only one single user is sending, in which case the transformations cancel each other out.

Through the canceling-out effect of the series of transformations of a Fourier Transformation FFT and after the distribution to the individual subcarriers f1 . . . fN of an Inverse Fourier Transformation IFFT this block can be omitted in the conversion or replaced by a repetition of the symbol

	sequence in accordance with the number of the assigned, now fictitious, subcarriers and subsequent frequency shifting for a distribution of the input data to the output data. A repeat of the timing signals is produced by the subcarriers which are not assigned to the user remaining unmodulated. Each individual period of the OFDM signal then corresponds in the final analysis to the inverse discrete Fourier Transformation of the subcarriers used. Thus, with ideal conversion and later error-free transmission over the interface the received OFDM then theoretically contains on the receiver side, behind the guard interval GI, a number of periods with the same data sequence in each case. The timing signals would thus correspond to a repeating sequence of the original inputs in the discrete Fourier Transformation which would be undertaken initially in accordance with the exemplary embodiment of FIG. 2. As can be seen from the bottom area of FIG. 4, this produces an equivalent system in which the blocks with the conversions of serial into parallel data, the subscriber-specific Fourier Transformations, the mapping or transmission on the subcarriers, the inverse Fourier Transformation and the conversion of parallel into serial data can be replaced by a series of repeating symbols and a corresponding frequency shift to be performed. Costa-782 at 0040-43. 12. A method for generating an OFDM symbol as a send signal in a communication system, comprising: mapping a complete data sequence from a data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 12.

	13. A method in accordance with claim 12, further comprising before said mapping encoding the complete data sequence from the data source to produce encoded data; and modulating the encoded data on the orthogonal subcarriers. Costa-782, claim 13. 15. A method for generating OFDM symbols for send signals in a communication system, comprising: mapping data from at least one data source to a plurality of orthogonal subcarriers, by transforming the data from the data sources; and assigning transformed data to the orthogonal subcarriers in a data source-specific manner independently of how the data is transformed. Costa-782, claim 15. 16. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by an orthogonal matrix. Costa-782, claim 16. 17. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by a Fourier Transformation. Costa-782, claim 17. 22. A communication device coupled to at least one data source, comprising: at least one interface receiving input data from the at least one data source;

	at least one of a memory device and at least one processing module temporary storing and processing, respectively, the input data from the at least one data source; and a control device controlling operation of said communication device and mapping a complete data sequence from each data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 22.
[11G] wherein the first polyphase code causes constructive and destructive interference between the plurality of modulated subcarriers to produce a first periodic pulse waveform having a peak value that is centered at a first time in an OFDM symbol interval, and	StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality: For example, Kaiser-1998 discloses:

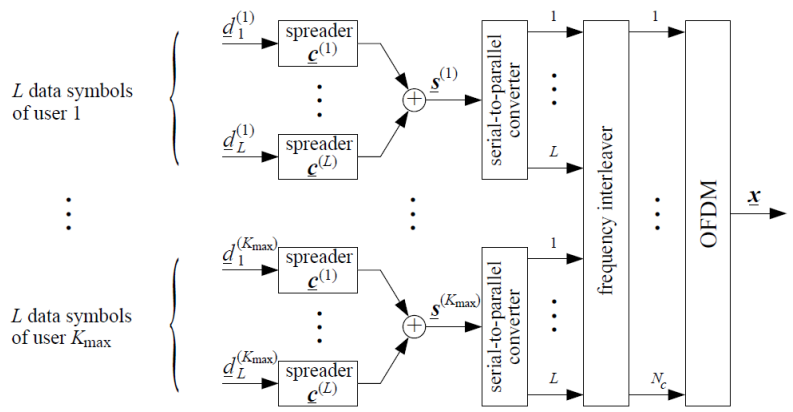


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be

observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users.

Kaiser-1998 at 130-131.

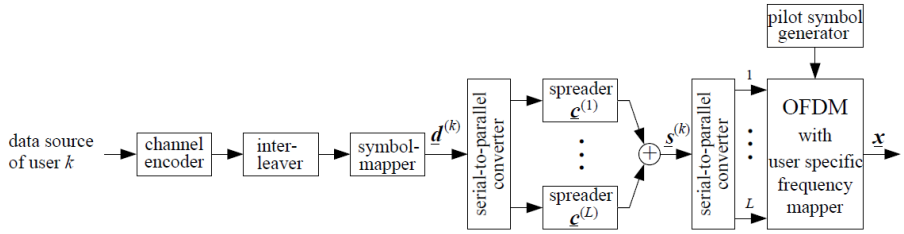
Between SS-MC-MA and MC-CDMA systems exist the following similarities:

- SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers.
- Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems.
- ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques.

Kaiser-1998 at 131.

Between SS-MC-MA and MC-CDMA systems exist the following differences:

- In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme.

	• MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation. • In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity. Kaiser-1998 at 131.  Figure B.2: SS-MC-MA transmitter of the kth user for the uplink Kaiser-1998 at Fig. B.2. SS-MC-MA Transmitter: Fig. B.2 shows an SS-MC-MA transmitter with channel coding for the data of the kth user, $k = 1 \ldots K$, for the uplink. The components channel encoding, interleaving, and symbol mapping are identical to those described in Chapter 4 for MC-CDMA systems. In SS-

MC-MA systems, L subsequent complex-valued data symbols $\underline{d}_l^{(k)}, l = 1 \dots L$, of user k are serial-to-parallel converted. The vector

$$\underline{d}^{(k)} = \left(\underline{d}_1^{(k)}, \underline{d}_2^{(k)}, \dots, \underline{d}_L^{(k)}\right)^T \quad (B.1)$$

represents one block of L parallel converted data symbols of the kth user. Each of the L data symbols is multiplied with another orthogonal spreading code of length L. The $L \times L$ matrix

$$\underline{C} = \left(\underline{c}_1\ \underline{c}_2\ \dots\ \underline{c}_L\right) = \begin{pmatrix} \underline{C}_{1,1} & \underline{C}_{2,1} & \cdots & \underline{C}_{L,1} \\ \underline{C}_{1,2} & \underline{C}_{2,2} & \cdots & \underline{C}_{L,2} \\ \vdots & \ddots & \cdots & \vdots \\ \underline{C}_{1,L} & \underline{C}_{2,L} & \cdots & \underline{C}_{L,L} \end{pmatrix} \quad (B.2)$$

represents the L different spreading codes $\underline{c}_l, l = 1, \dots, L$, used by user k. The matrix $\underline{C}$ is the same for all users. The modulated spreading codes are data symbol and, thus, chip synchronously added, resulting in the transmission vector

$$\underline{s}^{(k)} = \underline{C}\,\underline{d}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^T \quad (B.3)$$

consisting of L components. To increase the robustness of SS-MC-MA systems e.g. against inter cell interference, less than L data modulated spreading codes can be added to one transmission vector $\underline{s}^{(k)}$.

Kaiser-1998 at 131-132.

In the following, the performance of an SS-MC-MA mobile radio system in the uplink is presented. Table B.1 shows the SS-MC-MA system parameters used in the uplink. These parameters are chosen such that they correspond as far as possible with the MC-CDMA system parameters for the downlink presented in Table 6.1. The SS-MC-MA system parameters described in the following differ from those of the MC-CDMA system presented in Chapter 6. The SS-MC-MA system transmits only on 256

	subcarriers. Since the channel estimation in the considered SS-MC-MA system is based on a 1-D filtering in time direction which should fulfill two-times oversampling of the time-variant fading process, the overhead due to pilot symbols can be reduced with decreasing OFDM symbol durations. However, it has to be taken into account that with decreasing OFDM symbol duration the loss in bandwidth efficiency due to the guard interval increases. The used TDMA frame structure consisting of 4 time slots. A time slot corresponds to an OFDM frame consisting of 31 OFDM symbols as illustrated in Fig. B.4. Each user exclusively transmits on 8 subcarriers, where 3 of the 8 subcarriers used by the kth user are depicted. Hence, per user, a block of 8 serial data symbols is parallel converted and spread with orthogonal Walsh Hadamard codes of length L equal to 8, resulting after superposition in the transmission sequence $\underline{s}^{(k)}$, cf. (B.3). Note that in contrast to Fig. B.2, an additional interleaver is applied which scrambles 192 components of 24 transmission sequences $\underline{s}^{(k)}$ with the intention to increase the diversity potential of the system. Per OFDM symbol, 8 randomly interleaved components are mapped on 8 subcarriers exclusively used by the kth user. The 8 user specific subcarriers are distributed over the whole bandwidth. The receiver applies an MLSSE for data detection. The channel coding part is identical to that of the MC-CDMA system presented in Chapter 6. Kaiser-1998 at 133-135.

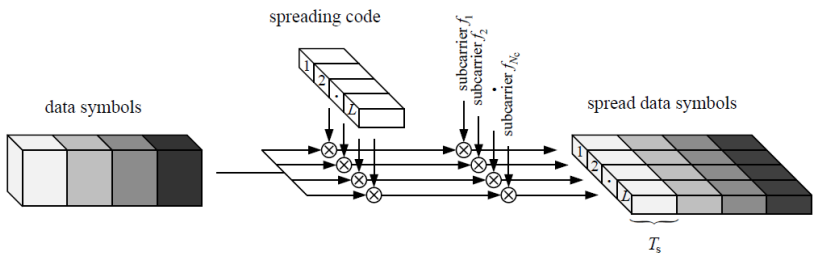
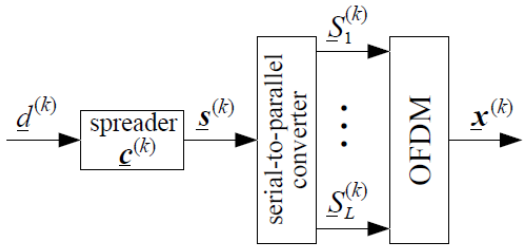


Figure 1.4: Principle of spreading of the data of a single user by MC-CDMA for the case $N_c = L$, i.e., $T_s = T_d$ and $T'_c = T_d$

Kaiser-1998 at Fig. 1.4.

Concept I: MC-CDMA is based on a serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, [FaP93, YLF93, CBJ93]. The high rate DS spread data stream is MC modulated in such a way, that the L chips of a spread data symbol are transmitted in parallel on different subcarriers. Thus, the assigned data symbol is simultaneously transmitted on L subcarriers. If the number of subcarriers N_c is equal to the spreading code length L, MC-CDMA requires the total bandwidth for the transmission of a single data symbol comparable to DS-CDMA. When choosing L smaller than N_c and introducing an appropriate frequency interleaving, the flexibility of an MC-CDMA system can be increased and the complexity of the data detector can be reduced [FaP93, Faz93]. Fig. 1.4 shows the principle of an equivalent realization of the serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3. Each data symbol is copied onto L substreams before multiplication with one chip of the spreading code per substream. A chip of the MC-CDMA spreading code grouped in the frequency domain has the duration T'_c, cf. Fig. 1.1, which is by a factor of N_c greater than the duration T_c of a chip of the DS-CDMA spreading code. The case of N_c equal to L is illustrated in Fig. 1.4, yielding that the data symbol duration T_d, the chip duration T'_c, and the OFDM symbol duration T_s are identical. Fig. 1.4 reflects the fact that MC-CDMA has a spreading code grouped in the frequency domain. Comparing

	the spread data symbols of DS-CDMA, cf. Fig. 1.2, with those of MC-CDMA, cf. Fig. 1.4, it can be seen that MC-CDMA offers an additional flexibility in the frequency domain, which results in simple methods for signal reconstruction in the frequency domain. MC-CDMA was introduced with OFDM for optimum use of the available bandwidth [FaP93, YLF93, CBJ93]. Most MC-CDMA systems were proposed for the downlink from a base station (BS) to a mobile station (MS) where powerful mobile receivers with low complexity are required [FaP93, YLF93, CBJ93]. The time/frequency synchronism between the users in the downlink allows a simple realization of an efficient channel estimation required for coherent detection. Kaiser-1998 at 6-7.  Figure 3.6: MC spread spectrum signal generation Kaiser-1998 at Fig. 3.6. The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be

transmitted over the radio channel is taken from the complex data symbol alphabet

$$\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \tag{3.24}$$

of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

$$\underline{c}^{(k)} = \left(\underline{C}_1^{(k)}, \underline{C}_2^{(k)}, \dots, \underline{C}_L^{(k)}\right)^{\mathrm{T}} \tag{3.25}$$

of the kth user. The chips $\underline{C}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet

$$\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \tag{3.26}$$

of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is

$$\frac{1}{T_c} = \frac{L}{T_d} \tag{3.27}$$

and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector

$$\underline{s}^{(k)} = \underline{d}^{(k)}\underline{c}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^{\mathrm{T}}. \tag{3.28}$$

The rate of the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread

spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d^{(k)}}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is

$$T_s' = T_g + N_c T_c. \quad (3.29)$$

The transmission of one data symbol per user per OFDM symbol requires

$$N_c = L \quad (3.30)$$

subcarriers. In this case, the OFDM symbol duration including the guard interval is

$$T_s' = T_g + T_d. \quad (3.31)$$

Kaiser-1998 at 39-40.

An MC-CDMA system designed for the transmission of one data symbol per user per OFDM symbol is referred to as a basic MC-CDMA system in the following. When applying orthogonal spreading codes $\underline{\boldsymbol{c}^{(k)}}$ like Walsh-Hadamard codes, the maximum number of active users $K_{\max}$ in the basic MC-CDMA system corresponds to the spreading code length L, i.e.,

$$K_{\max} = L. \quad (3.32)$$

Kaiser-1998 at 40.

• Frequency/time domain spreading code: Each MC-CDMA spreading code with a mapping on frequency slots can be transferred in a DS-CDMA spreading code with a mapping on time slots and vice versa by applying the Fourier transform [FBA94]. The key feature of the Fourier transform is that it preserves the correlation properties of the spreading code [Ach85]. Hence, an MC-CDMA system with a spreading code $\{\underline{C_l^{(k)}}\}, l = 1, \ldots, L,$

performs identically to a DS-CDMA system with a spreading code$\{\underline{c}_i^{(k)}\}, i = 1, \ldots, L$, when both spreading codes are related by the Fourier transform, i.e.,

$$\{\underline{C}_l^{(k)}\}, \quad l = 1, \ldots, L, \quad \bullet\!\!-\!\!\circ \quad \{\underline{c}_i^{(k)}\}, \quad i = 1, \ldots, L. \tag{3.84}$$

In (3.84), the symbol $\bullet\!\!-\!\!\circ$ denotes the discrete Fourier transformation. When, for instance, applying binary, real-valued, orthogonal MC-CDMA spreading codes, the equivalent DS-CDMA spreading codes are non-binary and complex-valued, but still orthogonal.

Kaiser-1998 at 62-63.

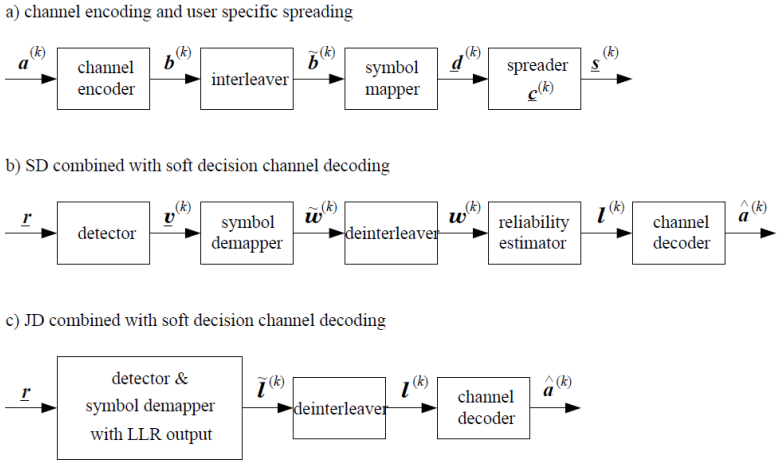


Figure 4.1: Concatenation of the spread spectrum technique with channel coding; a) channel encoding with subsequent data symbol spreading; b) SD and c) JD with optimum soft decision decoding

Kaiser-1998 at 65.

Performance and flexibility of mobile radio systems essentially depend on the choice of the multiple access scheme. The novel MC-CDMA scheme

	which is the topic of this thesis is a promising alternative to conventional FDMA, TDMA, and CDMA schemes. With MC-CDMA, each data modulated chip of the user specific spreading code is mapped onto a separate subcarrier, so that the chips of the spreading code and, hence, the data symbol is transmitted in parallel on multiple subcarriers. The application of OFDM enables one to avoid ISI and ICI in the detection process, resulting in simple SD and MD techniques. In MC-CDMA mobile radio systems, SD can be realized by equalizing each subcarrier individually, yielding only one complex-valued multiplication per subcarrier and OFDM symbol. Due to the M-, Q-, and M&Q-Modification of the MC-CDMA scheme, even the optimum JD techniques MLSSE and MLSE can be applied with reasonable complexity. Kaiser-1998 at 119. Brüninghaus-1997, which discloses: In this paper we will focus on Multi-Carrier CDMA (MC-CDMA). In contrast to a conventional OFDM system where every bit is assigned to a single subcarrier, the information is spread over several subcarriers using orthogonal codes. Since spreading is performed on information symbol level prior to subcarrier modulation, the resulting MC-CDMA signal is basically an OFDM signal. The advantage of this technique is a lower bit error rate in frequency-selective radio channels compared to a conventional OFDM system due to inherent frequency-diversity. The price to be paid is a higher computation complexity in the receiver since the frequency-selective radio channel leads to a loss of orthogonality of the spreading codes and interuser-interferences occur. A lot of research has been done to develop suitable detection or joint detection methods [4, 5, 6, 7] without considering the spreading matrix in detail. Brüninghaus-1997 at 187. In this paper we will discuss this item focussing on the special case that the spreading matrix equals the Fourier matrix. The two operations performed

in the transmitter, namely spreading and IFFT-processing, cancel each other resulting in a pure single-carrier system with blockwise processing. This special case was also mentioned in [8] but little was said about the consequences, which will be done in the following sections.

Brüninghaus-1997 at 188.

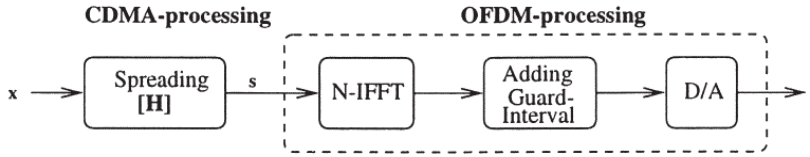


Figure 1: Block diagramm of a MC-CDMA transmitter (downlink)

Brüninghaus-1997 at 188.

The general block diagram of a MC-CDMA transmitter (only the downlink is considered in this paper) is depicted in Fig. 1. In a first step the complex data symbols $x_i, \quad 1 \leq i \leq M$, which can be elements of any arbitrary symbol set e.g. PSK or QAM, are spread over several subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation

$$s = [H] \cdot x \qquad (1)$$

where $x = (x_1, \ldots, x_M)^T$ is the vector of data symbols, $s = (s_1, \ldots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix. The M columns of the code matrix contain different spreading codes for every data symbol. To avoid interuser-interferences in AWGN the spreading codes should be mutually orthogonal. If the OFDM system consists of N subcarriers there are a maximum number of N orthogonal codes and $1 \leq M \leq N$ users can be supported every OFDM symbol. Apart from the described spreading procedure, the transmitter is identical to a conventional OFDM

transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard-interval is added) and D/A converted.

Brüninghaus-1997 at 188.

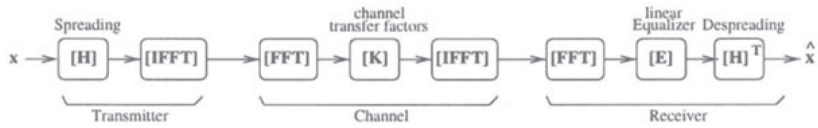


Figure 3: Model of a MC-CDMA transmission system with linear equalization

Brüninghaus-1997 at 190.

Both demands, i.e. minimal mean square error in frequency-selective fading channels and low dynamic range of the signal envelope, can also be met for the downlink if an FFT matrix is used as spreading matrix. In this case spreading and IFFT-processing cancel each other, see Fig. 3, and the transmission system degenerates into a single-carrier system, as depicted in Fig. 4. The main advantage of this step is that at this stage all knowledge about dynamic reduction of single carrier systems with linear modulation can be applied to create a time signal with low dynamic range.

Brüninghaus-1997 at 189.

The special choice of a FFT matrix as spreading matrix for Multi-Carrier CDMA leads to a single-carrier system with guard-interval. This way, the multi-carrier specific problems as high dynamic of the signal envelope, sensivity to phase noise and frequency/ clock synchronization errors can be avoided without losing the performance capacity of MC-CDMA. In case of linear equalization the receiver consists of a frequency domain equalizer with blockwise processing. Due to the guard-interval, this frequency domain equalizer outperforms the comparable time domain equalizer considerably and shows even in frequency-selective radio channels a

relatively good performance. Besides, the compuation complexity of such a receiver structure with blockwise processing in the frequency domain is lower than with processing in the time domain in case of highly dispersive channels.

Brüninghaus-1997 at 193.

Sorger-1997, which discloses:

> The first $L_\Delta Q$ chips $c_l^{(i)}$, $l = 0, \ldots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by
>
> $$T_\Delta = L_\Delta \cdot Q \cdot T_c, \quad (7)$$
>
> where L_Δ has to be chosen to meet the condition of Eq. (2). The transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user dependent phase vector $s^{(i)}$ of dimension L_c having components
>
> $$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \ldots, L_c - 1. \quad (8)$$
>
> The user dependent phase $\Phi^{(i)}$ is chosen to be
>
> $$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \quad (9)$$
>
> The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures the user discrimination by assigning to each user i a different set of orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as
>
> $$x^{(i)} = \left[c_0^{(i)}, c_1^{(i)} e^{-j\Phi^{(i)}}, c_2^{(i)} e^{-j2\Phi^{(i)}}, \ldots, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \quad (10)$$

Sorger-1997 at 113.

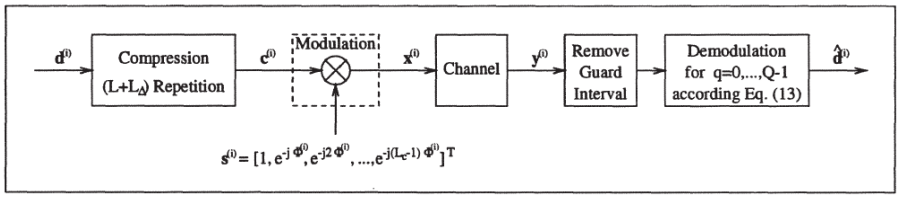


Figure 1: Block diagram of the proposed IFDMA system

Sorger-1997 at Fig. 1.

Brüninghaus-1998, which discloses:

> The combination of orthogonal frequency division multiplexing (OFDM) and code division multiplexing (CDM) has found great interest during the last few years. In contrast to a conventional OFDM system the information is spread over several subcarriers using orthogonal codes which leads to a diversity gain in frequency-selective channels. In this paper it is shown that such a system is technically equivalent to a single-carrier system with guard interval if the columns of a Fourier matrix are used as spreading codes. The pros and cons of such a system compared to an OFDM-CDM system with abritrary spreading matrix are described and discussed.

Brüninghaus-1998 at 2329.

> In the last years, multi-carrier transmission and especially OFDM (orthogonal frequency division multiplexing) have received much attention due to its ability of transmitting high data rates even in highly time dispersive radio channels with reasonable equalization effort. These systems are characterized by parallel data transmission over a number of generally narrowband subchannels. Recently, a combination of multi-carrier transmission and code division multiplexing (CDM) was proposed to improve the performance of multi-carrier systems [1], [2]. In this case every data symbol is spread over several subcarriers prior to subcarrier modulation and despread in the receiver, which is in fact a kind of

	frequency diversity. The same effect can be achieved with channel coding but it was shown in [3] that at least at code rates above 1/2 the combination of spreading and coding performs better than coding only. Brüninghaus-1998 at 2329. In the literature, Walsh-Hadamard codes are generally used as spreading codes but in principle every other orthogonal code matrix can be applied. In this paper we will focus on the special case that the Fourier matrix is used as orthogonal code matrix. Since the multi-carrier transmission signal is generated by an inverse Fourier-transform (IFFT), both operations - spreading and IFFT - cancel each other resulting in a pure single-carrier system with blockwise processing. This fact was already mentioned in [4] but without noticing that this kind of processing combines the advantages of single-carrier transmission, like constant signal envelope, simple clock and frequency synchronization, with the advantages of OFDM-CDM like high performance in frequency-selective channels. In the following sections, a brief review of OFDM-CDM is given, followed by a detailed discussion of the resultant transmission technique and its advantages. Brüninghaus-1998 at 2329. With OFDM-CDM the complex data symbols $x_i, \quad 1, \dots, M$, which can be elements of any arbitrary symbol set, e.g. PSK or QAM, are spread over *N* subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation $$s = [H] \cdot x \qquad (1)$$ where $x = (x_1, \dots, x_M)^T$ is the vector of data symbols, $s = (s_1, \dots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix of dimension$N \times M \quad (M \leq N)$. Apart from spreading, the transmitter is identical to a conventional OFDM transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard interval is

added) and D/A converted, see Fig. 1. In the receiver, the inverse processing is performed, see Fig. 2.

Brüninghaus-1998 at 2329.

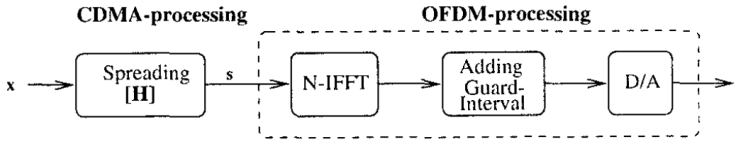


Fig. 1. Block diagram of a multi-carrier CDM transmitter

Brüninghaus-1998 at 2329.

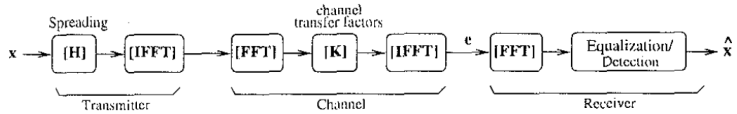


Fig. 3. Model of a multi-carrier CDM system

Brüninghaus-1998 at 2330.

The performance of the overall transmission system does not depend on the specific type of the orthogonal spreading matrix as long as every element of the matrix has the same magnitude which means that the energy is uniformly spread over all subcarriers [10]. Considering the case that all available orthogonal codes are used, i.e. the spreading matrix is a square matrix of dimension *N* x *N*, the matrix of the Fast Fourier transform meets the above mentioned demands as well as the often proposed Walsh-Hadamard matrix. If such an FFT-matrix is used spreading and OFDM processing cancel each and the transmission system degenerates into a linearly modulated single-carrier system with guard interval, i.e

$$s(t) = \sum_n x_n \cdot p(t - nT) \quad \text{where} \quad x_n = x_{n-N} \quad \text{if} \quad i(N + N_G) - N_G \leq n < i(N + N_G) \quad i \in Z \quad (2)$$

In Eq. (2), the parameter N_G describes the length of the guard interval in number of data symbols spaced by the symbol duration *T*.

Brüninghaus-1998 at 2330.

A. Dynamic of the signal envelope

It is well known that the envelope of an OFDM signal has a high dynamic which requires a linear power amplifier in the transmitter. A lot of studies have been performed with the aim to reduce the signal dynamic of multi-carrier systems but all methods known from literature [11] - [13] have certain drawbacks. These drawbacks are either high computation complexity, large memory requirements or signal distortions. At least in the case of absolute modulation (no differential encoding) these disadvantages can be overcome if the Fourier-matrix is used for spreading. Since the multi-carrier CDM system is thereby transformed into a single-carrier system with linear modulation the amplitude dynamic only depends on the pulse shape *p(t)*. In connection with second generation mobile systems this topic has been analyzed extensively and solutions are very well known: in case of binary transmission for example, MSK (minimum shift keying), which uses a sinusoidal pulse, can be applied leading to a constant envelope signal. Quaternary transmission can be realized with low amplitude dynamic using Offset-QPSK.

Brüninghaus-1998 at 2330.

Since the single-carrier system which results from an OFDM-CDM system with Fourier spreading matrix is a special case of an OFDM-CDM system, the same detection algorithms can be applied and the same performance can be expected.

	Brüninghaus-1998 at 2330. A general block diagram of an OFDM-CDM receiver with linear equalization [8] is depicted in Fig. 4. In case of a Fourier spreading matrix, despreading in the receiver is achieved by an inverse Fast-Fourier matrix, i.e. $[H]^H = [IFFT]$. The overall processing corresponds to a frequency domain equalization (FDE) since the received signal vector is first Fourier-transformed, multiplied by a diagonal equalization matrix and then transformed back into the time domain. Such an FDE was originally proposed in [17] to speed up the convergence of the equalizer coefficients in conjunction with the stochastic gradient method. In [18] the FDE was picked up again to compare single-carrier and multi-carrier (OFDM) transmission but without noticing that the considered single-carrier system is a special case of an OFDM-CDM system. Recently, the FDE was discussed for use in future mobile communication systems in combination with antenna diversity [20]. Brüninghaus-1998 at 2330. In contrast to a conventional single-carrier system, the single-carrier system resulting from OFDM-CDM with Fourier spreading matrix is characterized by a guard interval and the question arises why it should be advantageous to waste some part of the bandwidth. There are two reasons: the first one is the higher performance at the same number of equalizer coefficients in case of linear or decision feedback equalization. This results from the fact that the periodic extension of the data sequence in the transmitter in connection with the signal windowing the receiver leads to a cyclic convolution of the data sequence and the discrete-time channel impulse response. If the corresponding discrete-time channel transfer function contains no zeros, this cyclic convolution can be perfectly inverted in the receiver requiring not more than *N*(=length of data sequence) coefficients. To achieve the same effect with a conventional single-carrier system, generally an equalizer with an infinite number of taps is required,

	which cannot be implemented in a real system. Thus, an equalization error occurs, which limits the performance at high signal-to-noise-ratios. Brüninghaus-1998 at 2330-31. System parameters: • General - Bandwidth B = 2MHz - linear equalization based on MMSE criterion • OFDM-CDM with Fourier spreading matrix - blocklength: $T_N = 32\mu s$ - Guardlength: $T_G = 6.6\mu s$ - Number of symbols per block: $N = 64$ • Single-carrier system without guard interval - pulse with raised cosine spectral characteristic and rolloff' factor $\beta = 0.2$ - Symbol length: Ts = 600ns • Channel parameters: - Exponentially decreasing power delay profile from 0 to $5\mu s$ - Rayleigh channel - time invariant Brüninghaus-1998 at 2331. The special choice of an FFT matrix as spreading matrix for OFDM-CDM leads to a single-carrier system with guard interval. Such a single-carrier system has the same performance as the OFDM-CDM system but is less sensitive to nonlinear effects due to the reduced dynamic of the signal amplitude. In case of linear equalization, a single-carrier system with

guard-interval yields the same (low S/N) or even a better (high S/N) performance than the corresponding system without guard interval at the same number of equalizer coefficients and data rate. Besides, in highly time dispersive channels the computation complexity of such a receiver structure with blockwise processing is considerably lower than with continuous processing.

Brüninghaus-1998 at 2332.

Sorger-1998, which discloses:

The dimension of the IFDMA-symbol $c^{(i)}$ is $L_c = (L + L_\Delta)Q$ and the components $c_l^{(i)}$ can be written as

$$c_l^{(i)} = \frac{1}{L + L_\Delta} \cdot d_{l \bmod Q}^{(i)}, \quad l = 0, \dots, L_c - 1. \tag{6}$$

The first $L_\Delta Q$ chips $c_l^{(i)}, l = 0, \dots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by

$$T_\Delta = L_\Delta \cdot Q \cdot T_c. \tag{7}$$

where L_Δ has to be chosen to meet the condition of Equation (2). Finally, the transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user-dependent phase vector $s^{(i)}$ of dimension L_c having components

$$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \dots, L_c - 1. \tag{8}$$

The user-dependent phase $\Phi^{(i)}$ is chosen to be

$$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \tag{9}$$

The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures an orthogonal user discrimination by assigning to each user *i* a different set of

orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as

$$x^{(i)} = \left[c_0^{(i)},\, c_1^{(i)} e^{-j\Phi^{(i)}},\, c_2^{(i)} e^{-j2\Phi^{(i)}},\, \ldots,\, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \qquad (10)$$

Sorger-1998 at 1014.

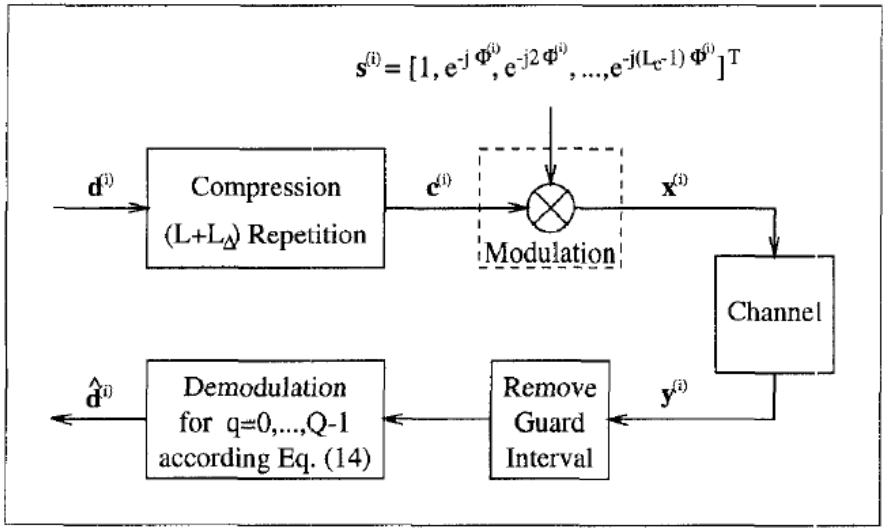


Figure 2: Block diagram of the proposed IFDMA system for a single user i

Sorger-1998 at Fig. 2.

Bury-1999, which discloses:

> We present a generalization and an extension of the block decision feedback equalizer described by Reinhardt in [1]. The original equalizer was derived for a class of transmission which is described by an orthogonal spreading over a group of non-interfering fading channels. We generalize

	this concept for block transmissions with arbitrary interference; the generalized description also includes reception with multiple antennas using joint diversity combining and equalization. In extension, we introduce soft feedback for all individual symbols, in contrast to the single soft value used in [1], offering an improved performance. We describe the proposed equalization method, provide examples for application, and illustrate the performance by simulation results. Bury-1999 at 345. In many practical cases it is convenient to transmit data in blocks which can be processed independently. Examples for block transmission methods are MC-CDM(A) on the basis of OFDM [3], Interleaved FDMA as described in [2], or serial transmission with termination to assure that there is no interference between blocks [4]. If there is interference within a block, the optimum detector performs a highly complex search of the most probable combination of transmit symbols. A less complex method is to employ equalization together with single symbol detection. Linear equalization allows simple implementation. The proposed decision feedback equalizer offers an improvement over linear equalization - however, at the cost of some complexity increase. Bury-1999 at 345-346. 6. SPREAD TRANSMISSION We now consider the special case of transmission over a set of interference free fading channels, where orthogonal symbol spreading is used to achieve a diversity gain. Figure 4 shows a model for this type of transmission.

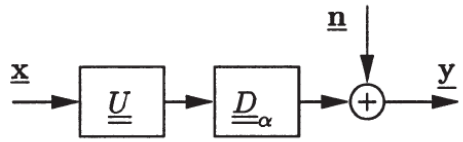


Figure 4 Transmission over non-interfering channels with orthogonal spreading

In this figure, $\underline{\underline{U}}$ is an orthogonal matrix for spreading, $\underline{\underline{D}}_\alpha$ is a diagonal matrix with the channel amplitudes on the main diagonal and zeros elsewhere, and we assume white noise with $\underline{\underline{\Phi}}_{nn} = \sigma_n^2 \cdot \underline{\underline{I}}$. The orthogonal spreading matrix has the property $\underline{\underline{U}}^H = \underline{\underline{U}}^{-1} = \underline{\underline{U}}$. For the cases of a Hadamard transform or a Fourier transform, multiplication with $\underline{\underline{U}}$ may be implemented as a fast algorithm (Fast Fourier Transform, FFT; Fast Hadamard Transform, FHT). By inserting $H = \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}}$ into equations (3), (4) and (5), we find

$$\underline{\underline{A}}_{\text{opt}}^{(0)} = \underline{\underline{U}}^H \cdot \underline{\underline{D}}_{\tilde{\alpha}} \quad \text{with} \quad \tilde{\alpha}_i = \frac{\alpha_i^*}{|\alpha_i|^2 + \frac{\sigma_n^2}{\sigma_x^2}} \tag{8}$$

$$\underline{\underline{A}}_{\text{opt}}^{(r)} = \underline{\underline{D}}_p^{(r)} \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)}, \tag{9}$$

$$\underline{\underline{B}}_{\text{opt}}^{(r)} = \underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)} - \text{diag}\left(\underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)}\right). \tag{10}$$

$$\underline{\underline{Q}}^{(r)} = \left(\underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \left(\underline{\underline{I}} - \underline{\underline{D}}_{|\varrho|^2}^{(r)}\right) \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H + \frac{\sigma_n^2}{\sigma_x^2} \cdot \underline{\underline{I}}\right)^{-1},$$

$$\frac{1}{p_i^{(r)}} = 1 + \underline{u}_i{}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{u}_i \cdot \left|\varrho_i^{(r)}\right|^2.$$

For the special case where for arbitrary i and fixed *r* the feedback values $\varrho_i^{(r)}$ are all identical, computation of the filter coefficients can be further

simplified, such that no matrix inversion is required; this has been derived in [1].

Bury-1999 at 350-51.

This model of spread transmission is applicable to, e.g., the following transmission schemes:

MC-SSMA (Multi-Carrier Spread Spectrum Multiple Access) as described in [3] uses a Hadamard transform to spread a vector of transmit symbols over a set of OFDM subchannels; each OFDM subchannel may be considered as a single Rayleigh fading channel. OFDM-CDMA is another name for essentially the same method.

IFDMA (Interleaved Frequency Division Multiple Access) as introduced in [2] can be described as an OFDM transmission where Fourier spreading is used to transmit over sets of equally spaced OFDM subchannels.

Serial block transmission over a multipath channel, using cyclic extension of transmitted blocks and corresponding extraction at the receiver, may be considered as an OFDM transmission with Fourier spreading over all subchannels. The equalizer can be implemented in the frequency domain by assuming a Fourier matrix for spreading. A linear equalizer for frequency domain equalization (FDE) has been presented in [4].

Bury-1999 at 351.

Bury-2000, which discloses:

Abstract - In this paper we investigate amplitude distributions of transmit signals for multi-carrier spread spectrum (MC-SS) transmission methods based on orthogonal frequency division multiplexing (OFDM), also called multi-carrier code division multiplexing (MC-CDM). In particular we compare Fourier spreading with the commonly used Walsh-Hadamard spreading. As a basis for the comparison we describe a general model. Both up- and downlink of multiple access transmission schemes employing

	either multi-carrier code division multiple access (MC-CDMA) or multi-carrier frequency division multiple access (MC-FDMA) are compared. Bury-2000 at 857. Multi-carrier code division multiplexing (MC-CDM) [1] is an interesting candidate for the physical layer in wireless high data rate local area networks. When compared to orthogonal frequency division multiplexing (OFDM), the additional spreading of MC-CDM produces a signal space diversity which improves power efficiency especially for high code rates [2]. A Hadamard transform is used for spreading in most MC-CDM system descriptions, e.g. [1]. However, further choices for orthogonal spreading are possible. With Fourier spreading [3], which can be implemented by a discrete Fourier transform (DFT) operation, it is clear that it can cancel the inverse discrete Fourier transform (IDFT) of an OFDM transmitter when spreading is done over all subcarriers, such that the result is a simple serial block transmission with cyclic extension [4]. This serial transmission can be regarded as a spread spectrum transmission, since the entire transmission bandwidth is covered by each transmitted symbol. The peak-to-average power ratio (PAPR) of a serial transmission is much lower than that of an OFDM transmission. The question that arises is: how is the situation when spreading is done not over all OFDM subcarriers but only over groups of carriers? Bury-2000 at 857. In [5] Golay complementary sequences have been used instead of Hadamard sequences for reducing the PAPR in MC-CDMA transmission, and a scrambling scheme was employed to further improve the amplitude distribution of the transmit signal. In this paper we suggest to employ a DFT for spreading, which can be implemented efficiently as a fast Fourier transform (FFT). Furthermore we extend our considerations to MC-FDMA, as introduced in [6] (named MC-SS-MA there).

Bury-2000 at 857.

> Subsequently we describe a model of a MC-CDM transmitter. In a multiple access context, this model is valid for both, MC-CDMA and MC-FDMA. We describe the methods used for computation of the amplitude distribution and the PAPR of the transmit signal. It is shown that, given the transmit symbol alphabet and the corresponding symbol probabilities, both amplitude distribution and PAPR are uniquely determined by a single matrix which describes the transmitters linear mapping from transmitted symbols to the transmit signal. Based on simulation results, we discuss the suitability of Hadamard and Fourier spreading for MC-CDM transmission methods.

Bury-2000 at 857.

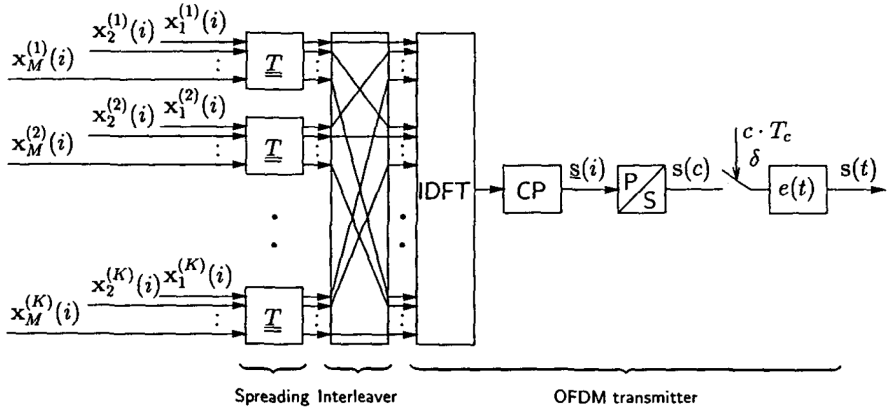


Fig. 1. Model of transmitter for OFDM-based MC-CDM.

Bury-2000 at 858.

> The model in Fig. 1 depicts a transmitter for MC-CDM based on OFDM. An OFDM transmitter is extended by an additional spreading, described by

	the transform matrices $\underline{\underline{T}}$, and by an interleaver. The OFDM transmitter consists of an IDFT, a cyclic prefix insertion CP, a parallel-to-serial conversion, and the conversion to continuous-time using an ideal Dirac sampler and a basic waveform $e(t)$, which is a Nyquist impulse. The delivered baseband transmit signal is $s(t)$. The number of OFDM subcarriers is N, the cyclic prefix has length L, transmit signal samples are indexed by c, and the Dirac sampler generates an impulse every T_c seconds. Bury-2000 at 857. Spreading is done by transforming a vector of M symbols through a matrix $\underline{\underline{T}}$. This square matrix is orthogonal, such that the condition $$\underline{\underline{T}}^H \underline{\underline{T}} = \underline{\underline{I}} \quad (1)$$ is fulfilled. Furthermore, to assure equal energy distribution, we consider only spreading matrices with the property that the absolute value of all matrix elements is constant $$\left|t_{i,k}\right| = \frac{1}{\sqrt{\underline{\underline{N}}}} \quad \forall\, i,k. \quad (2)$$ In literature usually a Hadamard transform is selected for $\underline{\underline{T}}$; however, further choices are possible, e.g. a DFT. Bury-2000 at 857-58. III. AMPLITUDE DISTRIBUTION OF THE TRANSMIT SIGNAL For a certain time instant t_0 the complex baseband transmit signal $s(t_0)$ is a random variable which is in general a linear combination of all random transmit symbols

$$s(t_0) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{K} \sum_{m=1}^{M} \alpha_{m,k,i}(t_0) x_m^{(k)}(i)\,. \qquad (3)$$

The coefficients $\alpha_{m,k,i}(t_0)$ are derived from $\underline{\underline{T}}$, $e(t)$, N, L, K, and M, as described subsequently. When the duration of the basic waveform $e(t)$ is finite, the infinite sum over i in this equation can be replaced by a finite sum. Then the probability density function (PDF) of the transmit signal at time $t_0, f_{s(t_0)}(x)$, is obtained from the PDFs of all contributing transmit symbols.

Bury-2000 at 858.

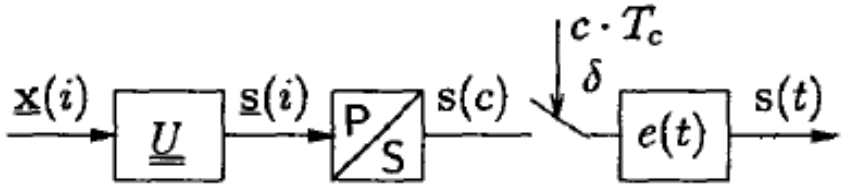


Fig. 2. Equivalent transmitter model.

Bury-2000 at 859.

Discrete-time computation

At discrete time we consider the signal $s(c)$ instead of $s(t)$. To obtain a simple description we join the spreading, interleaving, IDFT and cyclic extension of the transmitter in Fig. 1 into a single matrix $\underline{\underline{U}}$, see Fig. 2.

. . .

	The discrete-time transmit signal of a single OFDM block ($i = 0$) then represents the cyclo-stationary statistics of the transmit signal. We omit the block index i and write $$\underline{s} = \underline{\underline{U}} \cdot \underline{x}, \quad (6)$$ with vector elements $x_{(m+M(k-1))} = x_m^{(k)}(0)$ and $s_c = s(c)$. In equivalence to equation (3) we write $$s_c = \sum_{n=1}^{N} u_{c,n} x_n \,. \quad (7)$$ Hence, the PDF at a particular time instant c is related with a certain row in $\underline{\underline{U}}$. Bury-2000 at 859. From above equations we see that, given the transmit symbol alphabet and corresponding occurrence probabilities, the PDF of the discrete-time transmit signal, $f_{s(c)}(x)$, is determined by the transform matrix $\underline{\underline{U}}$. For the case of Fourier spreading, the matrix $\underline{\underline{U}}$ contains in most cases more zero elements than for Hadamard spreading. This already indicates a better amplitude distribution for Fourier spreading, because fewer random variables are summed. Bury-2000 at 859.

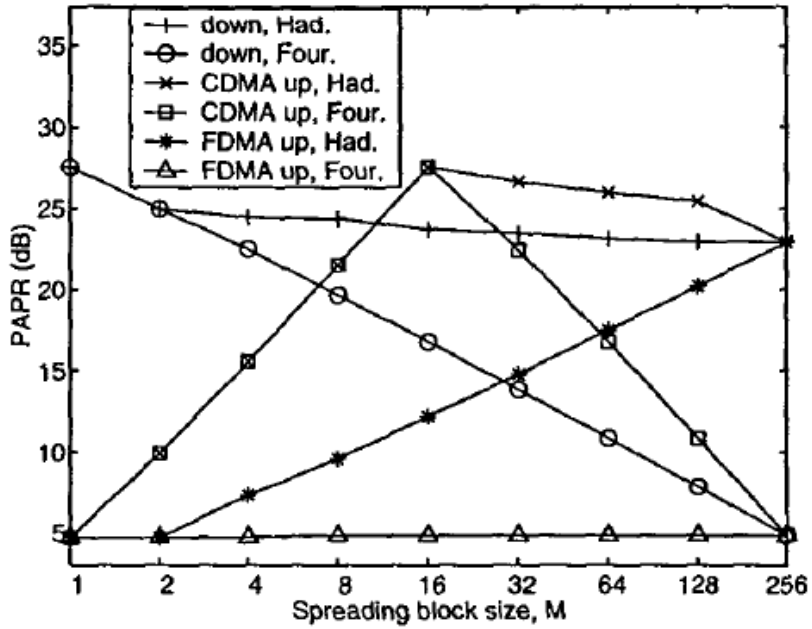


Fig. 3. PAPR as a function of the spreading block size. 4PSK, $N = 256$, $L = 32$, 'continuous' time.

Bury-2000 at 859.

Downlink

In the downlink, the PAPR is the same for both MC-CDMA and MC-FDMA. This is obvious because both systems are identical except for the assignment of transmitted symbols to users. For the trivial case of spreading over a single carrier and for the case of spreading over two carriers, both Hadamard and Fourier spreading deliver the same PAPR. In the latter case this happens because Hadamard and Fourier matrices are identical for spreading over two symbols. In the case of Hadamard spreading, when spreading is done over an increasing number of

	subcarriers, the PAPR remains nearly constant (with a slight decrease); for Fourier spreading, however, it decreases rapidly and reaches the PAPR of a single carrier transmission when spreading is done over all subcarriers. This means that for the downlink Fourier spreading clearly outperforms Hadamard spreading. The larger the spreading factor, the better the PAPR. Furthermore, assuming that a large number of users is desired, we consider the following: Since MC-FDMA requires (at least) one spreading block per user, the spreading blocks must be small in case of many users, resulting in a relatively large PAPR. For MC-CDMA, however, the larger the spreading block, the larger the possible number of users. Here the best choice with respect to PAPR is to use Fourier spreading over all carriers while assigning groups of input symbols for each user, resulting in the lowest possible PAPR. Bury-2000 at 859-60. Uplink In the uplink we distinguish between MC-CDMA and MC-FDMA. For MC-CDMA the PAPR of both Fourier and Hadamard spreading shows a strong increase for increasing spreading factors, reaching a maximum when the spreading factor equals the square root of the number of subcarriers. When the spreading factor is increased further, Hadamard spreading shows a slight decrease in PAPR while Fourier spreading shows a rapid decrease, reaching the PAPR of a serial transmission when spreading is done over all carriers. In contrast to MC-CDMA, MC-FDMA shows a much better behavior, with the PAPR being lower for the entire range of spreading factors, for the respective spreading methods. For Hadamard spreading, the PAPR increases for increasing spreading factors. For Fourier spreading, however, the PAPR remains nearly constant at a low level for all spreading factors. This shows that also in the uplink Fourier spreading outperforms Hadamard spreading in most cases. For the case of Fourier spreading in a

MC-FDMA uplink, the spreading factor may be selected arbitrarily, nearly without affecting the PAPR.

Bury-2000 at 860.

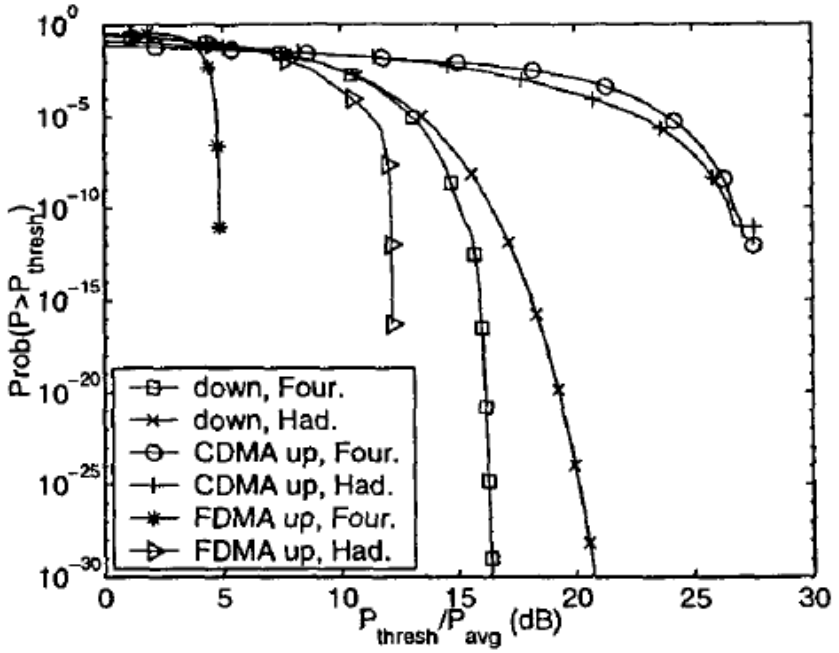
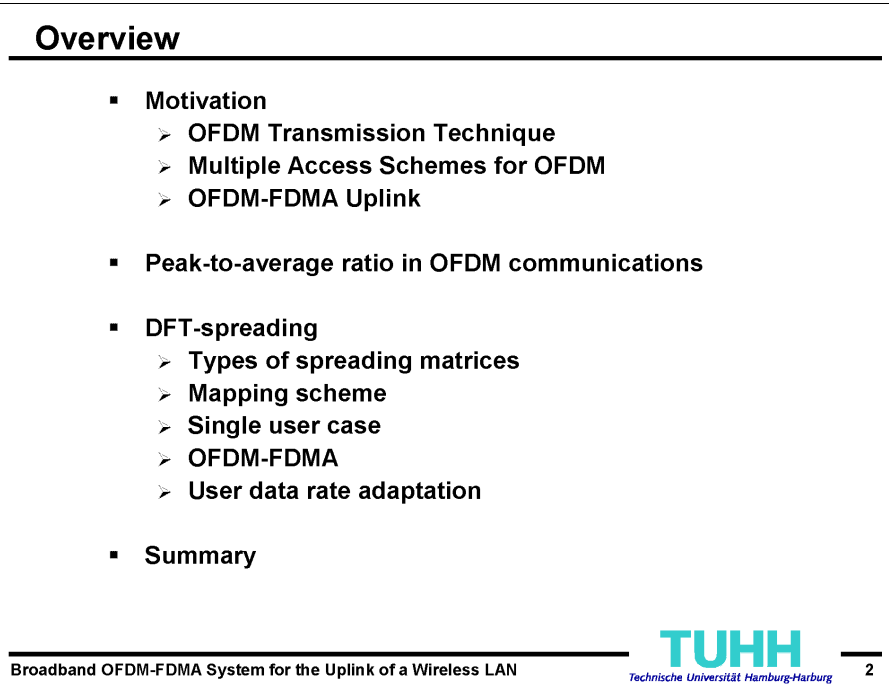


Fig. 4. Example for amplitude distribution.
4PSK, $N = 256$, $L = 32$, $M = 16$, 'continuous' time.

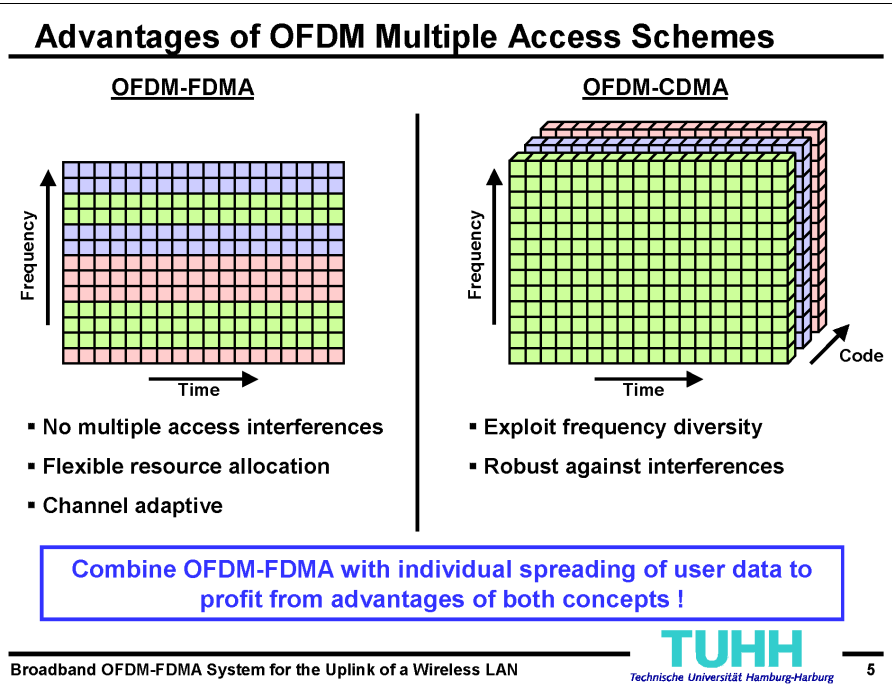
Bury-2000 at 860.

The graph shows that, in case of the downlink, Fourier spreading offers a more sharply limited amplitude distribution while Hadamard spreading produces continuously growing amplitudes at decreasing probabilities. Not only from the PAPR point of view, but also from the PDF of the amplitude

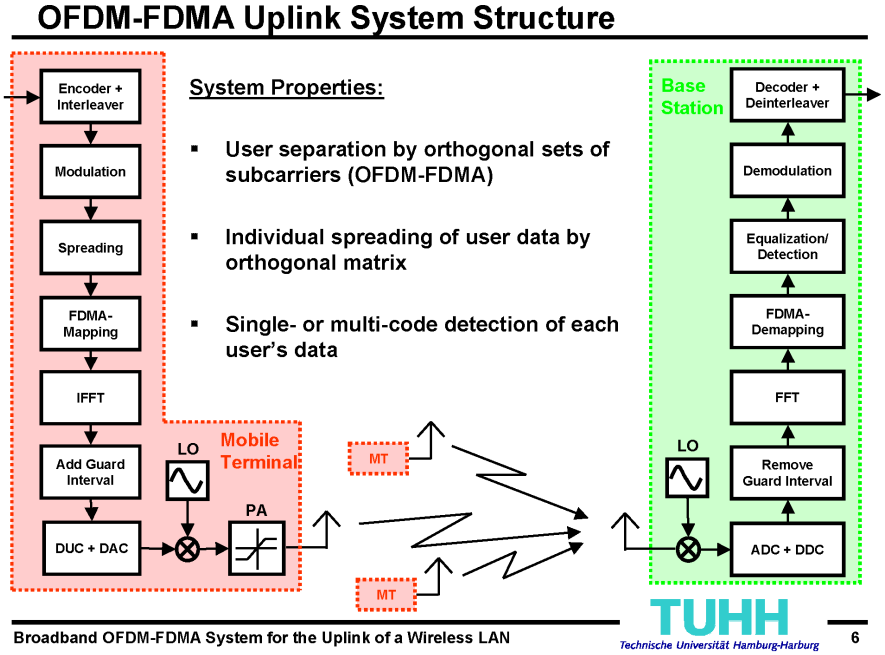
	it is clear that Fourier spreading is a better choice than Hadamard spreading. Bury-2000 at 860. Amplitude distributions of Hadamard spreading and Fourier spreading have been compared for OFDM based MC-CDM transmission methods, using a general matrix model. Comparison has been done for both up- and downlink in MC-CDMA and MC-FDMA multiple access scenarios, and for various spreading factors. For both up- and downlink Fourier spreading delivers a lower or equal PAPR. This superiority increases significantly for larger spreading factors. In the uplink, MC-FDMA delivers lower PAPRs than MC-CDMA. From the amplitude distribution point of view, the best choice is to employ Fourier spreading with MC-CDMA in the downlink and with MC-FDMA in the uplink. Bury-2000 at 860. Galda-2001, which discloses:



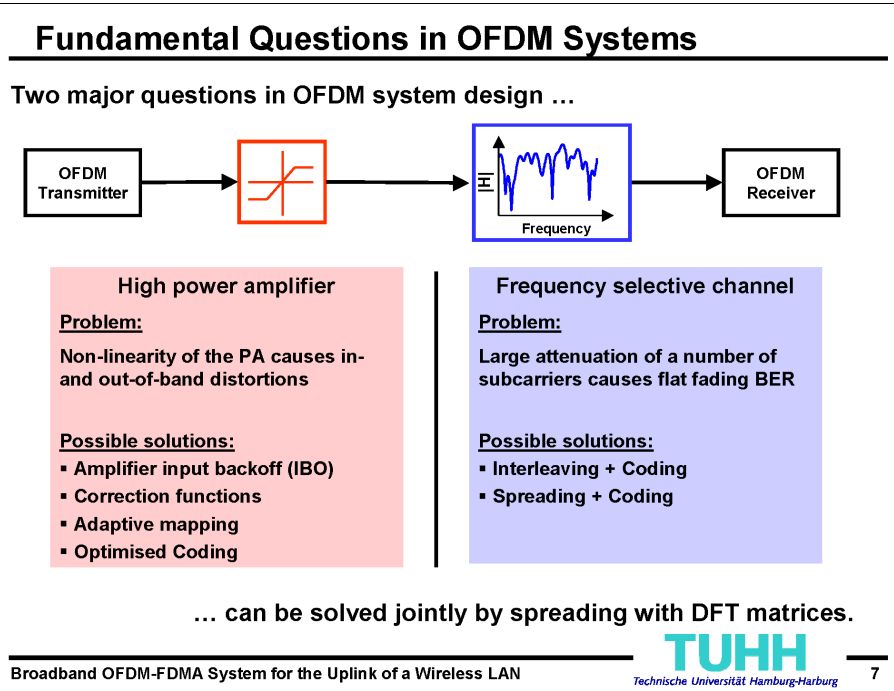
Galda-2001 at 2.



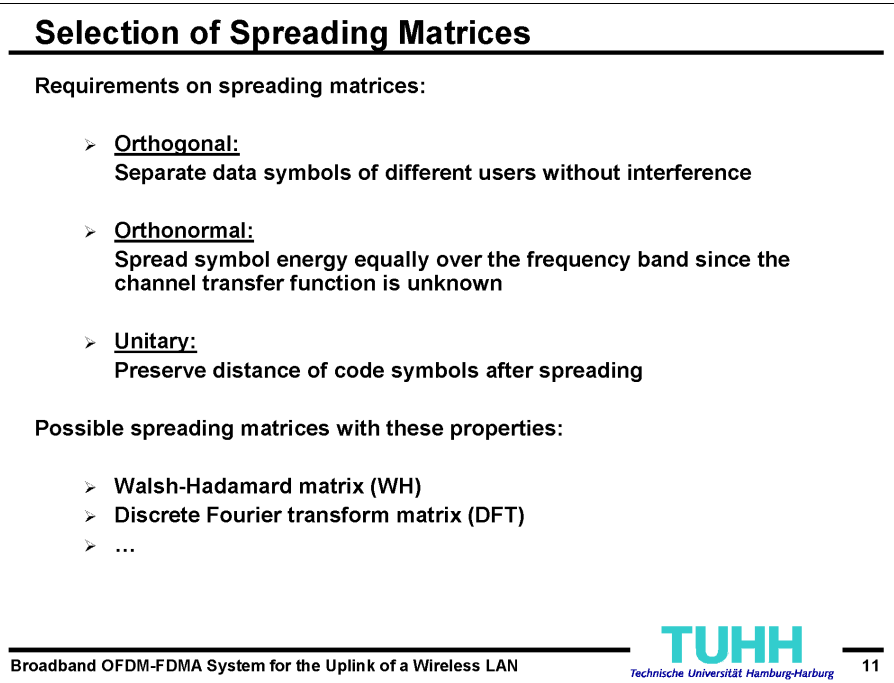
Galda-2001 at 5.



Galda-2001 at 6.



Galda-2001 at 7.



Selection of Spreading Matrices

Requirements on spreading matrices:

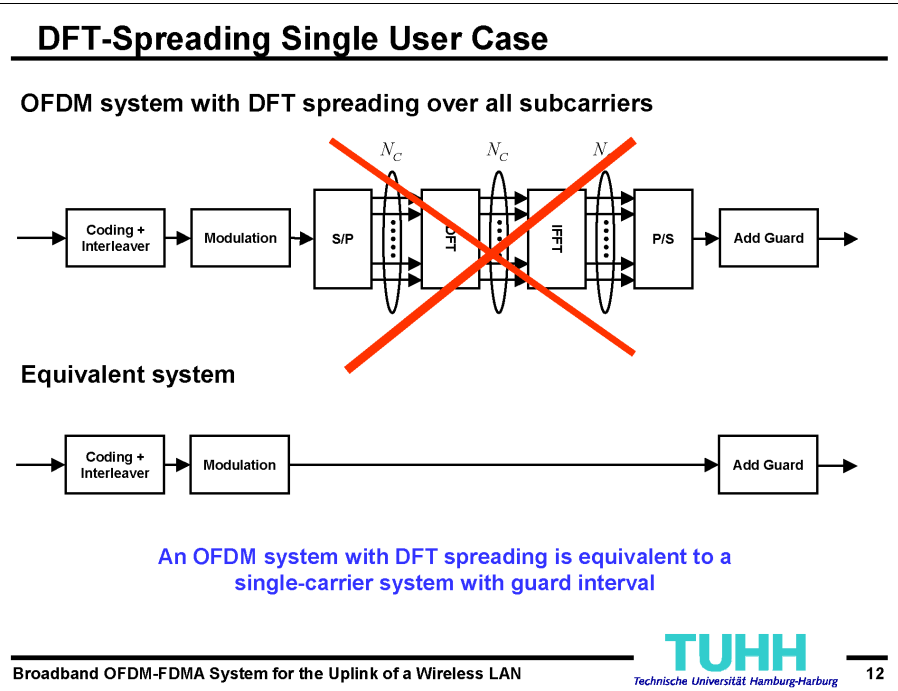
- Orthogonal:
  Separate data symbols of different users without interference
- Orthonormal:
  Spread symbol energy equally over the frequency band since the channel transfer function is unknown
- Unitary:
  Preserve distance of code symbols after spreading

Possible spreading matrices with these properties:

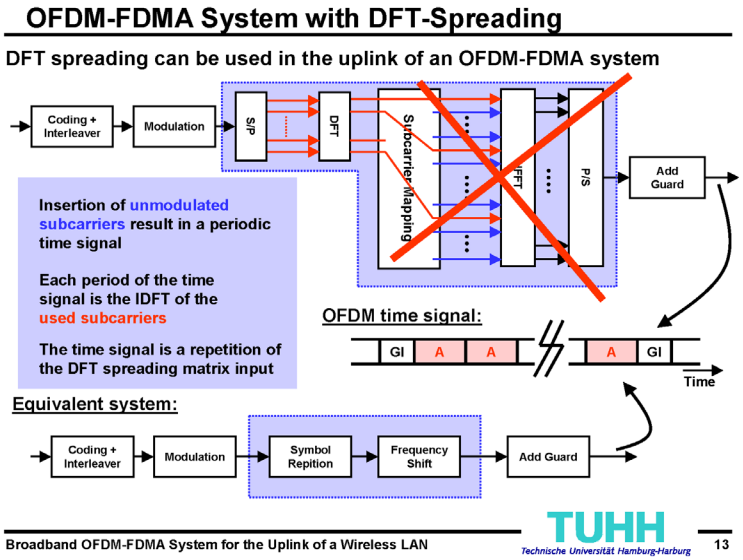
- Walsh-Hadamard matrix (WH)
- Discrete Fourier transform matrix (DFT)
- ...

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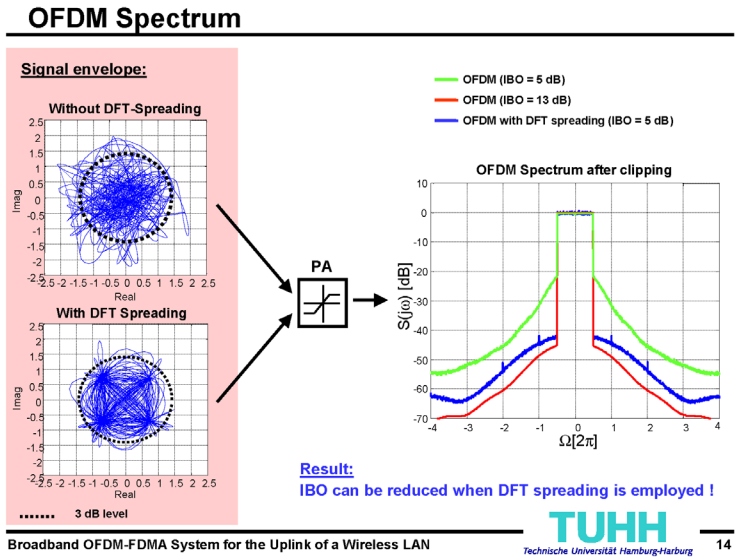
Galda-2001 at 11.



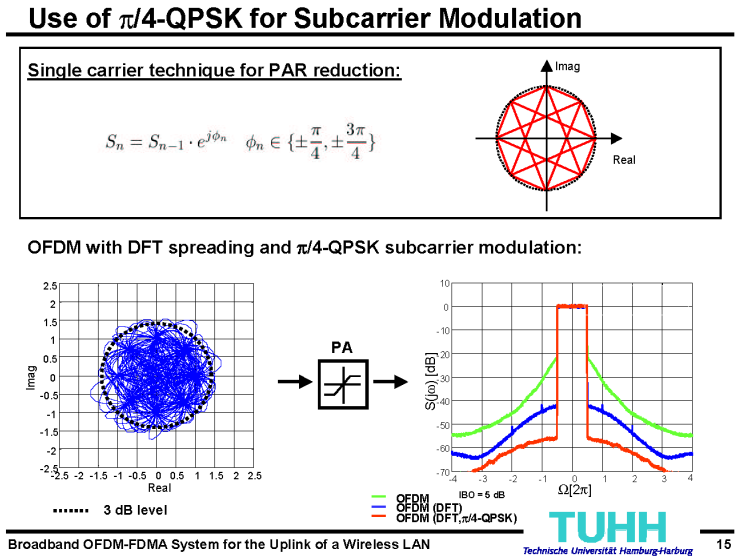
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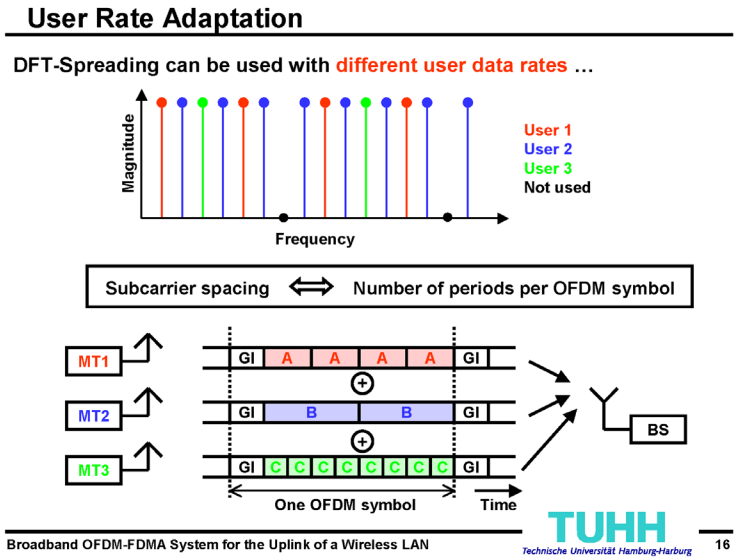
Galda-2001 at 13.



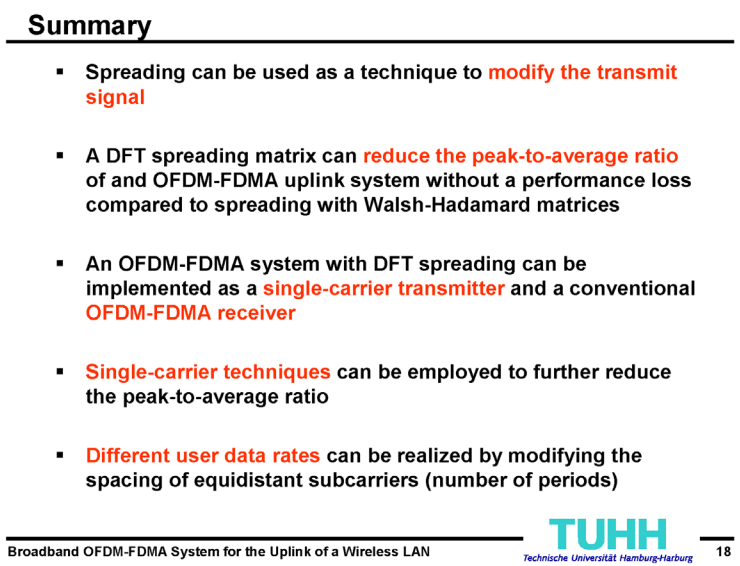
Galda-2001 at 14.



Galda-2001 at 15.



Galda-2001 at 16.



Galda-2001 at 18.

Galda-2002, which discloses:

> Abstract- The orthogonal frequency division multiplex (OFDM) transmission technique can efficiently deal with the effects of multi-path propagation in the broadband radio channel. It also has a high system inherent flexibility for designing a multiple access scheme by combining the conventional TDMA, FDMA and CDMA approaches with the OFDM modulation scheme. The FDMA multiple access scheme is especially interesting for an uplink of a communication system since it can completely avoid any multiple access interferences (MAI). Moreover, the peak-to-average ratio (PAR) of the uplink OFDM transmit signal can be greatly reduced if this OFDM-FDMA multiple access scheme is additionally combined with a data spreading technique based on a Discrete Fourier

	Transform (DFT) spreading matrix using only the user specific subcarriers. Since the DFT spreading operation and the IDFT operation used as a part of the OFDM modulation scheme cancel out each other the complexity of the transmitter structure for an OFDM-FDMA uplink can be greatly reduced. Galda-2002 at 1737. The subdivision of the transmission bandwidth into a set of orthogonal subcarriers can additionally be exploited by an OFDM-FDMA multiple access scheme. By allocating distinct sets of subcarriers to different users the available bandwidth can be flexibly shared between different mobile terminals while avoiding any multiple access interferences (MAI) between different users. The FDMA multiple access scheme offers not only a high flexibility for the radio resource management (RRM) but can also increase the bandwidth efficiency of the complete system by avoiding the use of highly attenuated subcarriers for specific users based on the knowledge of the channel transfer function [2]. Moreover, the OFDM-FDMA multiple access scheme can be adapted to the measured radio channel knowledge at the transmitter site using bit-loading techniques. If channel state information is not available the performance can be increased using an additional spreading over the subcarriers assigned to one user. The resulting computation complexity of the total system can by this means be adopted to the given system requirements which is especially of importance for the mobile terminal and in the uplink case. The alternative OFDM-FDMA multiple access scheme is therefore of importance for the uplink case and can be advantageous over OFDM-CDMA schemes because of its ability to avoid MAI if ideal carrier synchronization is assumed for all mobile terminals and the base station. Galda-2002 at 1737. Since the OFDM transmit signal results from the superposition of a large number of independent data symbols the envelope of the complex baseband

	time signal has in general a large peak-to-average ratio (PAR). The largest output power value of the amplifier will limit the maximum amplitude of the signal in the transmitter. Therefore, non-linear distortions due to clipping and amplification effects in the transmit signal will lead to both in-band and out-of-band emissions. In the past different techniques for reducing the PAR by changing the transmit signal independently from knowledge of other parts of the OFDM transmitter have been developed. But the PAR of the transmit signal envelope which employs an OFDM-FDMA multiple access scheme can significantly be reduced if additional spreading techniques are applied which spread the user data over the allocated subcarrier only. In this case an appropriate spreading technique must be designed reducing the PAR to a minimum value. It will be shown in this paper that using the Discrete Fourier Transform (DFT) matrix as an orthogonal spreading technique will reduce the PAR significantely [3]. Furthermore, the DFT based spreading operation and the IDFT based OFDM modulation technique cancel out each other which means that the transmitter structure can be simplified to a single carrier transmitter with an additional guard interval in this specific case which helps to reduce the computational complexity of the transmitter of the mobile terminal. Galda-2002 at 1737-38. This paper shows how an OFDM-FDMA uplink system can be combined with a user data spreading technique based on the DFT spreading matrix to reduce the PAR of the uplink signal without increasing the computational complexity of the transmitter. In Section II the structure of the analyzed OFDM-FDMA system combined with a DFT spreading matrix is described for the uplink application. In Section III the influence of a DFT matrix applied for data spreading is analyzed for an OFDM-TDMA multiple access scheme and is extended to an OFDM-FDMA system in a separate subsection. The general topic of non-linearities in an OFDM system is reviewed in Section IV. Quantitative results are given in Section V and Section VI summarizes the papers content.

Galda-2002 at 1738.

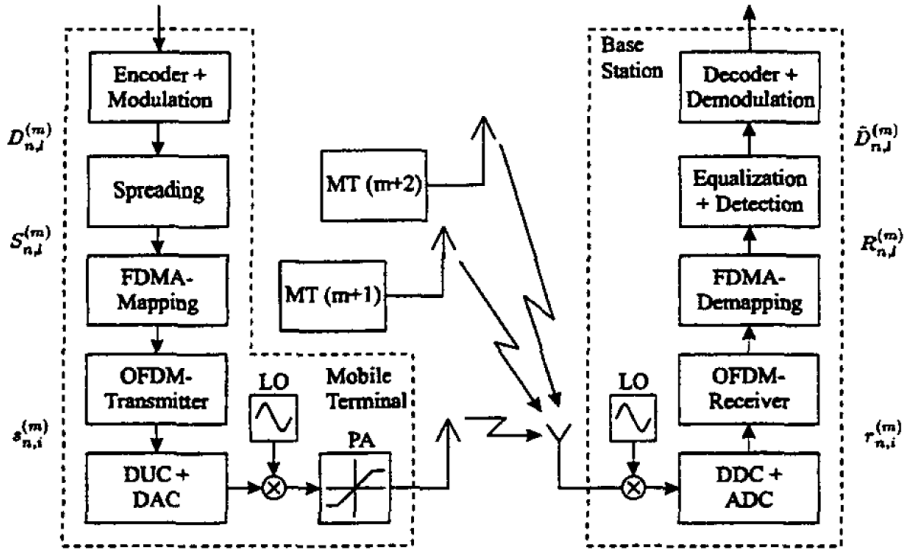


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

Galda-2002 at Fig. 1.

The baseband system model of an OFDM-FDMA uplink with individual spreading of user data is shown in Fig. 1. In this case M different users are considered and each user allocates L different subcarrier exclusively. The total number of subcarrier in the considered transmission system is $N_C = L \cdot M$. The input data stream for each mobile user $m, m = 0, \dots, M-1$, is convolutionally encoded in a first step. The bit sequence is then mapped onto L complex modulation symbols $D_l^{(m)}, l = 0, \dots, L-1$, of a coherent, higher-level modulation scheme. The L modulation symbols are spread over the L user specifically allocated subcarrier with an unitary spreading

matrix $[C]$ resulting in L complex transmit symbols $S_l^{(m)}$. The spreading operation can be denoted mathematically by the following simple matrix multiplication

$$\vec{S}^{(m)} = [C]\vec{D}^{(m)} \quad (1)$$

where each complex transmit symbol $S_l^{(m)}$ is calculated by the sum of L user modulation symbols $D_l^{(m)}$ weighted by L orthogonal code vectors $\widetilde{C_l} = \left(C_{l,0}, C_{l,1}, \dots, C_{l,l}\right)$ with $l = 0, \dots, L-1$

$$S_l^{(m)} = \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} \quad \text{for} \quad l = 0, \dots, L-1 \quad (2)$$

The transmit symbols $S_l(m)$ are then mapped onto L of the available N_C subcarrier which are exclusively allocated to user m. In principle, the set of subcarrier assigned to each user can be composed of any L out of N_C subcarrier that have not been assigned to another user.

Galda-2002 at 1738.

Independent of the considered spreading matrix C but assuming the equidistant allocation of subcarrier over the entire bandwidth the resulting OFDM time signal of user m can analytically be described as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \quad (3)$$

where N_G denotes the length of the guard interval which is inserted into the transmit time signal.

Galda-2002 at 1738.

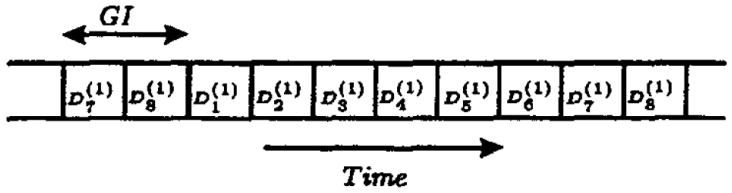


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

Galda-2002 at Fig. 3.

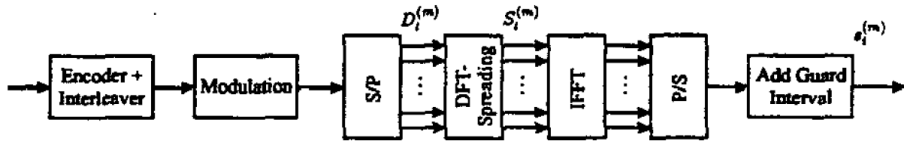
A. OFDM-TDMA with DFT Spreading

In [3] the Discrete Fourier Transformation (DFT) matrix has been used for spreading the vector $\vec{D}$ of length $L = N_C$ over all subcarriers of an OFDM system. If a single user is assumed in this OFDM system the spreading operation includes all subcarrier within the entire bandwidth. In this case the DFT spreading matrix and the IDFT operation in the OFDM modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore technically reduced to the serial sequence of complex transmit data symbols D_i to which a guard interval is added in the time domain as a cyclic prefix

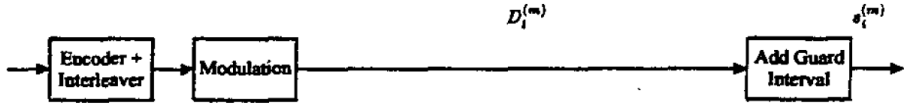
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \tag{5}$$

where mod denotes the modulo operation, as shown in Fig. 3.

Galda-2002 at 1739.



(a) OFDM transmitter including DFT spreading over all subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 4. In an OFDM system including a DFT spreading matrix and an IFFT for the OFDM modulation process both matrices cancel out each other.

Galda-2002 at Fig. 4.

> After calculating the FFT in the receiver which splits the received time signal into the orthogonal sub-channel the same single- or multi-code detection techniques can be applied which are well known from OFDM-CDMA receiver structures. The same bit error rate (BER) performance compared to a system using a Walsh-Hadamard spreading matrix can therefore be achieved if a DFT spreading matrix is considered instead. But in case of a DFT spreading matrix the resulting PAR is significantly reduced. The general structure of an OFDM transmitter including DFT spreading is shown in Fig. 4.

Galda-2002 at 1739.

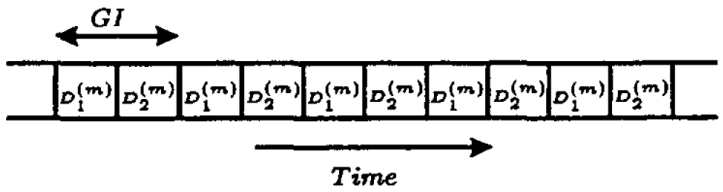


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

Galda-2002 at Fig. 5.

B. OFDM-FDMA with DFT Spreading

The advantage of a DFT spreading matrix can also be exploited in the uplink of an OFDM-FDMA system. If the user data is spread only over $L < N_C$ subcarriers then the DFT of length L used for spreading does not directly cancel out with the length N_C IDFT of the OFDM modulator in general. Only when the spreaded symbols $S_l^{(m)}$ are mapped onto equidistant located subcarriers with a spacing of $N_C/L = M$ the DFT spreading and the OFDM modulation can be removed in the transmitter structure. This can be seen by inserting Equation (2) into Equation (3) using the elements of the discrete Fourier matrix

$$C_{i,j} = \frac{1}{\sqrt{L}} \cdot e^{j2\pi ij/L} \qquad (6)$$

the transmit signal of user m can be written as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L}$$

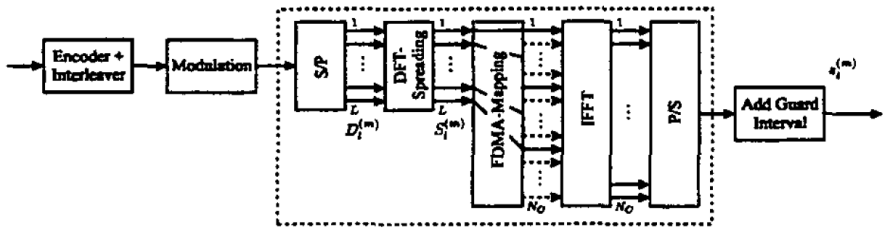
$$= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)}$$

$$= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu - i)$$

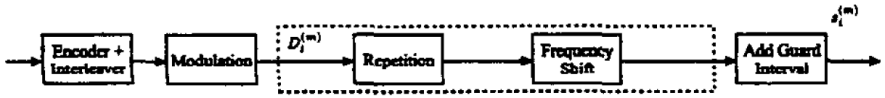
$$s_i^{(m)} = e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \quad (7)$$

for $i = -N_G, \ldots, 0, \ldots, N_C$ and the periodic dirac pulse sequence $\delta_L(\ \ )$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ sequence including an added guard interval as cyclic prefix, shown in Fig. 5. This periodic data sequence is multiplied by a user specific complex signal $e^{j2\pi im/N_C}$ due to the user individual frequency shift by m subcarriers of the complete allocated subcarrier set. The number of periods inside a single OFDM symbol is equal to the spacing M of the subcarriers allocated to user m.

Galda-2002 at 1739-40.



(a) OFDM-FDMA transmitter with DFT spreading over equidistant subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 6. In an OFDM-FDMA uplink system including DFT spreading matrix applied to a set of equidistant subcarriers the DFT spreading matrix and the OFDM IFFT transformation cancel out each other.

Galda-2002 at Fig. 6.

The structure of the OFDM transmitter can be simplified by this approach since both the DFT spreading operation and the IFFT calculation of the conventional OFDM transmitter cancel out and can be removed in the technical realization completely and will be replaced by a simple repetition process of the considered user data $D_l^{(m)}$. The simplified transmitter structure is depicted in Fig. 6. Any equidistant subcarrier allocation can be used with the proposed FDMA scheme since it only influences the number of periods of the transmit signal. Therefore the user data rate can be flexibly adjusted by assigning the required number of subcarriers to each user.

	Galda-2002 at 1740. In order to avoid non-linear distortions even in the case of a highly linear power amplifier a sufficient input-backoff (IBO) of the transmit signal to the amplifier has to be used. Even though the clipping probability of the OFDM signal can be reduced or even be avoided for an IBO larger than the PAR a system with large energy efficiency loss results. Alternatively, the effects which a non-linear device can have on the transmit power spectrum can be influenced by a reduction of the OFDM transmit signal PAR Different techniques have been developed which reduce the PAR of the OFDM signal by the means of a modified channel coding [5], an additive [6] or multiplicative [7] correction function or a selective mapping of modulation symbols to subcarriers [8]. A majority of these techniques has a high computational complexity due to the fact that they analyze the generated transmit signal and modify it either in the frequency or time domain to reduce its peak amplitudes. For a system employing coherent subcarrier modulation the PAR can also be reduced if the data symbols are spread by a Fourier matrix in frequency direction [3]. Galda-2002 at 1740. In this paper an OFDM-FDMA system concept for the uplink of a multi user communication system has been studied. It had be shown that if an OFDM-FDMA system with equidistant subcarrier allocation is combined with a user specific spreading using an discrete Fourier transform as a spreading matrix the transmitter structure can be greatly simplified without any performance degradation. Moreover, the peak-to-average ratio of the transmit signal is reduced to the PAR of the subcarrier modulation scheme which can limit the out-of-band and in-band emissions when the transmit signal is passed through a non-linear device. With the opportunity to independently adjust the user data rates the proposed technique offers an interesting alternative for reducing the complexity of the mobile terminal in the broadband radio uplink.

	Galda-2002 at 1741. Costa-193, which discloses: > The invention relates to a method and a communication system device for the generation of OFDM symbols, wherein data from one or more users or from one or more data sources (User 1–User M) are represented on a number of sub-carriers (Nc). According to the invention, in order to inhibit multiple-access interference (MAI) on application of the CDMA principle, the data are transformed in a data-source specific manner and only subsequently allocated to the sub-carriers, independently of the transformation. Costa-193 at abstract. > According to an alternative procedure, the user data can be spread over a specified number of sub-carriers and/or OFDM symbols by using orthogonal codes with the aid of an orthogonal matrix, as is the case with OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). In the OFDM-CDMA process, the data of all users is allocated to all available frequencies, wherein codes are used for separation. Without further measures, undesirable multiple access interferences occur in this case, in particular when considering a plurality of users or data sources whose data is received in parallel with one another. Costa-193 at 1:18-24. > To avoid this problem, the user data is thus spread over a plurality of sub-carriers only when sub-carriers are allocated to a plurality of users at the same time, which is referred to as OFDM-FDMA, with user-specific spreading of the reference data. Spreading and allocation of sub-carriers takes place in a common and comprehensive method step. So-called Walsh-Hadamard matrices of different sizes are mainly used for the spread, as described for example by M. Yee, J.-P. Linnartz: "Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading

	Channel," Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: "Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications," Kluwer Academic Publisher, 1996. Depending on the data rate required for transmission, different users are allocated a number between 1 and N of orthogonal codes, wherein N is the number of available sub-carriers. Costa-193 at 2:1-9. Furthermore, in K. Bruninghaus, H. Rohling: "Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission," Proc. IEEE VTC'98, Ottawa, Canada, 1998, a spread using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of the peak values to the average values (PAR: Peak-to-Average Ratios) is generally discussed, although multiple accesses are not considered. Costa-193 at 2:10-13. Advantageously, due to the data source-specific, i.e., exclusive, allocation of sub-carriers to the respective users or user data, to which the transformation result of an orthogonal transformation matrix or spread is transmitted, the undesirable multiple access interferences can be avoided, ideally completely, despite the application of the transformation. Advantageously, the choice of the orthogonal matrix is initially arbitrary. Furthermore, the transformation result can also be allocated to the exclusive sub-carriers of a user or a data source in any way. The separation of the spread of the user-specific data or data source-specific data and the allocation of the transformed or spread data to the sub-carriers of one or more OFDM symbols is particularly advantageous when a discrete Fourier transform (DFT) or fast Fourier transform (FFT) is used for the spread instead of, for example, the Walsh-Hadamard transform.

	In particular in combination with an equidistant arrangement of the sub-carriers on the carrier, in particular on the frequency axis, for the various user data or data sources, an OFDM-FDMA system then results in which the time signal or the OFDM symbols have a constant amplitude behind the usual inverse fast Fourier Transform (IFFT). This is a very significant advantage, because the various smoothing processes, which would currently have to be used, become unnecessary. Costa-193 at 3:1-13. In particular when combining a Fourier transform and an inverse Fourier transform, in a particularly preferred embodiment, a simplified generation of the OFDM symbols can also be carried out, because corresponding process steps can be omitted during their generation. In effect, the two successive Fourier transforms can cancel each other out, with the exception of, in particular, a frequency shift. Correspondingly, according to the invention, when communicating between, for example, a mobile user station and a base station in the uplink direction, it is possible to distribute/combine the incoming data from the individual data sources directly onto the corresponding OFDM symbol positions, if necessary after the usual encoding, interleaving, and modulation. This advantageously simplifies the structure of the transmitting communication station. The base station can expediently remain unchanged and continue to have the structure of an OFDM receiver, in order to be able to utilize the OFDM-specific advantages such as simple equalization of the received signal and separation of the user station data or users. Costa-193 at 4:1-10. FIG. [1] a scheme for a general multiple access, wherein the structure of an OFDM-FDMA system having user-specific spread of the data symbols is shown;

Costa-193 at 5:3-4.

> FIG. [2] schematically, a possible implementation of an OFDM-FDMA system having a particularly preferred FFT spread matrix and allocation of the user data to equidistant sub-carriers;

Costa-193 at 5:5-6.

> FIG. [3] schematically, an allocation of spread user data to equidistant sub-carriers, and

Costa-193 at 5:7.

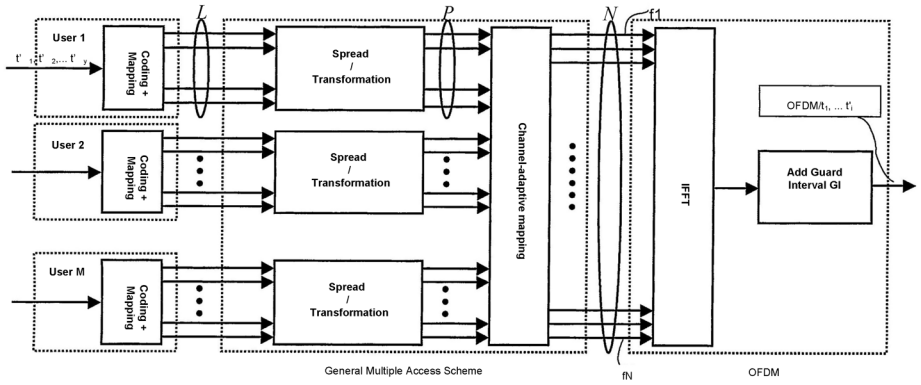


FIG. [1]

Costa-193 at Fig. 1.

> The following block shows the actual transformation or spread and the encoding of the data from different users onto the individual frequency sub-carriers.
>
> The data arriving on L data paths for each user is spread in a first step, i.e., distributed from a total of L data values onto P data values. This preferably serves to utilize the statistically independent propagation of the signals on

	different sub-carriers (frequency diversity). In the preferred exemplary embodiments, the number of individual data values or lines is not changed, although this is also possible, so that there are L complex data values per user before and after the spread. Analogous to the spread of the data with Walsh-Hadamard matrices as in OFDM-CDMA, L corresponds to the number of codes allocated to the user station and P to the number of available orthogonal code symbols. In this case, the spread corresponds to a full-load system. Costa-193 at 6:1-9. When describing the structure of the OFDM-FDMA system with the user-specific spread of the data symbols above, a conscious distinction is made between, on the one hand, spread/transformation and, on the other hand, mapping onto the sub-carriers. Costa-193 at 7:6-8. This separation is carried out in order to be able to transform or spread the data of the individual users, initially with the aid of an orthogonal matrix. In the subsequent step, the transformation result is then transferred onto sub-carriers, wherein sub-carriers are exclusively allocated to each of the individual users. In principle, the sub-carriers can be allocated in any way, wherein systems are preferred in which the first sub-carriers are allocated to the first user and the last sub-carriers to the last user. However, this is not absolutely necessary and is in particular undesirable in the case of a channel-adapted allocation, for example. However, systems in which the data of a user are mapped or transmitted onto sub-carriers that are distributed equidistantly across the frequency band are particularly preferred. Costa-193 at 7:9-15.

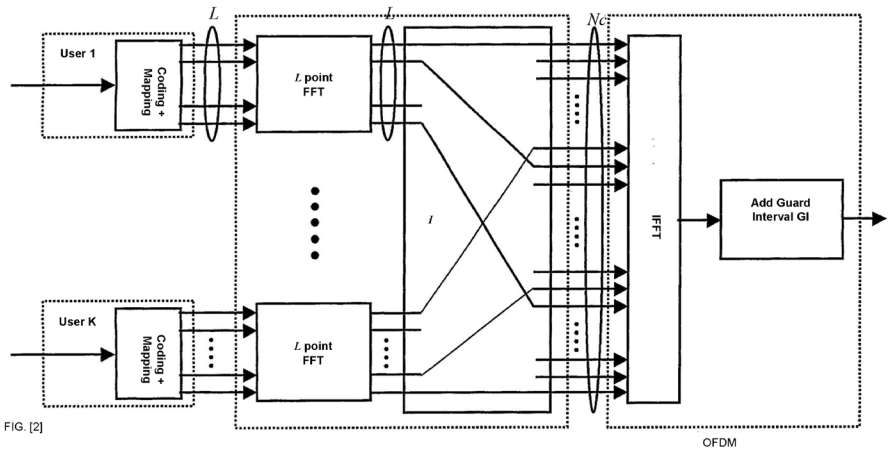


FIG. [2]

Costa-193 at Fig. 2.

> In principle, the selection of the orthogonal matrix is arbitrary. The Walsh-Hadamard transform, which is known per se, or especially a Fourier transform, in particular a discrete or fast Fourier transform, are preferred.
>
> The use of a fast Fourier transform FFT as a preferred form of transformation or spreading as well as the subsequent transfer to individual sub-carriers can be seen from FIG. [2], in an exemplary embodiment. The Fourier transforms FFT are carried out on a user-specific basis, i.e., the incoming data symbols of a user are fed in each case to their own Fourier transform.
>
> The data resulting from the individual user-specific Fourier transforms are then distributed to the individual frequency sub-carriers f1 ... fN, wherein the data of a user is preferably transmitted to sub-carriers that are not directly adjacent to one another. In principle, however, this distribution to the individual sub-carriers can take place in any manner.

Costa-193 at 8:7-15.

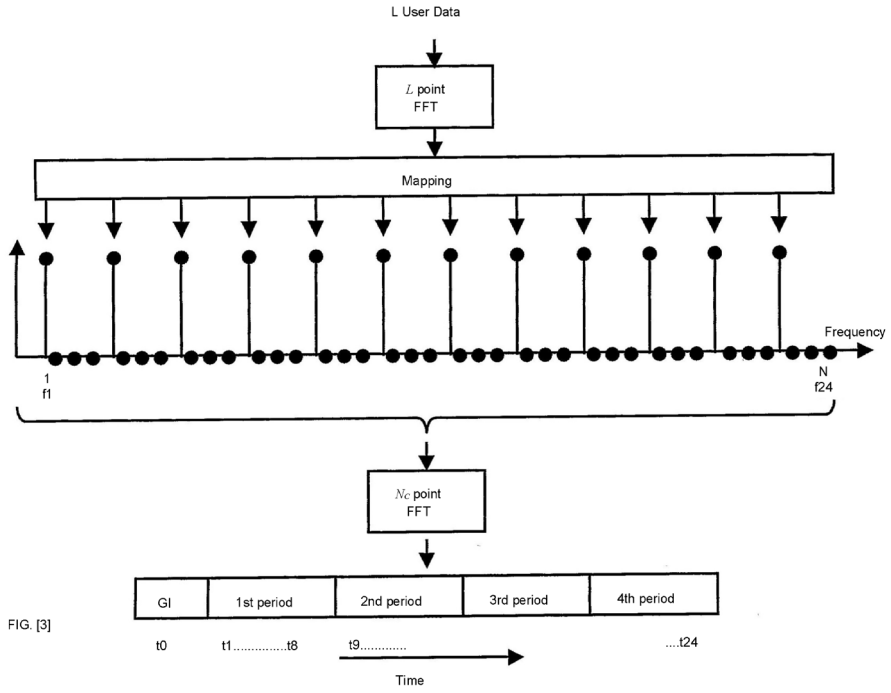


FIG. [3]

Costa-193 at Fig. 3.

> As can be seen from FIG. [3], a particularly preferred distribution of the individual data of the user-specific Fourier transforms takes place on an equidistant sequence of sub-carriers over the frequency axis. In the exemplary embodiment shown, L user data or data symbols having L data values of a user are introduced into the L-valued Fourier transform (L point FFT). According to the preferred exemplary embodiment, although not absolutely necessary, the Fourier transform in turn generates L data values which are mapped onto the N sub-carriers.

Costa-193 at 9:1-5.

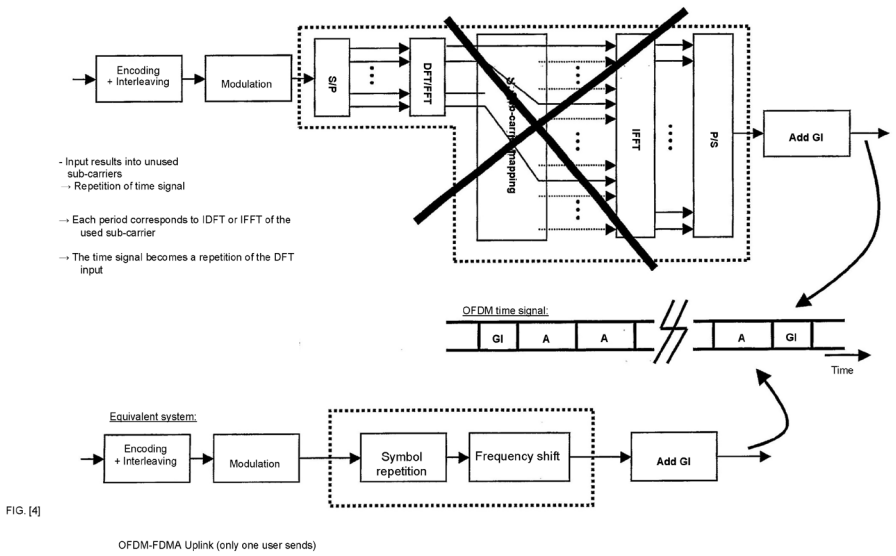


FIG. [4]

OFDM-FDMA Uplink (only one user sends)

Costa-193 at Fig. 4.

> Generalizing this with simple numbers, with a data symbol length L of the incoming user data and a mapping to L-valued transformation results, it requires a mapping to the sub-carriers f1...fN, wherein N sub-carriers are available. After the inverse Fourier transform, the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values are distributed equidistantly over N/L data periods, wherein the data periods can also be referred to as data blocks or data sections.

Costa-193 at 10:1-5.

> The particular advantage of combining a spread matrix formed by a Fourier transform FFT in combination with the equidistant distribution on the frequency axis is that, after the inverse Fourier transform, the result is a time signal having a constant amplitude in the uplink and a time signal having a peak value that is significantly reduced compared to a traditional

	OFDM system in the downlink. This constant amplitude results because the peak-to-average ratio (PAR) is significantly lower than other OFDM symbol generation methods. It corresponds precisely to the PAR of the modulation symbols before the transformation. If a PSK modulation were used here, then PAR=1. Costa-193 at 10:6-11. According to a further developed embodiment, if a Fourier transform is considered as a spread matrix and a subsequent inverse Fourier transform is considered for transmitting the individual frequency sub-carriers to a temporal data sequence, it can be determined that the two Fourier transforms then cancel each other out, purely theoretically, in terms of their effect. As a consequence, a particularly preferred embodiment for generating OFDM symbols can be implemented, as is shown in FIG. [4] for example for a transmission in the uplink from a user station to a network-side station, when only a single user transmits, wherein the transformations then cancel each other out. Due to the effect-cancelling transformation sequence of a Fourier transform FFT and after distribution to the individual sub-carriers f1...fN of an inverse Fourier transform IFFT, this block can be omitted during the implementation, or it can be replaced by repeating the symbol sequence according to the number of allocated, now fictitious, sub-carriers and subsequent frequency shift in the distribution of the input data onto the output data. Costa-193 at 11:1-10. 3. The method according to claim 1 or 2, in which, during the distribution of the input data onto the output data, the inputting of the data into the OFDM symbol is carried out by a repetition of the symbol sequence according to the number of allocated sub-carriers and a subsequent frequency shift.

	Costa-193, claim 3. 5. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using an orthogonal matrix. Costa-193, claim 5. 6. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using a Fourier transform (FFT). Costa-193, claim 6. Costa-782, which discloses: In accordance with an alternate procedure, by using orthogonal codes with the aid of an orthogonal matrix, the user data can be spread over a specified number of subcarriers and/or OFDM symbols, as with the methods known under OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). With the OFDM-CDMA method the data of all users is assigned to all available frequencies, in which case codes are used for separation. Without further measures, undesired multiple access interferences occur in this case and especially when considering a number of users or data sources for which the data enters in parallel. Costa-782 at 0005. To avoid this problem the user data is thus only spread over a number of subcarriers for simultaneous assignment of subcarriers to a number of users, which is referred to as OFDM-FDMA with user-specific spreading of payload data. Spreading and assignment of subcarriers is undertaken here in a common and comprehensive procedure step. What are known as Walsh-Hadamard Matrices of different sizes are predominantly used for spreading, as known for example from M. Yee, J.-P. Linnartz: Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading Channel,

	Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications, Kluwer Academic Publisher, 1996. In such systems different users, depending on the data rate required, are assigned a number between 1 and N of the orthogonal codes, with N being the number of available subcarriers. Costa-782 at 0006. Furthermore K. Bruninghaus, H. Rohling: Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission, Proc. IEEE VTC'98, Ottawa, channel, 1998, contains a general discussion of spreading using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of peak values to average values (PAR: Peak-to-Average-Ratios), in which case multiple accesses are not taken into account however. Costa-782 at 0007. The separation of spreading of user-specific data or data source-specific data and the assignment of the transformed or spread data to the subcarriers of one or more OFDM symbols is especially advantageous if a Discrete Fourier Transformation (DFT) or Fast Fourier Transformation (FFT) is used for the spreading instead of the Walsh-Hadamard Transformation for example. Costa-782 at 0011. Especially with the combination of a Fourier Transformation and an Inverse Fourier Transformation in an especially preferred embodiment a simplified generation of an OFDM symbol can be undertaken since the corresponding procedural steps can be omitted in its generation. The two successive Fourier Transformations can cancel each other out here in their effect except for especially one frequency shift. Correspondingly in

accordance with the invention it is possible in communication between for example a mobile user station and a base station in the uplink direction to distribute or to combine the incoming data of the individual data sources if necessary after normal encoding, interleaving and modulation directly onto the corresponding OFDM symbol positions. This advantageously simplifies the design of the sending communication station. Usefully the base can remain unchanged and continue to possess the structure of an OFDM receiver to enable it to exploit the OFDM-specific advantages such as simple equalization of the receive signal and separation of the user station data or the users.

Costa-782 at 0013.

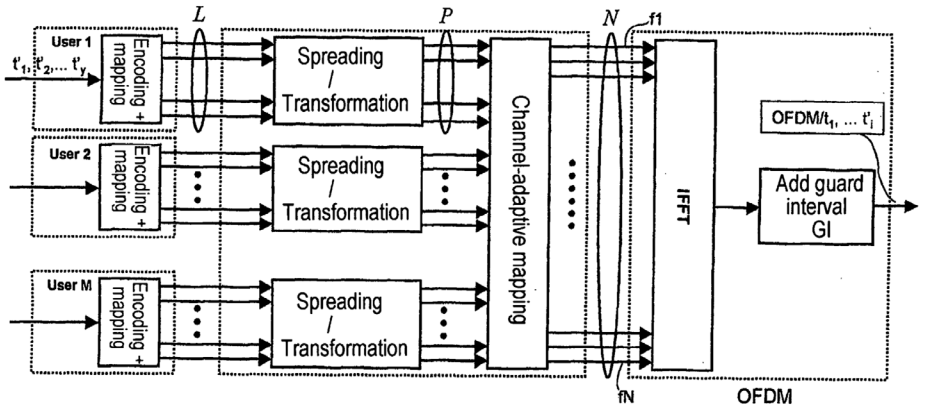
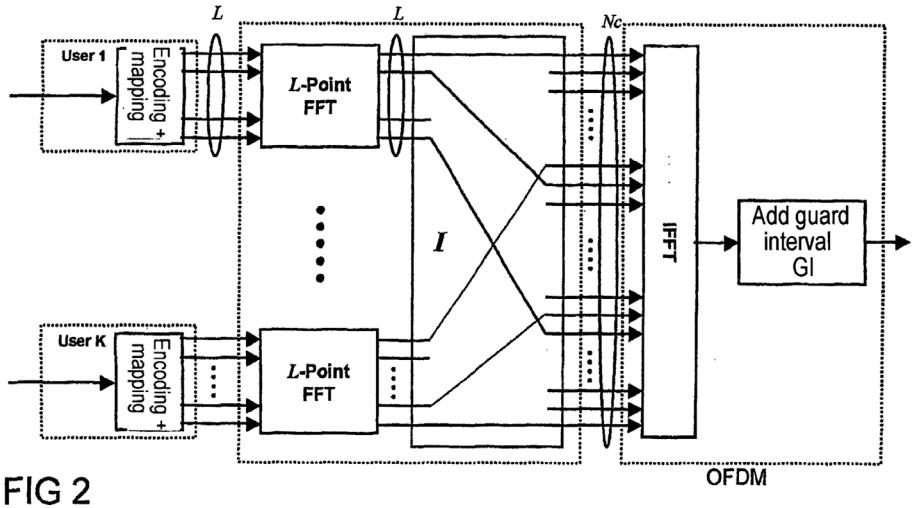


FIG 1

Costa-782 at Fig. 1.

The subsequent block shows the actual transformation or spreading and the encoding of the data of different users to the individual frequency subcarriers.

The data arriving in each case for a user on L data paths is spread in a first step, i.e. distributed from a total of L data values to P data values. This

	preferably serves to exploit the statistically independent propagation of the signals on different subcarriers (frequency diversity). In the preferred exemplary embodiment the number of the individual data values or lines is not changed although this is also possible so that before and after the spreading L complex data values per user are available in each case In analogy to the spreading of the data with Walsh-Hadamard Matrices for OFDM-CDMA, L corresponds to the number of codes assigned to the user station and P the number of the available orthogonal code symbols. The spreading in this case corresponds to a full load system. Costa-782 at 0022-23.  FIG 2 Costa-782 at Fig. 2. In this case basically any orthogonal matrix can be chosen. Preferred is the Walsh-Hadamard Transformation known per se or especially a Fourier Transformation, especially a Discrete or Fast Fourier Transformation.

	The application of a Fast Fourier Transformation FFT, as preferred form of the transformation or spreading, as well as the subsequent transmission on individual subcarriers can be seen from FIG. 2 in a typical embodiment. The Fourier Transformations FFT are executed user-specifically here, i.e. the data symbols of a user arriving are fed to a separate Fourier Transformation in each case. The data produced from the individual user-specific Fourier transformations is then distributed to the individual frequency subcarriers f1 . . . fN, with the data of a user preferably not being transmitted on directly adjacent subcarriers. Purely in principle however this distribution can be undertaken in any way on the individual subcarriers. Costa-782 at 0030-32.

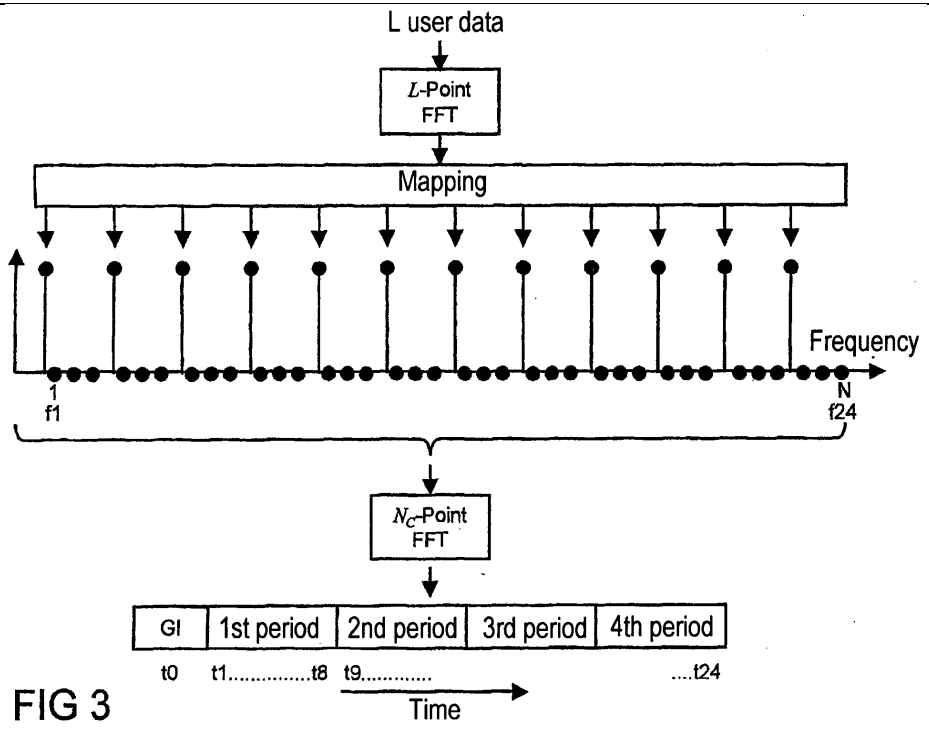


FIG 3

Costa-782 at Fig. 3.

> Put into simple generalized terms, with a data symbol length L of the user the data and a mapping to likewise L-point transformation results, this causes a mapping to subcarriers f1 . . . fN, with N subcarriers being available. After the inverse Fourier Transformation the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values here, with equidistantly distribution are distributed over N/L data periods, with the data periods also able to be referred to as data blocks or data sections.

Costa-782 at 0037.

	The particular advantage of the combination of a spread matrix formed by a Fourier Transformation FFT in combination with the equidistant distribution on the frequency axis lies in the fact that, after the inverse Fourier Transformation in the uplink a timing signal with a constant encapsulator and in the downlink a timing signal with a peak value which is much-reduced by contrast with a conventional OFDM system is produced. This constant encapsulator is produced since the peak to average value ratio (PAR) is far lower than with other generation methods for OFDM symbols. If a PSK modulation were to be used here, the PAR=1 Costa-782 at 0038. To assist understanding it is formally pointed out that a general linear transformation is involved here, that is even with the use of a Fourier Transformation to transform or spread the user-specific data no direct relationship of a frequency area to a period exists, as would be the case for normal considerations of Fourier Transformations. Costa-782 at 0039.

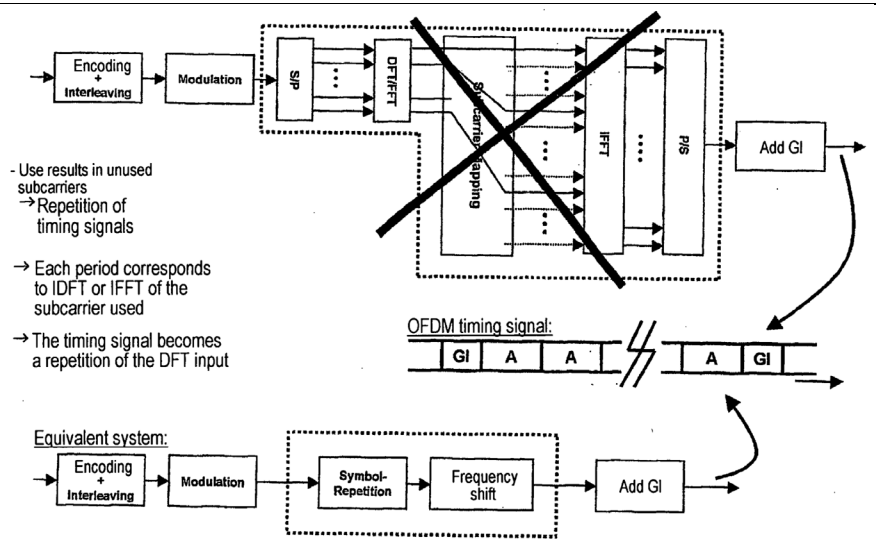


FIG 4: OFDM-FDMA Uplink (only one user sending)

Costa-782 at Fig. 4.

In accordance with a further developed embodiment, for the case of the consideration of a Fourier Transformation as spreading matrix and a subsequent Inverse Fourier Transformation to transmit the individual frequency subcarriers on a timing data sequence it can be established that purely theoretically the two Fourier Transformations cancel each other out. As a consequence a particularly preferred embodiment for generating OFDM symbols can be used, as is shown for example in FIG. 4 for example for a transmission in the uplink direction from a user station to a network-side station if only one single user is sending, in which case the transformations cancel each other out.

Through the canceling-out effect of the series of transformations of a Fourier Transformation FFT and after the distribution to the individual subcarriers f1 . . . fN of an Inverse Fourier Transformation IFFT this block can be omitted in the conversion or replaced by a repetition of the symbol

	sequence in accordance with the number of the assigned, now fictitious, subcarriers and subsequent frequency shifting for a distribution of the input data to the output data. A repeat of the timing signals is produced by the subcarriers which are not assigned to the user remaining unmodulated. Each individual period of the OFDM signal then corresponds in the final analysis to the inverse discrete Fourier Transformation of the subcarriers used. Thus, with ideal conversion and later error-free transmission over the interface the received OFDM then theoretically contains on the receiver side, behind the guard interval GI, a number of periods with the same data sequence in each case. The timing signals would thus correspond to a repeating sequence of the original inputs in the discrete Fourier Transformation which would be undertaken initially in accordance with the exemplary embodiment of FIG. 2. As can be seen from the bottom area of FIG. 4, this produces an equivalent system in which the blocks with the conversions of serial into parallel data, the subscriber-specific Fourier Transformations, the mapping or transmission on the subcarriers, the inverse Fourier Transformation and the conversion of parallel into serial data can be replaced by a series of repeating symbols and a corresponding frequency shift to be performed. Costa-782 at 0040-43. 12. A method for generating an OFDM symbol as a send signal in a communication system, comprising: mapping a complete data sequence from a data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 12.

	13. A method in accordance with claim 12, further comprising before said mapping encoding the complete data sequence from the data source to produce encoded data; and modulating the encoded data on the orthogonal subcarriers. Costa-782, claim 13. 15. A method for generating OFDM symbols for send signals in a communication system, comprising: mapping data from at least one data source to a plurality of orthogonal subcarriers, by transforming the data from the data sources; and assigning transformed data to the orthogonal subcarriers in a data source-specific manner independently of how the data is transformed. Costa-782, claim 15. 16. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by an orthogonal matrix. Costa-782, claim 16. 17. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by a Fourier Transformation. Costa-782, claim 17. 22. A communication device coupled to at least one data source, comprising: at least one interface receiving input data from the at least one data source;

	at least one of a memory device and at least one processing module temporary storing and processing, respectively, the input data from the at least one data source; and a control device controlling operation of said communication device and mapping a complete data sequence from each data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 22.
[11H] the second polyphase code causes constructive and destructive interference between the plurality of modulated subcarriers to produce a second periodic pulse waveform having a peak value that is centered at a second time in the OFDM symbol interval, the second time different from the first time.	StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality: For example, Kaiser-1998 discloses:

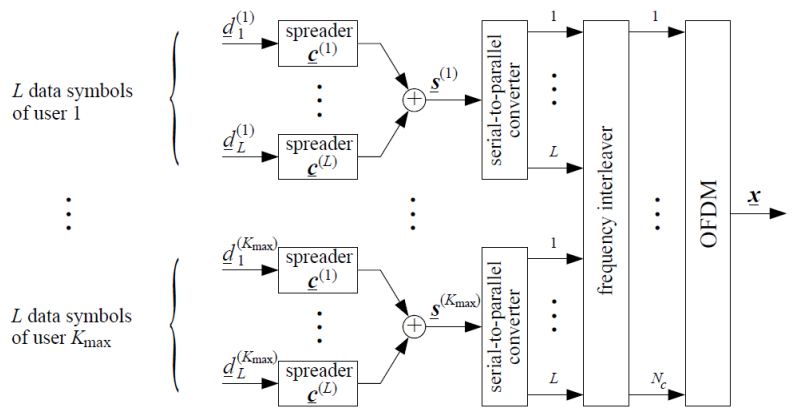
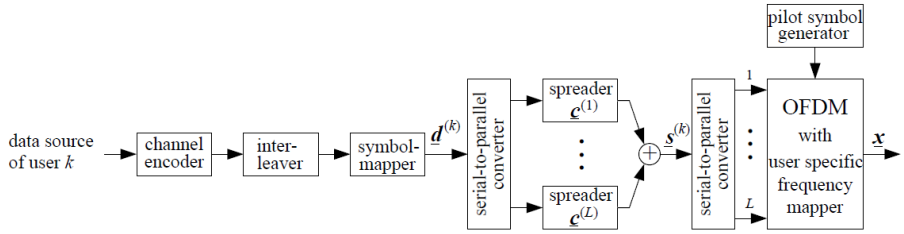


Figure B.1: Principle of SS-MC-MA illustrated for the transmitter in the downlink to enable a comparison with MC-CDMA shown in Fig. 3.8

Kaiser-1998 at Fig. B.1.

This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be

	observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers. • Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques. Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme.

	• MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation. • In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity. Kaiser-1998 at 131.  Figure B.2: SS-MC-MA transmitter of the kth user for the uplink Kaiser-1998 at Fig. B.2. SS-MC-MA Transmitter: Fig. B.2 shows an SS-MC-MA transmitter with channel coding for the data of the kth user, $k = 1 \ldots K$, for the uplink. The components channel encoding, interleaving, and symbol mapping are identical to those described in Chapter 4 for MC-CDMA systems. In SS-

MC-MA systems, L subsequent complex-valued data symbols $\underline{d}_l^{(k)}, l = 1 \dots L$, of user k are serial-to-parallel converted. The vector

$$\underline{d}^{(k)} = \left(\underline{d}_1^{(k)}, \underline{d}_2^{(k)}, \dots, \underline{d}_L^{(k)}\right)^T \quad (B.1)$$

represents one block of L parallel converted data symbols of the kth user. Each of the L data symbols is multiplied with another orthogonal spreading code of length L. The $L \times L$ matrix

$$\underline{C} = \left(\underline{c}_1\ \underline{c}_2\ \dots\ \underline{c}_L\right) = \begin{pmatrix} \underline{C}_{1,1} & \underline{C}_{2,1} & \cdots & \underline{C}_{L,1} \\ \underline{C}_{1,2} & \underline{C}_{2,2} & \cdots & \underline{C}_{L,2} \\ \vdots & \ddots & \cdots & \vdots \\ \underline{C}_{1,L} & \underline{C}_{2,L} & \cdots & \underline{C}_{L,L} \end{pmatrix} \quad (B.2)$$

represents the L different spreading codes $\underline{c}_l, l = 1, \dots, L$, used by user k. The matrix $\underline{C}$ is the same for all users. The modulated spreading codes are data symbol and, thus, chip synchronously added, resulting in the transmission vector

$$\underline{s}^{(k)} = \underline{C}\,\underline{d}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^T \quad (B.3)$$

consisting of L components. To increase the robustness of SS-MC-MA systems e.g. against inter cell interference, less than L data modulated spreading codes can be added to one transmission vector $\underline{s}^{(k)}$.

Kaiser-1998 at 131-132.

In the following, the performance of an SS-MC-MA mobile radio system in the uplink is presented. Table B.1 shows the SS-MC-MA system parameters used in the uplink. These parameters are chosen such that they correspond as far as possible with the MC-CDMA system parameters for the downlink presented in Table 6.1. The SS-MC-MA system parameters described in the following differ from those of the MC-CDMA system presented in Chapter 6. The SS-MC-MA system transmits only on 256

	subcarriers. Since the channel estimation in the considered SS-MC-MA system is based on a 1-D filtering in time direction which should fulfill two-times oversampling of the time-variant fading process, the overhead due to pilot symbols can be reduced with decreasing OFDM symbol durations. However, it has to be taken into account that with decreasing OFDM symbol duration the loss in bandwidth efficiency due to the guard interval increases. The used TDMA frame structure consisting of 4 time slots. A time slot corresponds to an OFDM frame consisting of 31 OFDM symbols as illustrated in Fig. B.4. Each user exclusively transmits on 8 subcarriers, where 3 of the 8 subcarriers used by the kth user are depicted. Hence, per user, a block of 8 serial data symbols is parallel converted and spread with orthogonal Walsh Hadamard codes of length L equal to 8, resulting after superposition in the transmission sequence $\underline{s}^{(k)}$, cf. (B.3). Note that in contrast to Fig. B.2, an additional interleaver is applied which scrambles 192 components of 24 transmission sequences $\underline{s}^{(k)}$ with the intention to increase the diversity potential of the system. Per OFDM symbol, 8 randomly interleaved components are mapped on 8 subcarriers exclusively used by the kth user. The 8 user specific subcarriers are distributed over the whole bandwidth. The receiver applies an MLSSE for data detection. The channel coding part is identical to that of the MC-CDMA system presented in Chapter 6. Kaiser-1998 at 133-135.

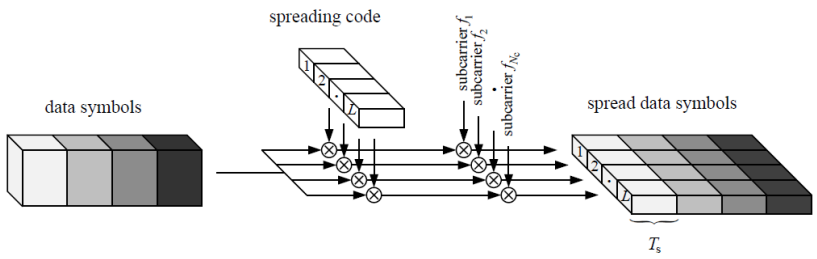


Figure 1.4: Principle of spreading of the data of a single user by MC-CDMA for the case $N_c = L$, i.e., $T_s = T_d$ and $T'_c = T_d$

Kaiser-1998 at Fig. 1.4.

Concept I: MC-CDMA is based on a serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, [FaP93, YLF93, CBJ93]. The high rate DS spread data stream is MC modulated in such a way, that the L chips of a spread data symbol are transmitted in parallel on different subcarriers. Thus, the assigned data symbol is simultaneously transmitted on L subcarriers. If the number of subcarriers N_c is equal to the spreading code length L, MC-CDMA requires the total bandwidth for the transmission of a single data symbol comparable to DS-CDMA. When choosing L smaller than N_c and introducing an appropriate frequency interleaving, the flexibility of an MC-CDMA system can be increased and the complexity of the data detector can be reduced [FaP93, Faz93]. Fig. 1.4 shows the principle of an equivalent realization of the serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3. Each data symbol is copied onto L substreams before multiplication with one chip of the spreading code per substream. A chip of the MC-CDMA spreading code grouped in the frequency domain has the duration T'_c, cf. Fig. 1.1, which is by a factor of N_c greater than the duration T_c of a chip of the DS-CDMA spreading code. The case of N_c equal to L is illustrated in Fig. 1.4, yielding that the data symbol duration T_d, the chip duration T'_c, and the OFDM symbol duration T_s are identical. Fig. 1.4 reflects the fact that MC-CDMA has a spreading code grouped in the frequency domain. Comparing

the spread data symbols of DS-CDMA, cf. Fig. 1.2, with those of MC-CDMA, cf. Fig. 1.4, it can be seen that MC-CDMA offers an additional flexibility in the frequency domain, which results in simple methods for signal reconstruction in the frequency domain. MC-CDMA was introduced with OFDM for optimum use of the available bandwidth [FaP93, YLF93, CBJ93]. Most MC-CDMA systems were proposed for the downlink from a base station (BS) to a mobile station (MS) where powerful mobile receivers with low complexity are required [FaP93, YLF93, CBJ93]. The time/frequency synchronism between the users in the downlink allows a simple realization of an efficient channel estimation required for coherent detection.

Kaiser-1998 at 6-7.

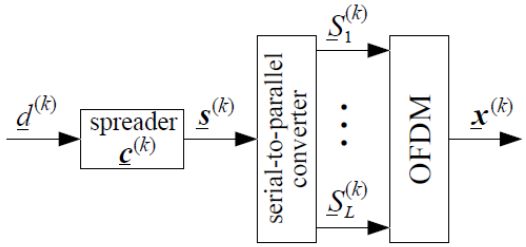


Figure 3.6: MC spread spectrum signal generation

Kaiser-1998 at Fig. 3.6.

The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be

transmitted over the radio channel is taken from the complex data symbol alphabet

$$\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \tag{3.24}$$

of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

$$\underline{c}^{(k)} = \left(\underline{C}_1^{(k)}, \underline{C}_2^{(k)}, \dots, \underline{C}_L^{(k)}\right)^{\mathrm{T}} \tag{3.25}$$

of the kth user. The chips $\underline{C}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet

$$\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \tag{3.26}$$

of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is

$$\frac{1}{T_c} = \frac{L}{T_d} \tag{3.27}$$

and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector

$$\underline{s}^{(k)} = \underline{d}^{(k)}\underline{c}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^{\mathrm{T}}. \tag{3.28}$$

The rate of the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread

spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d^{(k)}}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{S_l^{(k)}}$, $l = 1, \ldots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is

$$T_s' = T_g + N_c T_c. \quad (3.29)$$

The transmission of one data symbol per user per OFDM symbol requires

$$N_c = L \quad (3.30)$$

subcarriers. In this case, the OFDM symbol duration including the guard interval is

$$T_s' = T_g + T_d. \quad (3.31)$$

Kaiser-1998 at 39-40.

An MC-CDMA system designed for the transmission of one data symbol per user per OFDM symbol is referred to as a basic MC-CDMA system in the following. When applying orthogonal spreading codes $\underline{\boldsymbol{c}^{(k)}}$ like Walsh-Hadamard codes, the maximum number of active users $K_{\max}$ in the basic MC-CDMA system corresponds to the spreading code length L, i.e.,

$$K_{\max} = L. \quad (3.32)$$

Kaiser-1998 at 40.

• Frequency/time domain spreading code: Each MC-CDMA spreading code with a mapping on frequency slots can be transferred in a DS-CDMA spreading code with a mapping on time slots and vice versa by applying the Fourier transform [FBA94]. The key feature of the Fourier transform is that it preserves the correlation properties of the spreading code [Ach85]. Hence, an MC-CDMA system with a spreading code $\{\underline{C_l^{(k)}}\}, l = 1, \ldots, L,$

performs identically to a DS-CDMA system with a spreading code$\{\underline{c}_i^{(k)}\}, i = 1, \ldots, L$, when both spreading codes are related by the Fourier transform, i.e.,

$$\{\underline{C}_l^{(k)}\}, \quad l = 1, \ldots, L, \quad \bullet\!\!-\!\!\circ \quad \{\underline{c}_i^{(k)}\}, \quad i = 1, \ldots, L. \tag{3.84}$$

In (3.84), the symbol $\bullet\!\!-\!\!\circ$ denotes the discrete Fourier transformation. When, for instance, applying binary, real-valued, orthogonal MC-CDMA spreading codes, the equivalent DS-CDMA spreading codes are non-binary and complex-valued, but still orthogonal.

Kaiser-1998 at 62-63.

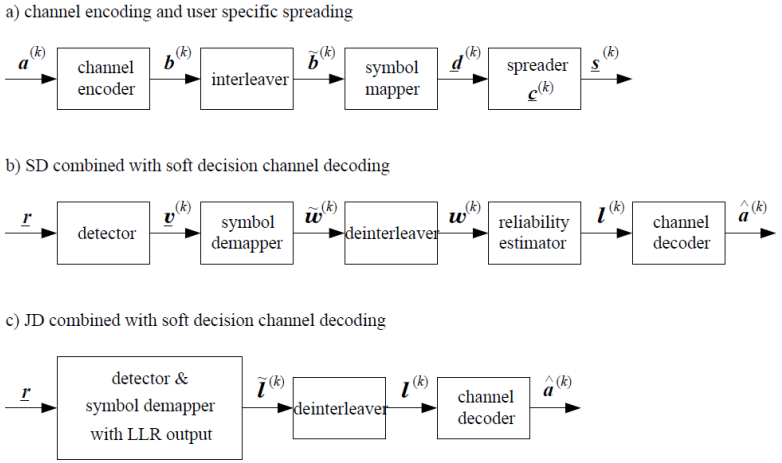


Figure 4.1: Concatenation of the spread spectrum technique with channel coding; a) channel encoding with subsequent data symbol spreading; b) SD and c) JD with optimum soft decision decoding

Kaiser-1998 at 65.

Performance and flexibility of mobile radio systems essentially depend on the choice of the multiple access scheme. The novel MC-CDMA scheme

	which is the topic of this thesis is a promising alternative to conventional FDMA, TDMA, and CDMA schemes. With MC-CDMA, each data modulated chip of the user specific spreading code is mapped onto a separate subcarrier, so that the chips of the spreading code and, hence, the data symbol is transmitted in parallel on multiple subcarriers. The application of OFDM enables one to avoid ISI and ICI in the detection process, resulting in simple SD and MD techniques. In MC-CDMA mobile radio systems, SD can be realized by equalizing each subcarrier individually, yielding only one complex-valued multiplication per subcarrier and OFDM symbol. Due to the M-, Q-, and M&Q-Modification of the MC-CDMA scheme, even the optimum JD techniques MLSSE and MLSE can be applied with reasonable complexity. Kaiser-1998 at 119. Brüninghaus-1997, which discloses: In this paper we will focus on Multi-Carrier CDMA (MC-CDMA). In contrast to a conventional OFDM system where every bit is assigned to a single subcarrier, the information is spread over several subcarriers using orthogonal codes. Since spreading is performed on information symbol level prior to subcarrier modulation, the resulting MC-CDMA signal is basically an OFDM signal. The advantage of this technique is a lower bit error rate in frequency-selective radio channels compared to a conventional OFDM system due to inherent frequency-diversity. The price to be paid is a higher computation complexity in the receiver since the frequency-selective radio channel leads to a loss of orthogonality of the spreading codes and interuser-interferences occur. A lot of research has been done to develop suitable detection or joint detection methods [4, 5, 6, 7] without considering the spreading matrix in detail. Brüninghaus-1997 at 187. In this paper we will discuss this item focussing on the special case that the spreading matrix equals the Fourier matrix. The two operations performed

in the transmitter, namely spreading and IFFT-processing, cancel each other resulting in a pure single-carrier system with blockwise processing. This special case was also mentioned in [8] but little was said about the consequences, which will be done in the following sections.

Brüninghaus-1997 at 188.

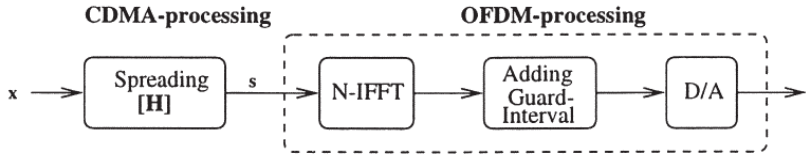


Figure 1: Block diagramm of a MC-CDMA transmitter (downlink)

Brüninghaus-1997 at 188.

The general block diagram of a MC-CDMA transmitter (only the downlink is considered in this paper) is depicted in Fig. 1. In a first step the complex data symbols $x_i, \quad 1 \leq i \leq M$, which can be elements of any arbitrary symbol set e.g. PSK or QAM, are spread over several subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation

$$s = [H] \cdot x \qquad (1)$$

where $x = (x_1, \ldots, x_M)^T$ is the vector of data symbols, $s = (s_1, \ldots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix. The M columns of the code matrix contain different spreading codes for every data symbol. To avoid interuser-interferences in AWGN the spreading codes should be mutually orthogonal. If the OFDM system consists of N subcarriers there are a maximum number of N orthogonal codes and $1 \leq M \leq N$ users can be supported every OFDM symbol. Apart from the described spreading procedure, the transmitter is identical to a conventional OFDM

transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard-interval is added) and D/A converted.

Brüninghaus-1997 at 188.

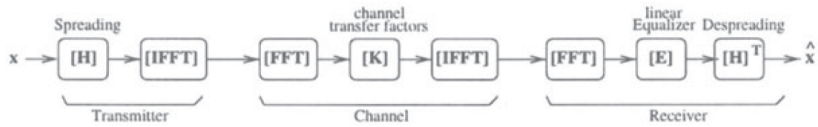


Figure 3: Model of a MC-CDMA transmission system with linear equalization

Brüninghaus-1997 at 190.

Both demands, i.e. minimal mean square error in frequency-selective fading channels and low dynamic range of the signal envelope, can also be met for the downlink if an FFT matrix is used as spreading matrix. In this case spreading and IFFT-processing cancel each other, see Fig. 3, and the transmission system degenerates into a single-carrier system, as depicted in Fig. 4. The main advantage of this step is that at this stage all knowledge about dynamic reduction of single carrier systems with linear modulation can be applied to create a time signal with low dynamic range.

Brüninghaus-1997 at 189.

The special choice of a FFT matrix as spreading matrix for Multi-Carrier CDMA leads to a single-carrier system with guard-interval. This way, the multi-carrier specific problems as high dynamic of the signal envelope, sensivity to phase noise and frequency/ clock synchronization errors can be avoided without losing the performance capacity of MC-CDMA. In case of linear equalization the receiver consists of a frequency domain equalizer with blockwise processing. Due to the guard-interval, this frequency domain equalizer outperforms the comparable time domain equalizer considerably and shows even in frequency-selective radio channels a

relatively good performance. Besides, the compuation complexity of such a receiver structure with blockwise processing in the frequency domain is lower than with processing in the time domain in case of highly dispersive channels.

Brüninghaus-1997 at 193.

Sorger-1997, which discloses:

The first $L_\Delta Q$ chips $c_l^{(i)}$, $l = 0, \ldots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by

$$T_\Delta = L_\Delta \cdot Q \cdot T_c, \tag{7}$$

where L_Δ has to be chosen to meet the condition of Eq. (2). The transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user dependent phase vector $s^{(i)}$ of dimension L_c having components

$$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \ldots, L_c - 1. \tag{8}$$

The user dependent phase $\Phi^{(i)}$ is chosen to be

$$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \tag{9}$$

The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures the user discrimination by assigning to each user i a different set of orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as

$$x^{(i)} = \left[c_0^{(i)}, c_1^{(i)} e^{-j\Phi^{(i)}}, c_2^{(i)} e^{-j2\Phi^{(i)}}, \ldots, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \tag{10}$$

Sorger-1997 at 113.

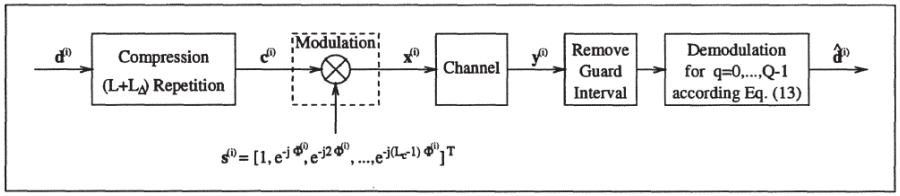


Figure 1: Block diagram of the proposed IFDMA system

Sorger-1997 at Fig. 1.

Brüninghaus-1998, which discloses:

> The combination of orthogonal frequency division multiplexing (OFDM) and code division multiplexing (CDM) has found great interest during the last few years. In contrast to a conventional OFDM system the information is spread over several subcarriers using orthogonal codes which leads to a diversity gain in frequency-selective channels. In this paper it is shown that such a system is technically equivalent to a single-carrier system with guard interval if the columns of a Fourier matrix are used as spreading codes. The pros and cons of such a system compared to an OFDM-CDM system with abritrary spreading matrix are described and discussed.

Brüninghaus-1998 at 2329.

> In the last years, multi-carrier transmission and especially OFDM (orthogonal frequency division multiplexing) have received much attention due to its ability of transmitting high data rates even in highly time dispersive radio channels with reasonable equalization effort. These systems are characterized by parallel data transmission over a number of generally narrowband subchannels. Recently, a combination of multi-carrier transmission and code division multiplexing (CDM) was proposed to improve the performance of multi-carrier systems [1], [2]. In this case every data symbol is spread over several subcarriers prior to subcarrier modulation and despread in the receiver, which is in fact a kind of

frequency diversity. The same effect can be achieved with channel coding but it was shown in [3] that at least at code rates above 1/2 the combination of spreading and coding performs better than coding only.

Brüninghaus-1998 at 2329.

In the literature, Walsh-Hadamard codes are generally used as spreading codes but in principle every other orthogonal code matrix can be applied. In this paper we will focus on the special case that the Fourier matrix is used as orthogonal code matrix. Since the multi-carrier transmission signal is generated by an inverse Fourier-transform (IFFT), both operations - spreading and IFFT - cancel each other resulting in a pure single-carrier system with blockwise processing. This fact was already mentioned in [4] but without noticing that this kind of processing combines the advantages of single-carrier transmission, like constant signal envelope, simple clock and frequency synchronization, with the advantages of OFDM-CDM like high performance in frequency-selective channels. In the following sections, a brief review of OFDM-CDM is given, followed by a detailed discussion of the resultant transmission technique and its advantages.

Brüninghaus-1998 at 2329.

With OFDM-CDM the complex data symbols $x_i, \quad 1, \dots, M$, which can be elements of any arbitrary symbol set, e.g. PSK or QAM, are spread over *N* subcarriers using orthogonal codes. The spreading can be described analytically by a matrix operation

$$s = [H] \cdot x \qquad (1)$$

where $x = (x_1, \dots, x_M)^T$ is the vector of data symbols, $s = (s_1, \dots, s_N)^T$ is the vector of modulation symbols and $[H]$ is the code matrix of dimension$N \times M \quad (M \leq N)$. Apart from spreading, the transmitter is identical to a conventional OFDM transmitter, i.e. the resulting signal sequence is IFFT-processed, periodically extended (a guard interval is

added) and D/A converted, see Fig. 1. In the receiver, the inverse processing is performed, see Fig. 2.

Brüninghaus-1998 at 2329.

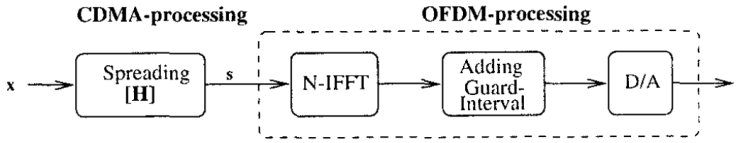


Fig. 1. Block diagram of a multi-carrier CDM transmitter

Brüninghaus-1998 at 2329.

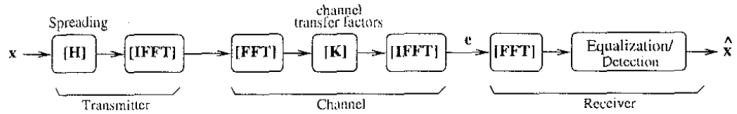


Fig. 3. Model of a multi-carrier CDM system

Brüninghaus-1998 at 2330.

The performance of the overall transmission system does not depend on the specific type of the orthogonal spreading matrix as long as every element of the matrix has the same magnitude which means that the energy is uniformly spread over all subcarriers [10]. Considering the case that all available orthogonal codes are used, i.e. the spreading matrix is a square matrix of dimension *N* x *N*, the matrix of the Fast Fourier transform meets the above mentioned demands as well as the often proposed Walsh-Hadamard matrix. If such an FFT-matrix is used spreading and OFDM processing cancel each and the transmission system degenerates into a linearly modulated single-carrier system with guard interval, i.e

$$s(t) = \sum_n x_n \cdot p(t - nT) \quad \text{where} \quad x_n = x_{n-N} \quad \text{if} \quad i(N + N_G) - N_G \leq n < i(N + N_G) \quad i \in Z \quad (2)$$

In Eq. (2), the parameter N_G describes the length of the guard interval in number of data symbols spaced by the symbol duration *T*.

Brüninghaus-1998 at 2330.

A. Dynamic of the signal envelope

It is well known that the envelope of an OFDM signal has a high dynamic which requires a linear power amplifier in the transmitter. A lot of studies have been performed with the aim to reduce the signal dynamic of multi-carrier systems but all methods known from literature [11] - [13] have certain drawbacks. These drawbacks are either high computation complexity, large memory requirements or signal distortions. At least in the case of absolute modulation (no differential encoding) these disadvantages can be overcome if the Fourier-matrix is used for spreading. Since the multi-carrier CDM system is thereby transformed into a single-carrier system with linear modulation the amplitude dynamic only depends on the pulse shape *p(t)*. In connection with second generation mobile systems this topic has been analyzed extensively and solutions are very well known: in case of binary transmission for example, MSK (minimum shift keying), which uses a sinusoidal pulse, can be applied leading to a constant envelope signal. Quaternary transmission can be realized with low amplitude dynamic using Offset-QPSK.

Brüninghaus-1998 at 2330.

Since the single-carrier system which results from an OFDM-CDM system with Fourier spreading matrix is a special case of an OFDM-CDM system, the same detection algorithms can be applied and the same performance can be expected.

	Brüninghaus-1998 at 2330. A general block diagram of an OFDM-CDM receiver with linear equalization [8] is depicted in Fig. 4. In case of a Fourier spreading matrix, despreading in the receiver is achieved by an inverse Fast-Fourier matrix, i.e. $[H]^H = [IFFT]$. The overall processing corresponds to a frequency domain equalization (FDE) since the received signal vector is first Fourier-transformed, multiplied by a diagonal equalization matrix and then transformed back into the time domain. Such an FDE was originally proposed in [17] to speed up the convergence of the equalizer coefficients in conjunction with the stochastic gradient method. In [18] the FDE was picked up again to compare single-carrier and multi-carrier (OFDM) transmission but without noticing that the considered single-carrier system is a special case of an OFDM-CDM system. Recently, the FDE was discussed for use in future mobile communication systems in combination with antenna diversity [20]. Brüninghaus-1998 at 2330. In contrast to a conventional single-carrier system, the single-carrier system resulting from OFDM-CDM with Fourier spreading matrix is characterized by a guard interval and the question arises why it should be advantageous to waste some part of the bandwidth. There are two reasons: the first one is the higher performance at the same number of equalizer coefficients in case of linear or decision feedback equalization. This results from the fact that the periodic extension of the data sequence in the transmitter in connection with the signal windowing the receiver leads to a cyclic convolution of the data sequence and the discrete-time channel impulse response. If the corresponding discrete-time channel transfer function contains no zeros, this cyclic convolution can be perfectly inverted in the receiver requiring not more than *N*(=length of data sequence) coefficients. To achieve the same effect with a conventional single-carrier system, generally an equalizer with an infinite number of taps is required,

	which cannot be implemented in a real system. Thus, an equalization error occurs, which limits the performance at high signal-to-noise-ratios. Brüninghaus-1998 at 2330-31. System parameters: • General - Bandwidth B = 2MHz - linear equalization based on MMSE criterion • OFDM-CDM with Fourier spreading matrix - blocklength: $T_N = 32\mu s$ - Guardlength: $T_G = 6.6\mu s$ - Number of symbols per block: $N = 64$ • Single-carrier system without guard interval - pulse with raised cosine spectral characteristic and rolloff' factor $\beta = 0.2$ - Symbol length: Ts = 600ns • Channel parameters: - Exponentially decreasing power delay profile from 0 to $5\mu s$ - Rayleigh channel - time invariant Brüninghaus-1998 at 2331. The special choice of an FFT matrix as spreading matrix for OFDM-CDM leads to a single-carrier system with guard interval. Such a single-carrier system has the same performance as the OFDM-CDM system but is less sensitive to nonlinear effects due to the reduced dynamic of the signal amplitude. In case of linear equalization, a single-carrier system with

guard-interval yields the same (low S/N) or even a better (high S/N) performance than the corresponding system without guard interval at the same number of equalizer coefficients and data rate. Besides, in highly time dispersive channels the computation complexity of such a receiver structure with blockwise processing is considerably lower than with continuous processing.

Brüninghaus-1998 at 2332.

Sorger-1998, which discloses:

The dimension of the IFDMA-symbol $c^{(i)}$ is $L_c = (L + L_\Delta)Q$ and the components $c_l^{(i)}$ can be written as

$$c_l^{(i)} = \frac{1}{L + L_\Delta} \cdot d_{l \bmod Q}^{(i)}, \quad l = 0, \dots, L_c - 1. \tag{6}$$

The first $L_\Delta Q$ chips $c_l^{(i)}, l = 0, \dots, L_\Delta Q - 1$, belong to the guard interval. Thus, the duration T_Δ of the guard interval is given by

$$T_\Delta = L_\Delta \cdot Q \cdot T_c. \tag{7}$$

where L_Δ has to be chosen to meet the condition of Equation (2). Finally, the transmission signal $x^{(i)}$ is constructed out of the IFDMA-symbol $c^{(i)}$ by elementwise multiplication with a user-dependent phase vector $s^{(i)}$ of dimension L_c having components

$$s_l^{(i)} = \exp\{-j \cdot l \cdot \Phi^{(i)}\}, \quad l = 0, \dots, L_c - 1. \tag{8}$$

The user-dependent phase $\Phi^{(i)}$ is chosen to be

$$\Phi^{(i)} = i \cdot \frac{2\pi}{QL}. \tag{9}$$

The elementwise multiplication of the two vectors $c^{(i)}$ and $s^{(i)}$ assures an orthogonal user discrimination by assigning to each user *i* a different set of

orthogonal frequencies. The resulting transmission signal vector $x^{(i)}$ can be written as

$$x^{(i)} = \left[c_0^{(i)},\, c_1^{(i)} e^{-j\Phi^{(i)}},\, c_2^{(i)} e^{-j2\Phi^{(i)}},\, \ldots,\, c_{L_c-1}^{(i)} e^{-j(L_c-1)\Phi^{(i)}}\right]^T. \qquad (10)$$

Sorger-1998 at 1014.

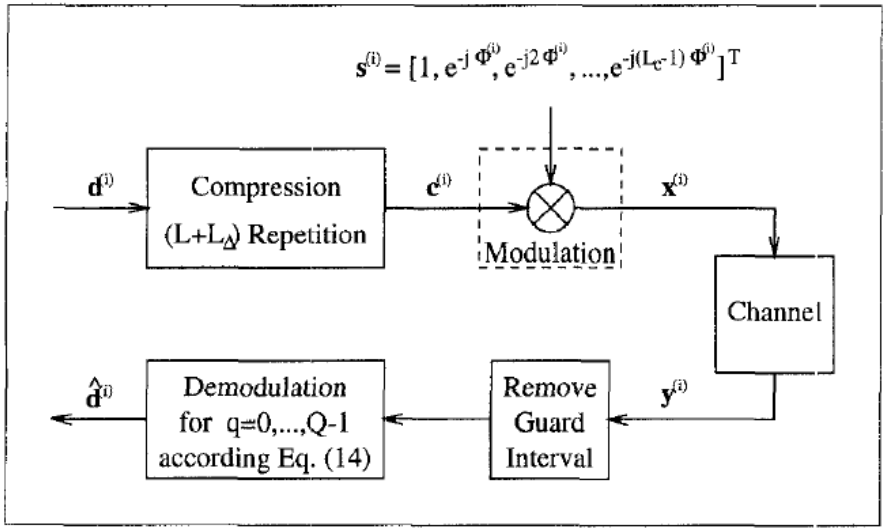


Figure 2: Block diagram of the proposed IFDMA system for a single user i

Sorger-1998 at Fig. 2.

Bury-1999, which discloses:

> We present a generalization and an extension of the block decision feedback equalizer described by Reinhardt in [1]. The original equalizer was derived for a class of transmission which is described by an orthogonal spreading over a group of non-interfering fading channels. We generalize

	this concept for block transmissions with arbitrary interference; the generalized description also includes reception with multiple antennas using joint diversity combining and equalization. In extension, we introduce soft feedback for all individual symbols, in contrast to the single soft value used in [1], offering an improved performance. We describe the proposed equalization method, provide examples for application, and illustrate the performance by simulation results. Bury-1999 at 345. In many practical cases it is convenient to transmit data in blocks which can be processed independently. Examples for block transmission methods are MC-CDM(A) on the basis of OFDM [3], Interleaved FDMA as described in [2], or serial transmission with termination to assure that there is no interference between blocks [4]. If there is interference within a block, the optimum detector performs a highly complex search of the most probable combination of transmit symbols. A less complex method is to employ equalization together with single symbol detection. Linear equalization allows simple implementation. The proposed decision feedback equalizer offers an improvement over linear equalization - however, at the cost of some complexity increase. Bury-1999 at 345-346. 6. SPREAD TRANSMISSION We now consider the special case of transmission over a set of interference free fading channels, where orthogonal symbol spreading is used to achieve a diversity gain. Figure 4 shows a model for this type of transmission.

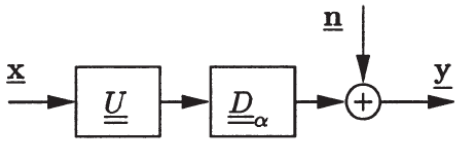


Figure 4 Transmission over non-interfering channels with orthogonal spreading

In this figure, $\underline{\underline{U}}$ is an orthogonal matrix for spreading, $\underline{\underline{D}}_\alpha$ is a diagonal matrix with the channel amplitudes on the main diagonal and zeros elsewhere, and we assume white noise with $\underline{\underline{\Phi}}_{nn} = \sigma_n^2 \cdot \underline{\underline{I}}$. The orthogonal spreading matrix has the property $\underline{\underline{U}}^H = \underline{\underline{U}}^{-1} = \underline{\underline{U}}$. For the cases of a Hadamard transform or a Fourier transform, multiplication with $\underline{\underline{U}}$ may be implemented as a fast algorithm (Fast Fourier Transform, FFT; Fast Hadamard Transform, FHT). By inserting $H = \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}}$ into equations (3), (4) and (5), we find

$$\underline{\underline{A}}_{\text{opt}}^{(0)} = \underline{\underline{U}}^H \cdot \underline{\underline{D}}_{\tilde{\alpha}} \quad \text{with} \quad \tilde{\alpha}_i = \frac{\alpha_i^*}{|\alpha_i|^2 + \frac{\sigma_n^2}{\sigma_x^2}} \tag{8}$$

$$\underline{\underline{A}}_{\text{opt}}^{(r)} = \underline{\underline{D}}_p^{(r)} \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)}, \tag{9}$$

$$\underline{\underline{B}}_{\text{opt}}^{(r)} = \underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)} - \text{diag}\left(\underline{\underline{A}}_{\text{opt}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \underline{\underline{D}}_\varrho^{(r)}\right). \tag{10}$$

$$\underline{\underline{Q}}^{(r)} = \left(\underline{\underline{D}}_\alpha \cdot \underline{\underline{U}} \cdot \left(\underline{\underline{I}} - \underline{\underline{D}}_{|\varrho|^2}^{(r)}\right) \cdot \underline{\underline{U}}^H \cdot \underline{\underline{D}}_\alpha{}^H + \frac{\sigma_n^2}{\sigma_x^2} \cdot \underline{\underline{I}}\right)^{-1},$$

$$\frac{1}{p_i^{(r)}} = 1 + \underline{u}_i{}^H \cdot \underline{\underline{D}}_\alpha{}^H \cdot \underline{\underline{Q}}^{(r)} \cdot \underline{\underline{D}}_\alpha \cdot \underline{u}_i \cdot \left|\varrho_i^{(r)}\right|^2.$$

For the special case where for arbitrary i and fixed *r* the feedback values $\varrho_i^{(r)}$ are all identical, computation of the filter coefficients can be further

simplified, such that no matrix inversion is required; this has been derived in [1].

Bury-1999 at 350-51.

This model of spread transmission is applicable to, e.g., the following transmission schemes:

MC-SSMA (Multi-Carrier Spread Spectrum Multiple Access) as described in [3] uses a Hadamard transform to spread a vector of transmit symbols over a set of OFDM subchannels; each OFDM subchannel may be considered as a single Rayleigh fading channel. OFDM-CDMA is another name for essentially the same method.

IFDMA (Interleaved Frequency Division Multiple Access) as introduced in [2] can be described as an OFDM transmission where Fourier spreading is used to transmit over sets of equally spaced OFDM subchannels.

Serial block transmission over a multipath channel, using cyclic extension of transmitted blocks and corresponding extraction at the receiver, may be considered as an OFDM transmission with Fourier spreading over all subchannels. The equalizer can be implemented in the frequency domain by assuming a Fourier matrix for spreading. A linear equalizer for frequency domain equalization (FDE) has been presented in [4].

Bury-1999 at 351.

Bury-2000, which discloses:

Abstract - In this paper we investigate amplitude distributions of transmit signals for multi-carrier spread spectrum (MC-SS) transmission methods based on orthogonal frequency division multiplexing (OFDM), also called multi-carrier code division multiplexing (MC-CDM). In particular we compare Fourier spreading with the commonly used Walsh-Hadamard spreading. As a basis for the comparison we describe a general model. Both up- and downlink of multiple access transmission schemes employing

	either multi-carrier code division multiple access (MC-CDMA) or multi-carrier frequency division multiple access (MC-FDMA) are compared. Bury-2000 at 857. Multi-carrier code division multiplexing (MC-CDM) [1] is an interesting candidate for the physical layer in wireless high data rate local area networks. When compared to orthogonal frequency division multiplexing (OFDM), the additional spreading of MC-CDM produces a signal space diversity which improves power efficiency especially for high code rates [2]. A Hadamard transform is used for spreading in most MC-CDM system descriptions, e.g. [1]. However, further choices for orthogonal spreading are possible. With Fourier spreading [3], which can be implemented by a discrete Fourier transform (DFT) operation, it is clear that it can cancel the inverse discrete Fourier transform (IDFT) of an OFDM transmitter when spreading is done over all subcarriers, such that the result is a simple serial block transmission with cyclic extension [4]. This serial transmission can be regarded as a spread spectrum transmission, since the entire transmission bandwidth is covered by each transmitted symbol. The peak-to-average power ratio (PAPR) of a serial transmission is much lower than that of an OFDM transmission. The question that arises is: how is the situation when spreading is done not over all OFDM subcarriers but only over groups of carriers? Bury-2000 at 857. In [5] Golay complementary sequences have been used instead of Hadamard sequences for reducing the PAPR in MC-CDMA transmission, and a scrambling scheme was employed to further improve the amplitude distribution of the transmit signal. In this paper we suggest to employ a DFT for spreading, which can be implemented efficiently as a fast Fourier transform (FFT). Furthermore we extend our considerations to MC-FDMA, as introduced in [6] (named MC-SS-MA there).

Bury-2000 at 857.

> Subsequently we describe a model of a MC-CDM transmitter. In a multiple access context, this model is valid for both, MC-CDMA and MC-FDMA. We describe the methods used for computation of the amplitude distribution and the PAPR of the transmit signal. It is shown that, given the transmit symbol alphabet and the corresponding symbol probabilities, both amplitude distribution and PAPR are uniquely determined by a single matrix which describes the transmitters linear mapping from transmitted symbols to the transmit signal. Based on simulation results, we discuss the suitability of Hadamard and Fourier spreading for MC-CDM transmission methods.

Bury-2000 at 857.

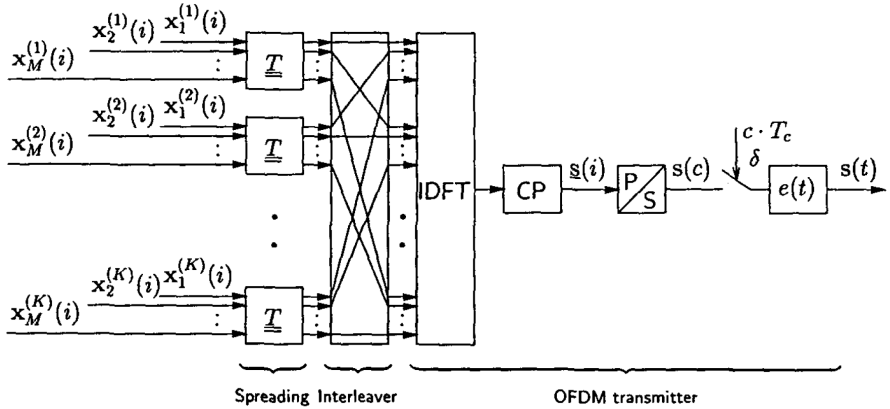


Fig. 1. Model of transmitter for OFDM-based MC-CDM.

Bury-2000 at 858.

> The model in Fig. 1 depicts a transmitter for MC-CDM based on OFDM. An OFDM transmitter is extended by an additional spreading, described by

	the transform matrices $\underline{\underline{T}}$, and by an interleaver. The OFDM transmitter consists of an IDFT, a cyclic prefix insertion CP, a parallel-to-serial conversion, and the conversion to continuous-time using an ideal Dirac sampler and a basic waveform $e(t)$, which is a Nyquist impulse. The delivered baseband transmit signal is $s(t)$. The number of OFDM subcarriers is N, the cyclic prefix has length L, transmit signal samples are indexed by c, and the Dirac sampler generates an impulse every T_c seconds. Bury-2000 at 857. Spreading is done by transforming a vector of M symbols through a matrix $\underline{\underline{T}}$. This square matrix is orthogonal, such that the condition $$\underline{\underline{T}}^H \underline{\underline{T}} = \underline{\underline{I}} \quad (1)$$ is fulfilled. Furthermore, to assure equal energy distribution, we consider only spreading matrices with the property that the absolute value of all matrix elements is constant $$\left|t_{i,k}\right| = \frac{1}{\sqrt{\underline{\underline{N}}}} \quad \forall\, i,k. \quad (2)$$ In literature usually a Hadamard transform is selected for $\underline{\underline{T}}$; however, further choices are possible, e.g. a DFT. Bury-2000 at 857-58. III. AMPLITUDE DISTRIBUTION OF THE TRANSMIT SIGNAL For a certain time instant t_0 the complex baseband transmit signal $s(t_0)$ is a random variable which is in general a linear combination of all random transmit symbols

$$s(t_0) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{K} \sum_{m=1}^{M} \alpha_{m,k,i}(t_0) x_m^{(k)}(i)\,. \qquad (3)$$

The coefficients $\alpha_{m,k,i}(t_0)$ are derived from $\underline{\underline{T}}$, $e(t)$, N, L, K, and M, as described subsequently. When the duration of the basic waveform $e(t)$ is finite, the infinite sum over i in this equation can be replaced by a finite sum. Then the probability density function (PDF) of the transmit signal at time $t_0, f_{s(t_0)}(x)$, is obtained from the PDFs of all contributing transmit symbols.

Bury-2000 at 858.

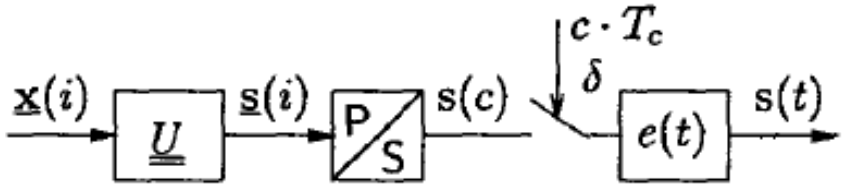


Fig. 2. Equivalent transmitter model.

Bury-2000 at 859.

Discrete-time computation

At discrete time we consider the signal $s(c)$ instead of $s(t)$. To obtain a simple description we join the spreading, interleaving, IDFT and cyclic extension of the transmitter in Fig. 1 into a single matrix $\underline{\underline{U}}$, see Fig. 2.

. . .

	The discrete-time transmit signal of a single OFDM block ($i = 0$) then represents the cyclo-stationary statistics of the transmit signal. We omit the block index i and write $$\underline{s} = \underline{\underline{U}} \cdot \underline{x}, \quad (6)$$ with vector elements $x_{(m+M(k-1))} = x_m^{(k)}(0)$ and $s_c = s(c)$. In equivalence to equation (3) we write $$s_c = \sum_{n=1}^{N} u_{c,n} x_n \,. \quad (7)$$ Hence, the PDF at a particular time instant c is related with a certain row in $\underline{\underline{U}}$. Bury-2000 at 859. From above equations we see that, given the transmit symbol alphabet and corresponding occurrence probabilities, the PDF of the discrete-time transmit signal, $f_{s(c)}(x)$, is determined by the transform matrix $\underline{\underline{U}}$. For the case of Fourier spreading, the matrix $\underline{\underline{U}}$ contains in most cases more zero elements than for Hadamard spreading. This already indicates a better amplitude distribution for Fourier spreading, because fewer random variables are summed. Bury-2000 at 859.

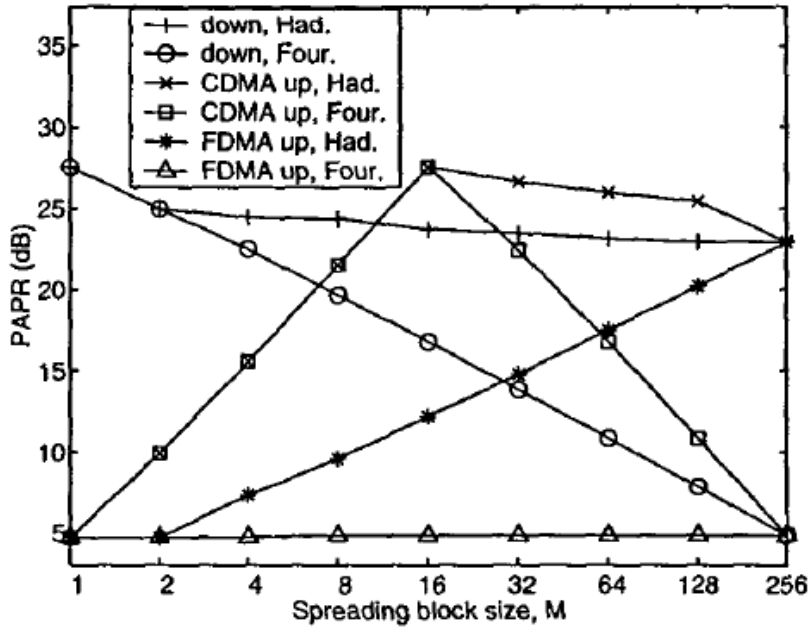


Fig. 3. PAPR as a function of the spreading block size. 4PSK, $N = 256$, $L = 32$, 'continuous' time.

Bury-2000 at 859.

Downlink

In the downlink, the PAPR is the same for both MC-CDMA and MC-FDMA. This is obvious because both systems are identical except for the assignment of transmitted symbols to users. For the trivial case of spreading over a single carrier and for the case of spreading over two carriers, both Hadamard and Fourier spreading deliver the same PAPR. In the latter case this happens because Hadamard and Fourier matrices are identical for spreading over two symbols. In the case of Hadamard spreading, when spreading is done over an increasing number of

	subcarriers, the PAPR remains nearly constant (with a slight decrease); for Fourier spreading, however, it decreases rapidly and reaches the PAPR of a single carrier transmission when spreading is done over all subcarriers. This means that for the downlink Fourier spreading clearly outperforms Hadamard spreading. The larger the spreading factor, the better the PAPR. Furthermore, assuming that a large number of users is desired, we consider the following: Since MC-FDMA requires (at least) one spreading block per user, the spreading blocks must be small in case of many users, resulting in a relatively large PAPR. For MC-CDMA, however, the larger the spreading block, the larger the possible number of users. Here the best choice with respect to PAPR is to use Fourier spreading over all carriers while assigning groups of input symbols for each user, resulting in the lowest possible PAPR. Bury-2000 at 859-60. Uplink In the uplink we distinguish between MC-CDMA and MC-FDMA. For MC-CDMA the PAPR of both Fourier and Hadamard spreading shows a strong increase for increasing spreading factors, reaching a maximum when the spreading factor equals the square root of the number of subcarriers. When the spreading factor is increased further, Hadamard spreading shows a slight decrease in PAPR while Fourier spreading shows a rapid decrease, reaching the PAPR of a serial transmission when spreading is done over all carriers. In contrast to MC-CDMA, MC-FDMA shows a much better behavior, with the PAPR being lower for the entire range of spreading factors, for the respective spreading methods. For Hadamard spreading, the PAPR increases for increasing spreading factors. For Fourier spreading, however, the PAPR remains nearly constant at a low level for all spreading factors. This shows that also in the uplink Fourier spreading outperforms Hadamard spreading in most cases. For the case of Fourier spreading in a

MC-FDMA uplink, the spreading factor may be selected arbitrarily, nearly without affecting the PAPR.

Bury-2000 at 860.

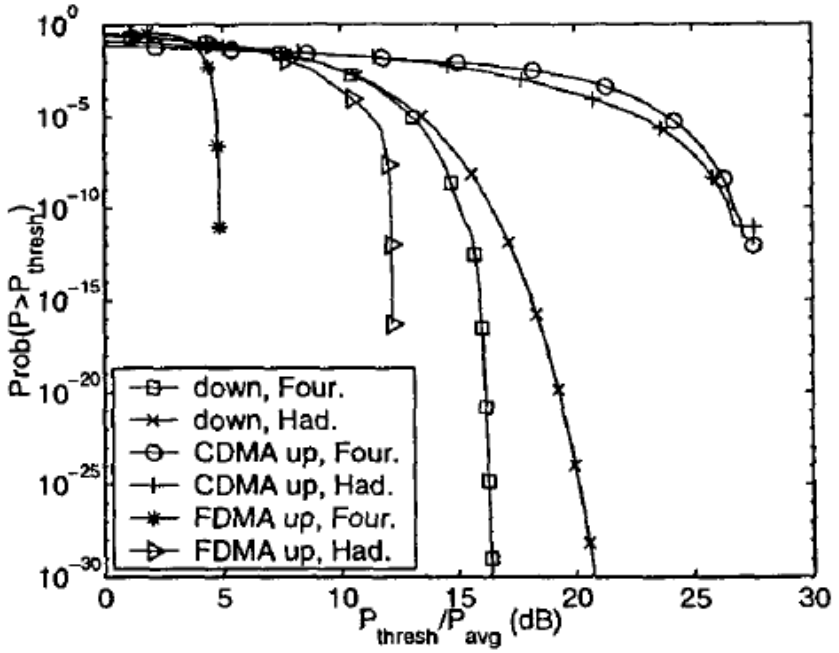
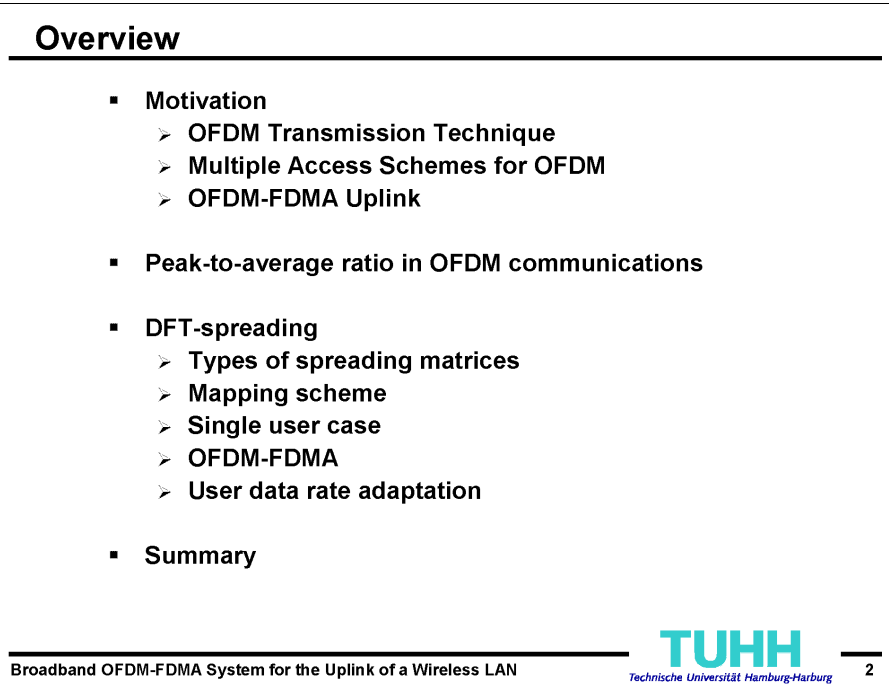


Fig. 4. Example for amplitude distribution.
4PSK, $N = 256$, $L = 32$, $M = 16$, 'continuous' time.

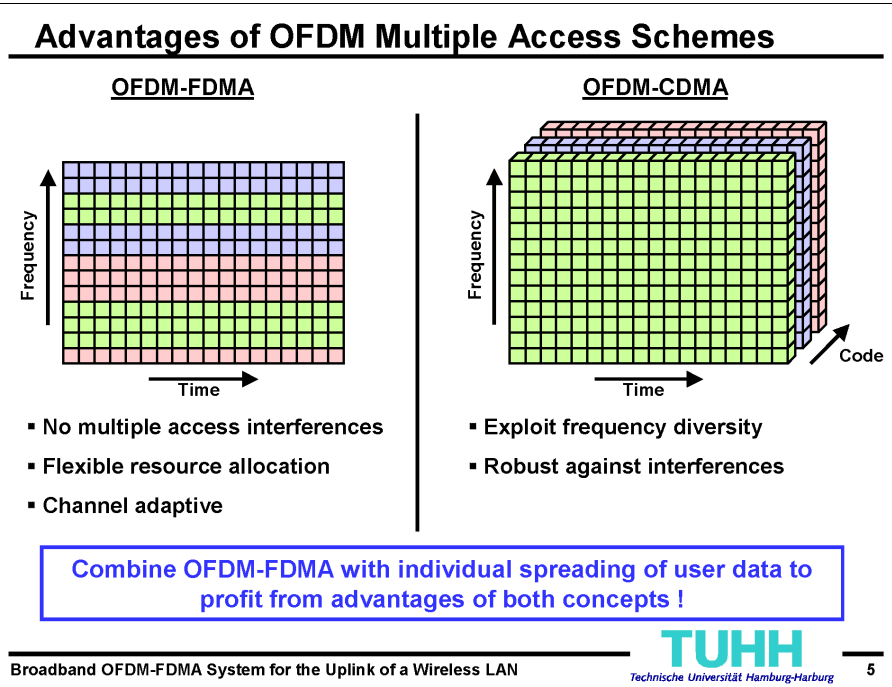
Bury-2000 at 860.

The graph shows that, in case of the downlink, Fourier spreading offers a more sharply limited amplitude distribution while Hadamard spreading produces continuously growing amplitudes at decreasing probabilities. Not only from the PAPR point of view, but also from the PDF of the amplitude

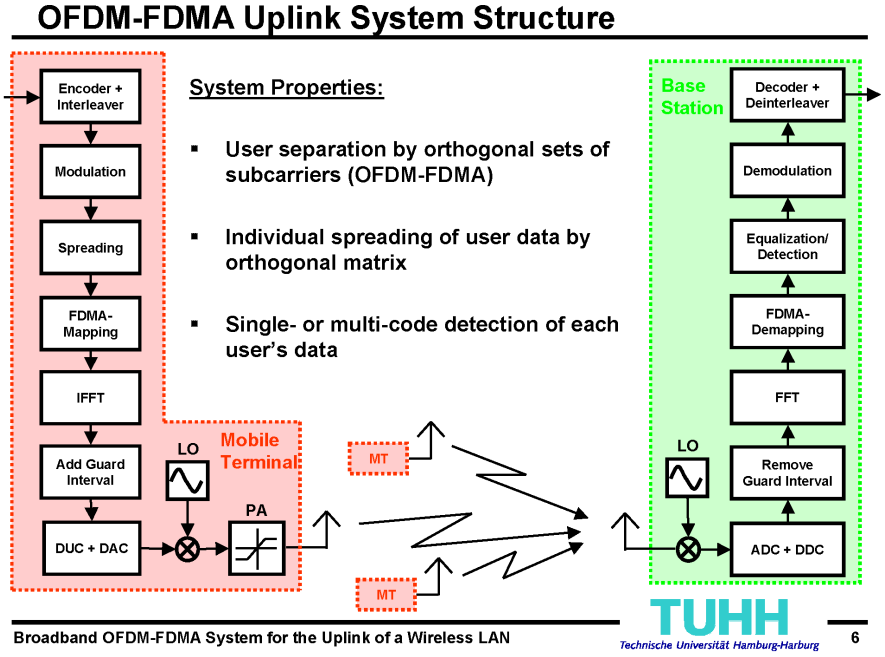
	it is clear that Fourier spreading is a better choice than Hadamard spreading. Bury-2000 at 860. Amplitude distributions of Hadamard spreading and Fourier spreading have been compared for OFDM based MC-CDM transmission methods, using a general matrix model. Comparison has been done for both up- and downlink in MC-CDMA and MC-FDMA multiple access scenarios, and for various spreading factors. For both up- and downlink Fourier spreading delivers a lower or equal PAPR. This superiority increases significantly for larger spreading factors. In the uplink, MC-FDMA delivers lower PAPRs than MC-CDMA. From the amplitude distribution point of view, the best choice is to employ Fourier spreading with MC-CDMA in the downlink and with MC-FDMA in the uplink. Bury-2000 at 860. Galda-2001, which discloses:



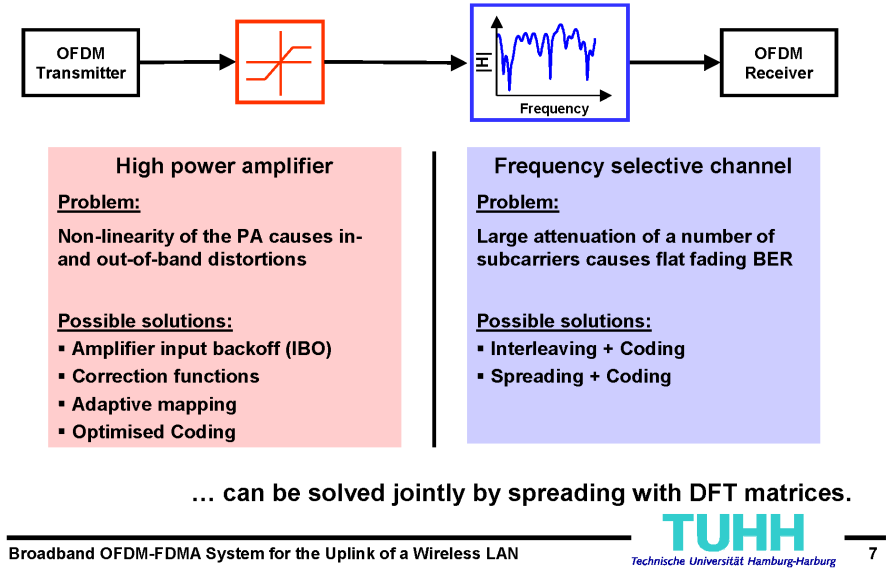
Galda-2001 at 2.



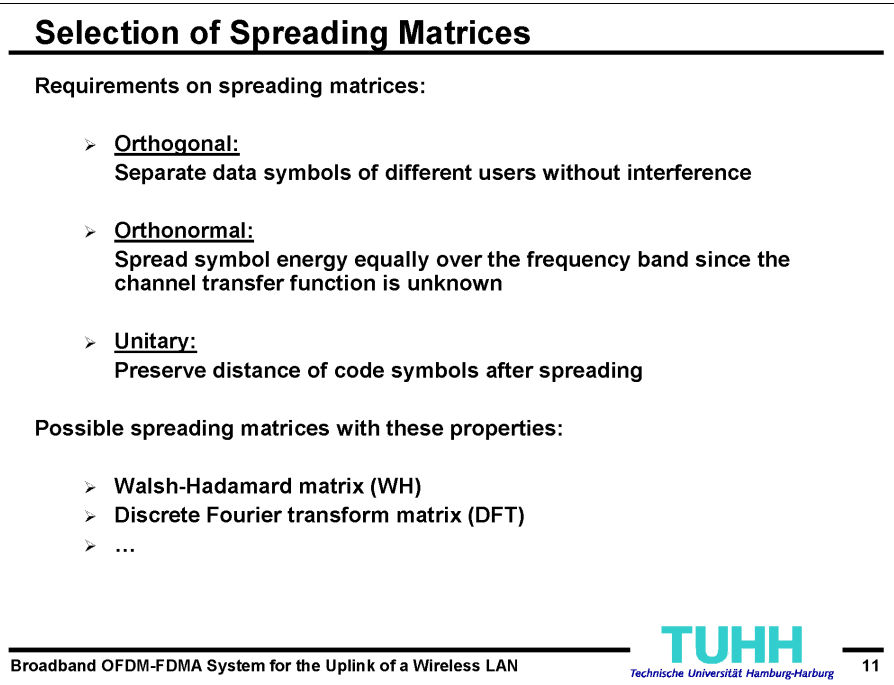
Galda-2001 at 5.



Galda-2001 at 6.



Galda-2001 at 7.



Selection of Spreading Matrices

Requirements on spreading matrices:

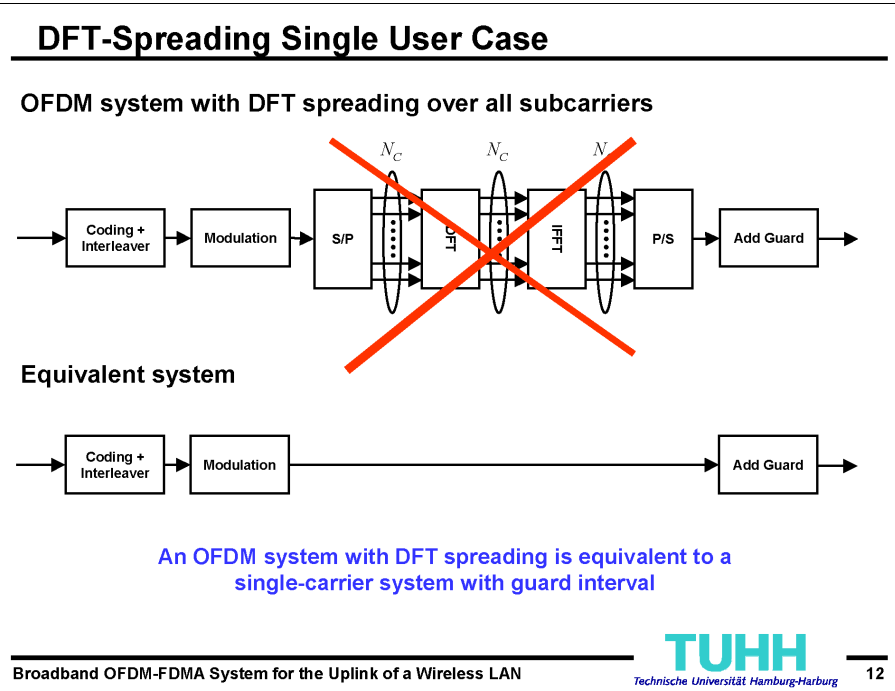
- Orthogonal:
  Separate data symbols of different users without interference
- Orthonormal:
  Spread symbol energy equally over the frequency band since the channel transfer function is unknown
- Unitary:
  Preserve distance of code symbols after spreading

Possible spreading matrices with these properties:

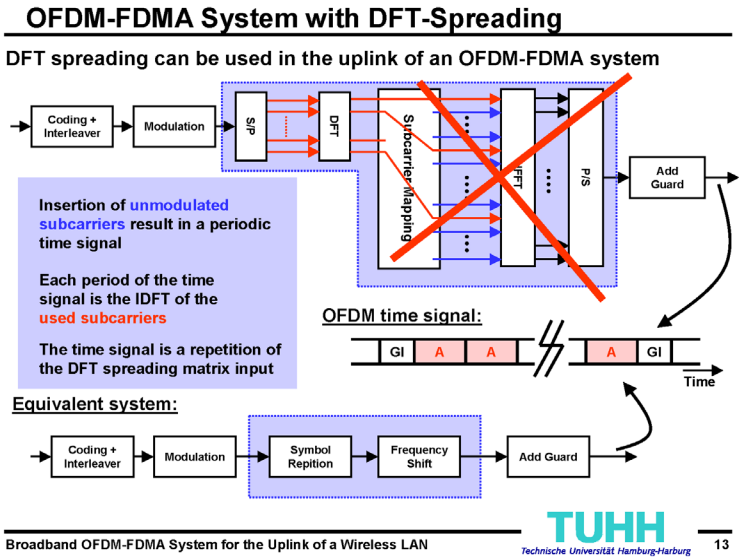
- Walsh-Hadamard matrix (WH)
- Discrete Fourier transform matrix (DFT)
- ...

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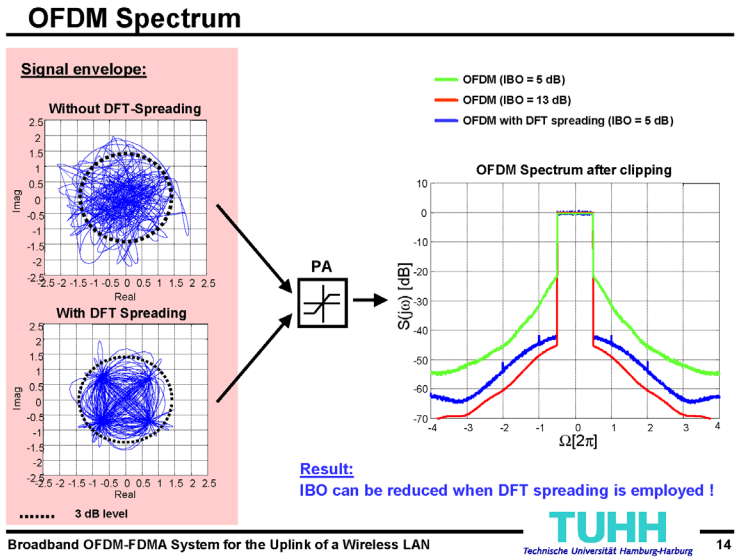
Galda-2001 at 11.



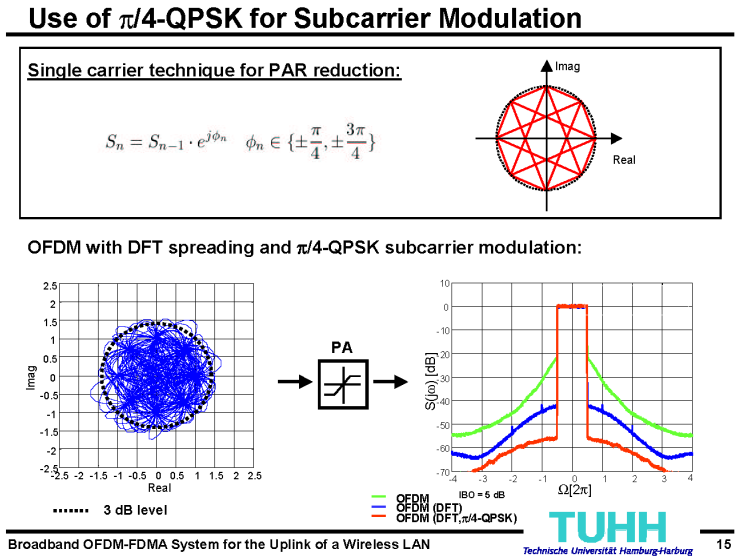
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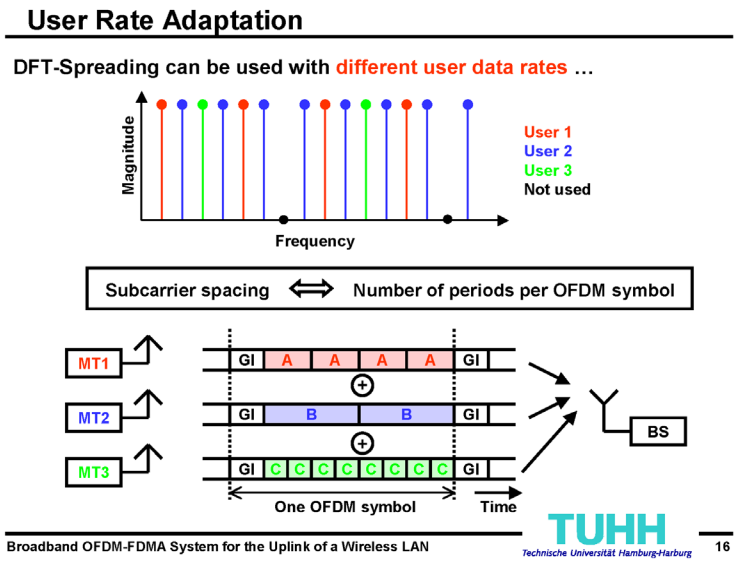
Galda-2001 at 13.



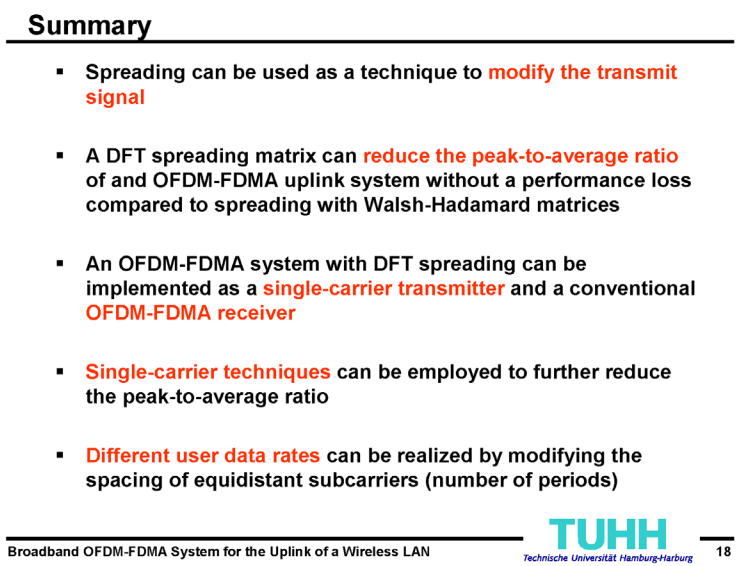
Galda-2001 at 14.



Galda-2001 at 15.



Galda-2001 at 16.



Galda-2001 at 18.

Galda-2002, which discloses:

> Abstract- The orthogonal frequency division multiplex (OFDM) transmission technique can efficiently deal with the effects of multi-path propagation in the broadband radio channel. It also has a high system inherent flexibility for designing a multiple access scheme by combining the conventional TDMA, FDMA and CDMA approaches with the OFDM modulation scheme. The FDMA multiple access scheme is especially interesting for an uplink of a communication system since it can completely avoid any multiple access interferences (MAI). Moreover, the peak-to-average ratio (PAR) of the uplink OFDM transmit signal can be greatly reduced if this OFDM-FDMA multiple access scheme is additionally combined with a data spreading technique based on a Discrete Fourier

	Transform (DFT) spreading matrix using only the user specific subcarriers. Since the DFT spreading operation and the IDFT operation used as a part of the OFDM modulation scheme cancel out each other the complexity of the transmitter structure for an OFDM-FDMA uplink can be greatly reduced. Galda-2002 at 1737. The subdivision of the transmission bandwidth into a set of orthogonal subcarriers can additionally be exploited by an OFDM-FDMA multiple access scheme. By allocating distinct sets of subcarriers to different users the available bandwidth can be flexibly shared between different mobile terminals while avoiding any multiple access interferences (MAI) between different users. The FDMA multiple access scheme offers not only a high flexibility for the radio resource management (RRM) but can also increase the bandwidth efficiency of the complete system by avoiding the use of highly attenuated subcarriers for specific users based on the knowledge of the channel transfer function [2]. Moreover, the OFDM-FDMA multiple access scheme can be adapted to the measured radio channel knowledge at the transmitter site using bit-loading techniques. If channel state information is not available the performance can be increased using an additional spreading over the subcarriers assigned to one user. The resulting computation complexity of the total system can by this means be adopted to the given system requirements which is especially of importance for the mobile terminal and in the uplink case. The alternative OFDM-FDMA multiple access scheme is therefore of importance for the uplink case and can be advantageous over OFDM-CDMA schemes because of its ability to avoid MAI if ideal carrier synchronization is assumed for all mobile terminals and the base station. Galda-2002 at 1737. Since the OFDM transmit signal results from the superposition of a large number of independent data symbols the envelope of the complex baseband

	time signal has in general a large peak-to-average ratio (PAR). The largest output power value of the amplifier will limit the maximum amplitude of the signal in the transmitter. Therefore, non-linear distortions due to clipping and amplification effects in the transmit signal will lead to both in-band and out-of-band emissions. In the past different techniques for reducing the PAR by changing the transmit signal independently from knowledge of other parts of the OFDM transmitter have been developed. But the PAR of the transmit signal envelope which employs an OFDM-FDMA multiple access scheme can significantly be reduced if additional spreading techniques are applied which spread the user data over the allocated subcarrier only. In this case an appropriate spreading technique must be designed reducing the PAR to a minimum value. It will be shown in this paper that using the Discrete Fourier Transform (DFT) matrix as an orthogonal spreading technique will reduce the PAR significantely [3]. Furthermore, the DFT based spreading operation and the IDFT based OFDM modulation technique cancel out each other which means that the transmitter structure can be simplified to a single carrier transmitter with an additional guard interval in this specific case which helps to reduce the computational complexity of the transmitter of the mobile terminal. Galda-2002 at 1737-38. This paper shows how an OFDM-FDMA uplink system can be combined with a user data spreading technique based on the DFT spreading matrix to reduce the PAR of the uplink signal without increasing the computational complexity of the transmitter. In Section II the structure of the analyzed OFDM-FDMA system combined with a DFT spreading matrix is described for the uplink application. In Section III the influence of a DFT matrix applied for data spreading is analyzed for an OFDM-TDMA multiple access scheme and is extended to an OFDM-FDMA system in a separate subsection. The general topic of non-linearities in an OFDM system is reviewed in Section IV. Quantitative results are given in Section V and Section VI summarizes the papers content.

Galda-2002 at 1738.

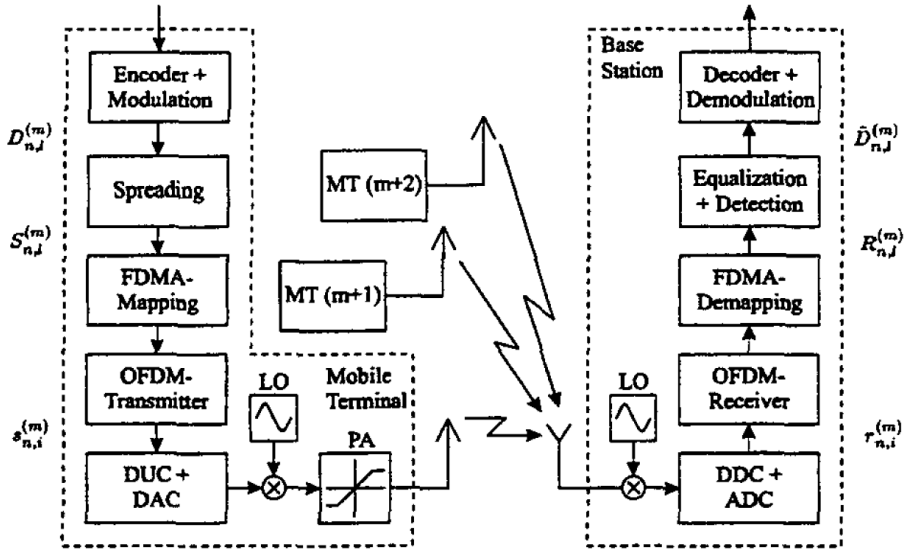


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

Galda-2002 at Fig. 1.

The baseband system model of an OFDM-FDMA uplink with individual spreading of user data is shown in Fig. 1. In this case M different users are considered and each user allocates L different subcarrier exclusively. The total number of subcarrier in the considered transmission system is $N_C = L \cdot M$. The input data stream for each mobile user $m, m = 0, \dots, M-1$, is convolutionally encoded in a first step. The bit sequence is then mapped onto L complex modulation symbols $D_l^{(m)}, l = 0, \dots, L-1$, of a coherent, higher-level modulation scheme. The L modulation symbols are spread over the L user specifically allocated subcarrier with an unitary spreading

matrix $[C]$ resulting in L complex transmit symbols $S_l^{(m)}$. The spreading operation can be denoted mathematically by the following simple matrix multiplication

$$\vec{S}^{(m)} = [C]\vec{D}^{(m)} \quad (1)$$

where each complex transmit symbol $S_l^{(m)}$ is calculated by the sum of L user modulation symbols $D_l^{(m)}$ weighted by L orthogonal code vectors $\widetilde{C_l} = \left(C_{l,0}, C_{l,1}, \dots, C_{l,l}\right)$ with $l = 0, \dots, L-1$

$$S_l^{(m)} = \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} \quad \text{for} \quad l = 0, \dots, L-1 \quad (2)$$

The transmit symbols $S_l(m)$ are then mapped onto L of the available N_C subcarrier which are exclusively allocated to user m. In principle, the set of subcarrier assigned to each user can be composed of any L out of N_C subcarrier that have not been assigned to another user.

Galda-2002 at 1738.

Independent of the considered spreading matrix C but assuming the equidistant allocation of subcarrier over the entire bandwidth the resulting OFDM time signal of user m can analytically be described as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \quad (3)$$

where N_G denotes the length of the guard interval which is inserted into the transmit time signal.

Galda-2002 at 1738.

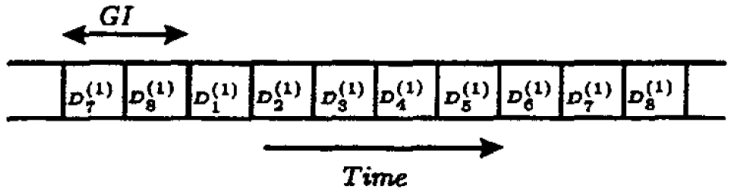


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

Galda-2002 at Fig. 3.

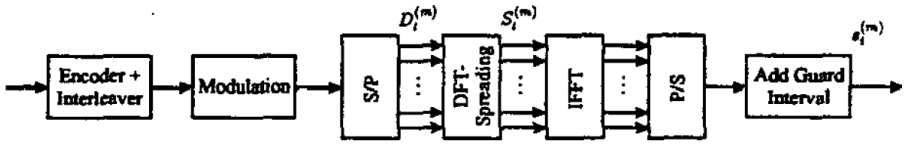
A. OFDM-TDMA with DFT Spreading

In [3] the Discrete Fourier Transformation (DFT) matrix has been used for spreading the vector $\vec{D}$ of length $L = N_C$ over all subcarriers of an OFDM system. If a single user is assumed in this OFDM system the spreading operation includes all subcarrier within the entire bandwidth. In this case the DFT spreading matrix and the IDFT operation in the OFDM modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore technically reduced to the serial sequence of complex transmit data symbols D_i to which a guard interval is added in the time domain as a cyclic prefix

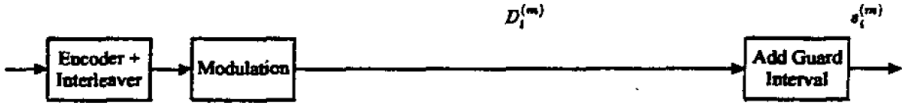
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for} \quad i = -N_G, \dots, 0, \dots, N_C \tag{5}$$

where mod denotes the modulo operation, as shown in Fig. 3.

Galda-2002 at 1739.



(a) OFDM transmitter including DFT spreading over all subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 4. In an OFDM system including a DFT spreading matrix and an IFFT for the OFDM modulation process both matrices cancel out each other.

Galda-2002 at Fig. 4.

> After calculating the FFT in the receiver which splits the received time signal into the orthogonal sub-channel the same single- or multi-code detection techniques can be applied which are well known from OFDM-CDMA receiver structures. The same bit error rate (BER) performance compared to a system using a Walsh-Hadamard spreading matrix can therefore be achieved if a DFT spreading matrix is considered instead. But in case of a DFT spreading matrix the resulting PAR is significantly reduced. The general structure of an OFDM transmitter including DFT spreading is shown in Fig. 4.

Galda-2002 at 1739.

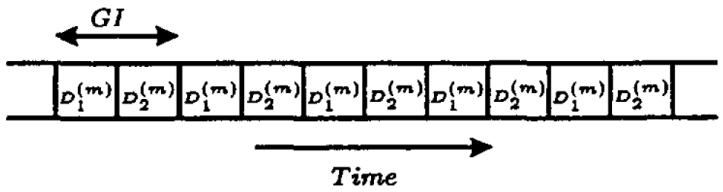


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

Galda-2002 at Fig. 5.

B. OFDM-FDMA with DFT Spreading

The advantage of a DFT spreading matrix can also be exploited in the uplink of an OFDM-FDMA system. If the user data is spread only over $L < N_C$ subcarriers then the DFT of length L used for spreading does not directly cancel out with the length N_C IDFT of the OFDM modulator in general. Only when the spreaded symbols $S_l^{(m)}$ are mapped onto equidistant located subcarriers with a spacing of $N_C/L = M$ the DFT spreading and the OFDM modulation can be removed in the transmitter structure. This can be seen by inserting Equation (2) into Equation (3) using the elements of the discrete Fourier matrix

$$C_{i,j} = \frac{1}{\sqrt{L}} \cdot e^{j2\pi ij/L} \qquad (6)$$

the transmit signal of user m can be written as

$$s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L}$$

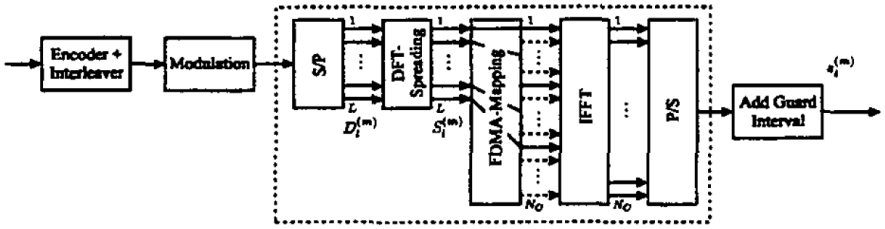
$$= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)}$$

$$= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu - i)$$

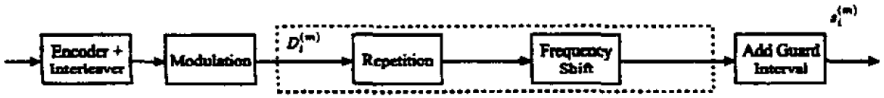
$$s_i^{(m)} = e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \quad (7)$$

for $i = -N_G, \ldots, 0, \ldots, N_C$ and the periodic dirac pulse sequence $\delta_L(\ \ )$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ sequence including an added guard interval as cyclic prefix, shown in Fig. 5. This periodic data sequence is multiplied by a user specific complex signal $e^{j2\pi im/N_C}$ due to the user individual frequency shift by m subcarriers of the complete allocated subcarrier set. The number of periods inside a single OFDM symbol is equal to the spacing M of the subcarriers allocated to user m.

Galda-2002 at 1739-40.



(a) OFDM-FDMA transmitter with DFT spreading over equidistant subcarriers



(b) Realistic but simplified OFDM transmitter structure

Fig. 6. In an OFDM-FDMA uplink system including DFT spreading matrix applied to a set of equidistant subcarriers the DFT spreading matrix and the OFDM IFFT transformation cancel out each other.

Galda-2002 at Fig. 6.

The structure of the OFDM transmitter can be simplified by this approach since both the DFT spreading operation and the IFFT calculation of the conventional OFDM transmitter cancel out and can be removed in the technical realization completely and will be replaced by a simple repetition process of the considered user data $D_l^{(m)}$. The simplified transmitter structure is depicted in Fig. 6. Any equidistant subcarrier allocation can be used with the proposed FDMA scheme since it only influences the number of periods of the transmit signal. Therefore the user data rate can be flexibly adjusted by assigning the required number of subcarriers to each user.

	Galda-2002 at 1740. In order to avoid non-linear distortions even in the case of a highly linear power amplifier a sufficient input-backoff (IBO) of the transmit signal to the amplifier has to be used. Even though the clipping probability of the OFDM signal can be reduced or even be avoided for an IBO larger than the PAR a system with large energy efficiency loss results. Alternatively, the effects which a non-linear device can have on the transmit power spectrum can be influenced by a reduction of the OFDM transmit signal PAR Different techniques have been developed which reduce the PAR of the OFDM signal by the means of a modified channel coding [5], an additive [6] or multiplicative [7] correction function or a selective mapping of modulation symbols to subcarriers [8]. A majority of these techniques has a high computational complexity due to the fact that they analyze the generated transmit signal and modify it either in the frequency or time domain to reduce its peak amplitudes. For a system employing coherent subcarrier modulation the PAR can also be reduced if the data symbols are spread by a Fourier matrix in frequency direction [3]. Galda-2002 at 1740. In this paper an OFDM-FDMA system concept for the uplink of a multi user communication system has been studied. It had be shown that if an OFDM-FDMA system with equidistant subcarrier allocation is combined with a user specific spreading using an discrete Fourier transform as a spreading matrix the transmitter structure can be greatly simplified without any performance degradation. Moreover, the peak-to-average ratio of the transmit signal is reduced to the PAR of the subcarrier modulation scheme which can limit the out-of-band and in-band emissions when the transmit signal is passed through a non-linear device. With the opportunity to independently adjust the user data rates the proposed technique offers an interesting alternative for reducing the complexity of the mobile terminal in the broadband radio uplink.

	Galda-2002 at 1741. Costa-193, which discloses: > The invention relates to a method and a communication system device for the generation of OFDM symbols, wherein data from one or more users or from one or more data sources (User 1–User M) are represented on a number of sub-carriers (Nc). According to the invention, in order to inhibit multiple-access interference (MAI) on application of the CDMA principle, the data are transformed in a data-source specific manner and only subsequently allocated to the sub-carriers, independently of the transformation. Costa-193 at abstract. > According to an alternative procedure, the user data can be spread over a specified number of sub-carriers and/or OFDM symbols by using orthogonal codes with the aid of an orthogonal matrix, as is the case with OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). In the OFDM-CDMA process, the data of all users is allocated to all available frequencies, wherein codes are used for separation. Without further measures, undesirable multiple access interferences occur in this case, in particular when considering a plurality of users or data sources whose data is received in parallel with one another. Costa-193 at 1:18-24. > To avoid this problem, the user data is thus spread over a plurality of sub-carriers only when sub-carriers are allocated to a plurality of users at the same time, which is referred to as OFDM-FDMA, with user-specific spreading of the reference data. Spreading and allocation of sub-carriers takes place in a common and comprehensive method step. So-called Walsh-Hadamard matrices of different sizes are mainly used for the spread, as described for example by M. Yee, J.-P. Linnartz: "Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading

	Channel," Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: "Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications," Kluwer Academic Publisher, 1996. Depending on the data rate required for transmission, different users are allocated a number between 1 and N of orthogonal codes, wherein N is the number of available sub-carriers. Costa-193 at 2:1-9. Furthermore, in K. Bruninghaus, H. Rohling: "Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission," Proc. IEEE VTC'98, Ottawa, Canada, 1998, a spread using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of the peak values to the average values (PAR: Peak-to-Average Ratios) is generally discussed, although multiple accesses are not considered. Costa-193 at 2:10-13. Advantageously, due to the data source-specific, i.e., exclusive, allocation of sub-carriers to the respective users or user data, to which the transformation result of an orthogonal transformation matrix or spread is transmitted, the undesirable multiple access interferences can be avoided, ideally completely, despite the application of the transformation. Advantageously, the choice of the orthogonal matrix is initially arbitrary. Furthermore, the transformation result can also be allocated to the exclusive sub-carriers of a user or a data source in any way. The separation of the spread of the user-specific data or data source-specific data and the allocation of the transformed or spread data to the sub-carriers of one or more OFDM symbols is particularly advantageous when a discrete Fourier transform (DFT) or fast Fourier transform (FFT) is used for the spread instead of, for example, the Walsh-Hadamard transform.

	In particular in combination with an equidistant arrangement of the sub-carriers on the carrier, in particular on the frequency axis, for the various user data or data sources, an OFDM-FDMA system then results in which the time signal or the OFDM symbols have a constant amplitude behind the usual inverse fast Fourier Transform (IFFT). This is a very significant advantage, because the various smoothing processes, which would currently have to be used, become unnecessary. Costa-193 at 3:1-13. In particular when combining a Fourier transform and an inverse Fourier transform, in a particularly preferred embodiment, a simplified generation of the OFDM symbols can also be carried out, because corresponding process steps can be omitted during their generation. In effect, the two successive Fourier transforms can cancel each other out, with the exception of, in particular, a frequency shift. Correspondingly, according to the invention, when communicating between, for example, a mobile user station and a base station in the uplink direction, it is possible to distribute/combine the incoming data from the individual data sources directly onto the corresponding OFDM symbol positions, if necessary after the usual encoding, interleaving, and modulation. This advantageously simplifies the structure of the transmitting communication station. The base station can expediently remain unchanged and continue to have the structure of an OFDM receiver, in order to be able to utilize the OFDM-specific advantages such as simple equalization of the received signal and separation of the user station data or users. Costa-193 at 4:1-10. FIG. [1] a scheme for a general multiple access, wherein the structure of an OFDM-FDMA system having user-specific spread of the data symbols is shown;

Costa-193 at 5:3-4.

> FIG. [2] schematically, a possible implementation of an OFDM-FDMA system having a particularly preferred FFT spread matrix and allocation of the user data to equidistant sub-carriers;

Costa-193 at 5:5-6.

> FIG. [3] schematically, an allocation of spread user data to equidistant sub-carriers, and

Costa-193 at 5:7.

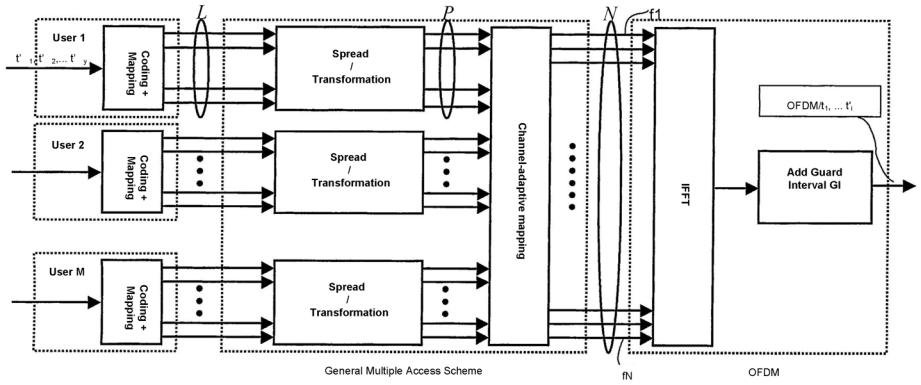


FIG. [1]

Costa-193 at Fig. 1.

> The following block shows the actual transformation or spread and the encoding of the data from different users onto the individual frequency sub-carriers.
>
> The data arriving on L data paths for each user is spread in a first step, i.e., distributed from a total of L data values onto P data values. This preferably serves to utilize the statistically independent propagation of the signals on

	different sub-carriers (frequency diversity). In the preferred exemplary embodiments, the number of individual data values or lines is not changed, although this is also possible, so that there are L complex data values per user before and after the spread. Analogous to the spread of the data with Walsh-Hadamard matrices as in OFDM-CDMA, L corresponds to the number of codes allocated to the user station and P to the number of available orthogonal code symbols. In this case, the spread corresponds to a full-load system. Costa-193 at 6:1-9. When describing the structure of the OFDM-FDMA system with the user-specific spread of the data symbols above, a conscious distinction is made between, on the one hand, spread/transformation and, on the other hand, mapping onto the sub-carriers. Costa-193 at 7:6-8. This separation is carried out in order to be able to transform or spread the data of the individual users, initially with the aid of an orthogonal matrix. In the subsequent step, the transformation result is then transferred onto sub-carriers, wherein sub-carriers are exclusively allocated to each of the individual users. In principle, the sub-carriers can be allocated in any way, wherein systems are preferred in which the first sub-carriers are allocated to the first user and the last sub-carriers to the last user. However, this is not absolutely necessary and is in particular undesirable in the case of a channel-adapted allocation, for example. However, systems in which the data of a user are mapped or transmitted onto sub-carriers that are distributed equidistantly across the frequency band are particularly preferred. Costa-193 at 7:9-15.

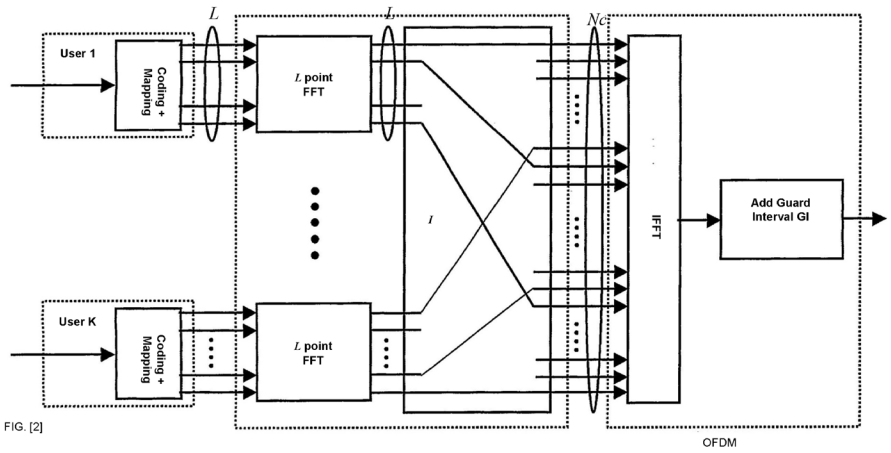


FIG. [2]

Costa-193 at Fig. 2.

> In principle, the selection of the orthogonal matrix is arbitrary. The Walsh-Hadamard transform, which is known per se, or especially a Fourier transform, in particular a discrete or fast Fourier transform, are preferred.
>
> The use of a fast Fourier transform FFT as a preferred form of transformation or spreading as well as the subsequent transfer to individual sub-carriers can be seen from FIG. [2], in an exemplary embodiment. The Fourier transforms FFT are carried out on a user-specific basis, i.e., the incoming data symbols of a user are fed in each case to their own Fourier transform.
>
> The data resulting from the individual user-specific Fourier transforms are then distributed to the individual frequency sub-carriers f1 ... fN, wherein the data of a user is preferably transmitted to sub-carriers that are not directly adjacent to one another. In principle, however, this distribution to the individual sub-carriers can take place in any manner.

Costa-193 at 8:7-15.

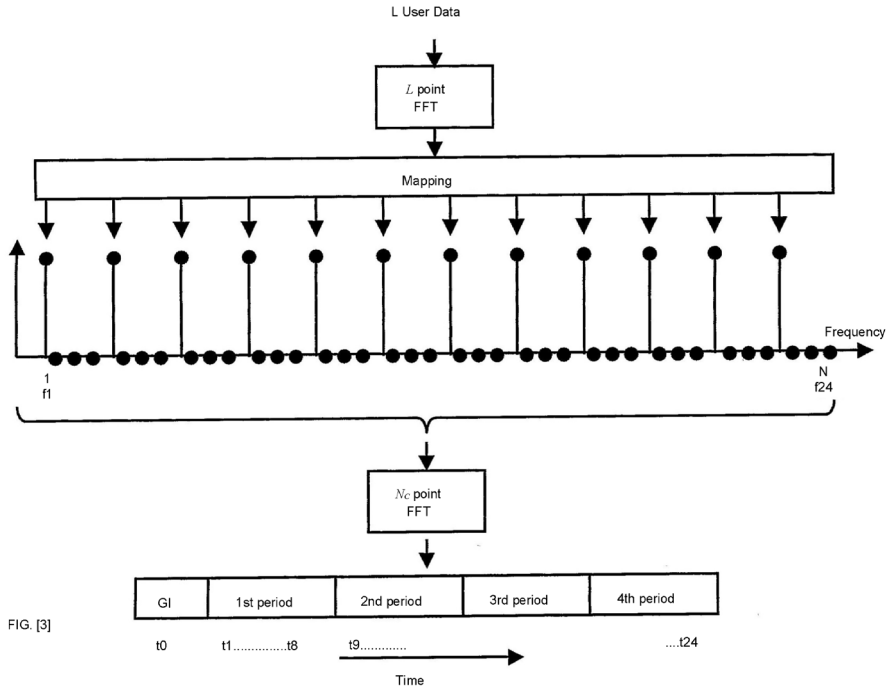


FIG. [3]

Costa-193 at Fig. 3.

> As can be seen from FIG. [3], a particularly preferred distribution of the individual data of the user-specific Fourier transforms takes place on an equidistant sequence of sub-carriers over the frequency axis. In the exemplary embodiment shown, L user data or data symbols having L data values of a user are introduced into the L-valued Fourier transform (L point FFT). According to the preferred exemplary embodiment, although not absolutely necessary, the Fourier transform in turn generates L data values which are mapped onto the N sub-carriers.

Costa-193 at 9:1-5.

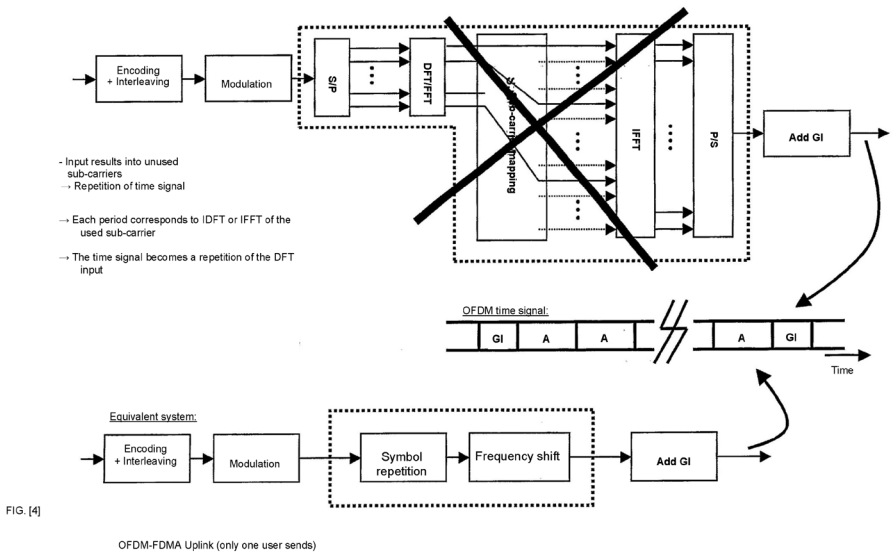


FIG. [4]

OFDM-FDMA Uplink (only one user sends)

Costa-193 at Fig. 4.

> Generalizing this with simple numbers, with a data symbol length L of the incoming user data and a mapping to L-valued transformation results, it requires a mapping to the sub-carriers f1...fN, wherein N sub-carriers are available. After the inverse Fourier transform, the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values are distributed equidistantly over N/L data periods, wherein the data periods can also be referred to as data blocks or data sections.

Costa-193 at 10:1-5.

> The particular advantage of combining a spread matrix formed by a Fourier transform FFT in combination with the equidistant distribution on the frequency axis is that, after the inverse Fourier transform, the result is a time signal having a constant amplitude in the uplink and a time signal having a peak value that is significantly reduced compared to a traditional

	OFDM system in the downlink. This constant amplitude results because the peak-to-average ratio (PAR) is significantly lower than other OFDM symbol generation methods. It corresponds precisely to the PAR of the modulation symbols before the transformation. If a PSK modulation were used here, then PAR=1. Costa-193 at 10:6-11. According to a further developed embodiment, if a Fourier transform is considered as a spread matrix and a subsequent inverse Fourier transform is considered for transmitting the individual frequency sub-carriers to a temporal data sequence, it can be determined that the two Fourier transforms then cancel each other out, purely theoretically, in terms of their effect. As a consequence, a particularly preferred embodiment for generating OFDM symbols can be implemented, as is shown in FIG. [4] for example for a transmission in the uplink from a user station to a network-side station, when only a single user transmits, wherein the transformations then cancel each other out. Due to the effect-cancelling transformation sequence of a Fourier transform FFT and after distribution to the individual sub-carriers f1...fN of an inverse Fourier transform IFFT, this block can be omitted during the implementation, or it can be replaced by repeating the symbol sequence according to the number of allocated, now fictitious, sub-carriers and subsequent frequency shift in the distribution of the input data onto the output data. Costa-193 at 11:1-10. 3. The method according to claim 1 or 2, in which, during the distribution of the input data onto the output data, the inputting of the data into the OFDM symbol is carried out by a repetition of the symbol sequence according to the number of allocated sub-carriers and a subsequent frequency shift.

	Costa-193, claim 3. 5. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using an orthogonal matrix. Costa-193, claim 5. 6. The method according to claim 4, in which the transformation, in particular as a spread, is carried out using a Fourier transform (FFT). Costa-193, claim 6. Costa-782, which discloses: In accordance with an alternate procedure, by using orthogonal codes with the aid of an orthogonal matrix, the user data can be spread over a specified number of subcarriers and/or OFDM symbols, as with the methods known under OFDM-CDMA or MC-CDMA (CDMA: Code Division Multiple Access; MC: Multiple Carrier). With the OFDM-CDMA method the data of all users is assigned to all available frequencies, in which case codes are used for separation. Without further measures, undesired multiple access interferences occur in this case and especially when considering a number of users or data sources for which the data enters in parallel. Costa-782 at 0005. To avoid this problem the user data is thus only spread over a number of subcarriers for simultaneous assignment of subcarriers to a number of users, which is referred to as OFDM-FDMA with user-specific spreading of payload data. Spreading and assignment of subcarriers is undertaken here in a common and comprehensive procedure step. What are known as Walsh-Hadamard Matrices of different sizes are predominantly used for spreading, as known for example from M. Yee, J.-P. Linnartz: Controlled Equalization of Multi-Carrier CDMA in an Indoor Rician Fading Channel,

	Proc. IEEE VTC'94, Stockholm, Sweden, 1994, or T. Müller, K. Bruninghaus, H. Rohling: Performance of Coherent OFDM-CDMA for Broadband Mobile Communications, Wireless Personal Communications, Kluwer Academic Publisher, 1996. In such systems different users, depending on the data rate required, are assigned a number between 1 and N of the orthogonal codes, with N being the number of available subcarriers. Costa-782 at 0006. Furthermore K. Bruninghaus, H. Rohling: Multi Carrier Spread Spectrum and its Relationship to Single-Carrier Transmission, Proc. IEEE VTC'98, Ottawa, channel, 1998, contains a general discussion of spreading using an FFT matrix (FFT: Fast Fourier Transformation) to reduce the ratio of peak values to average values (PAR: Peak-to-Average-Ratios), in which case multiple accesses are not taken into account however. Costa-782 at 0007. The separation of spreading of user-specific data or data source-specific data and the assignment of the transformed or spread data to the subcarriers of one or more OFDM symbols is especially advantageous if a Discrete Fourier Transformation (DFT) or Fast Fourier Transformation (FFT) is used for the spreading instead of the Walsh-Hadamard Transformation for example. Costa-782 at 0011. Especially with the combination of a Fourier Transformation and an Inverse Fourier Transformation in an especially preferred embodiment a simplified generation of an OFDM symbol can be undertaken since the corresponding procedural steps can be omitted in its generation. The two successive Fourier Transformations can cancel each other out here in their effect except for especially one frequency shift. Correspondingly in

accordance with the invention it is possible in communication between for example a mobile user station and a base station in the uplink direction to distribute or to combine the incoming data of the individual data sources if necessary after normal encoding, interleaving and modulation directly onto the corresponding OFDM symbol positions. This advantageously simplifies the design of the sending communication station. Usefully the base can remain unchanged and continue to possess the structure of an OFDM receiver to enable it to exploit the OFDM-specific advantages such as simple equalization of the receive signal and separation of the user station data or the users.

Costa-782 at 0013.

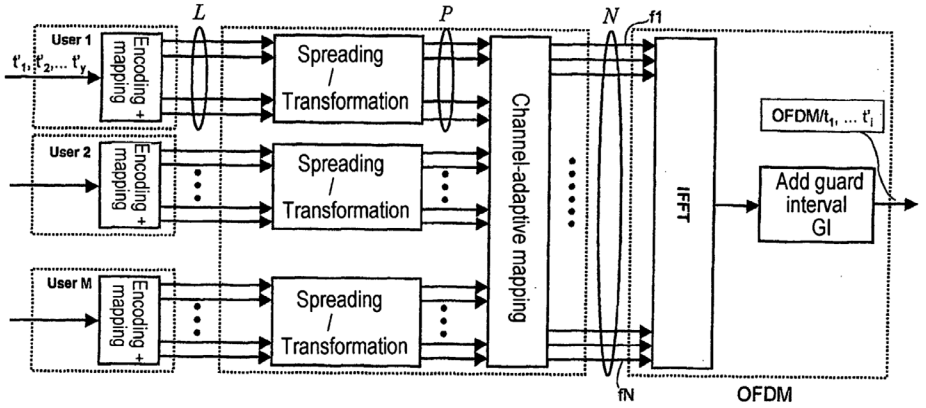


FIG 1

Costa-782 at Fig. 1.

The subsequent block shows the actual transformation or spreading and the encoding of the data of different users to the individual frequency subcarriers.

The data arriving in each case for a user on L data paths is spread in a first step, i.e. distributed from a total of L data values to P data values. This

preferably serves to exploit the statistically independent propagation of the signals on different subcarriers (frequency diversity). In the preferred exemplary embodiment the number of the individual data values or lines is not changed although this is also possible so that before and after the spreading L complex data values per user are available in each case In analogy to the spreading of the data with Walsh-Hadamard Matrices for OFDM-CDMA, L corresponds to the number of codes assigned to the user station and P the number of the available orthogonal code symbols. The spreading in this case corresponds to a full load system.

Costa-782 at 0022-23.

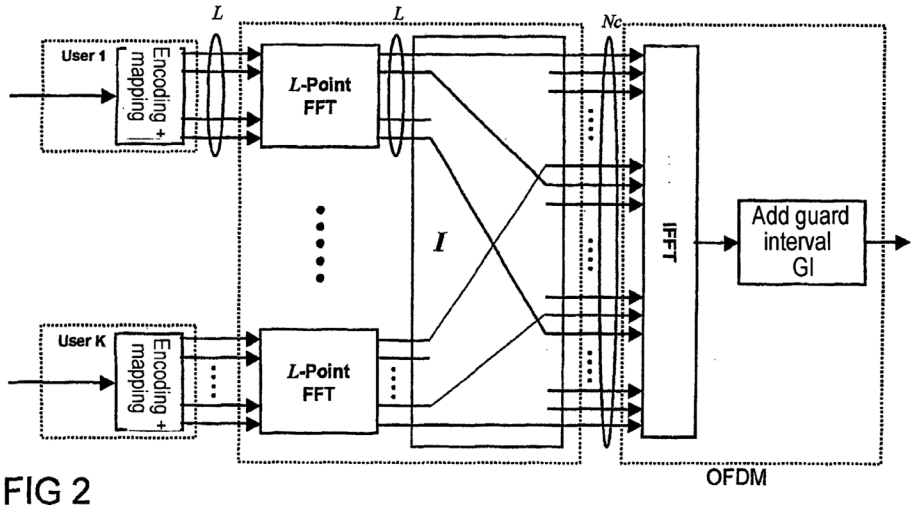


FIG 2

Costa-782 at Fig. 2.

In this case basically any orthogonal matrix can be chosen. Preferred is the Walsh-Hadamard Transformation known per se or especially a Fourier Transformation, especially a Discrete or Fast Fourier Transformation.

	The application of a Fast Fourier Transformation FFT, as preferred form of the transformation or spreading, as well as the subsequent transmission on individual subcarriers can be seen from FIG. 2 in a typical embodiment. The Fourier Transformations FFT are executed user-specifically here, i.e. the data symbols of a user arriving are fed to a separate Fourier Transformation in each case. The data produced from the individual user-specific Fourier transformations is then distributed to the individual frequency subcarriers f1 . . . fN, with the data of a user preferably not being transmitted on directly adjacent subcarriers. Purely in principle however this distribution can be undertaken in any way on the individual subcarriers. Costa-782 at 0030-32.

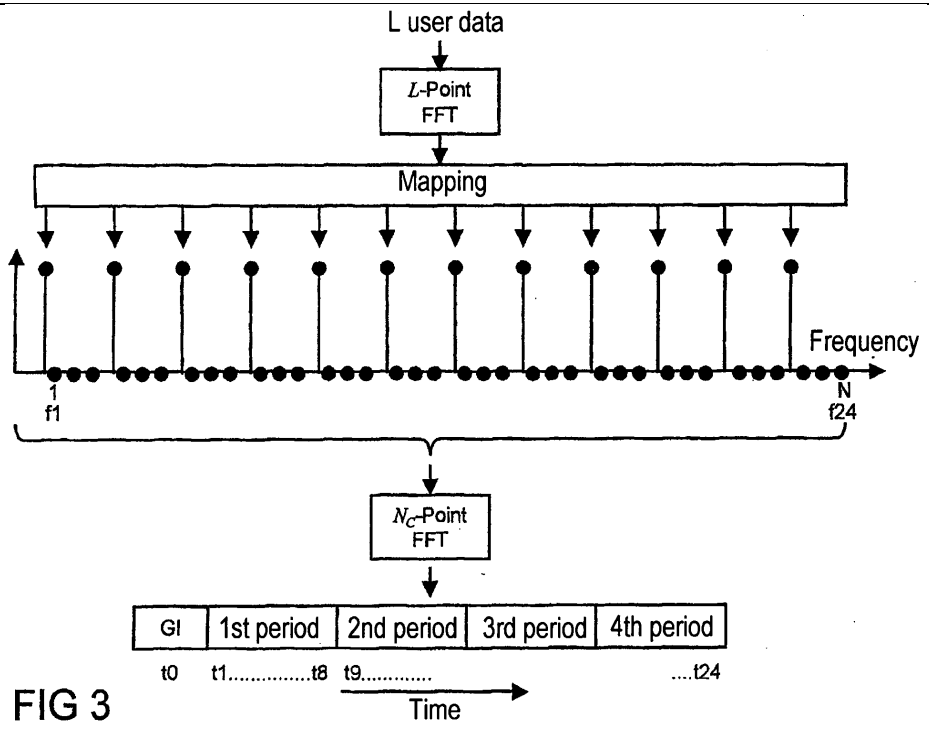


FIG 3

Costa-782 at Fig. 3.

> Put into simple generalized terms, with a data symbol length L of the user the data and a mapping to likewise L-point transformation results, this causes a mapping to subcarriers f1 . . . fN, with N subcarriers being available. After the inverse Fourier Transformation the OFDM symbol then has the length N plus the length of the guard interval GI. The individual data values here, with equidistantly distribution are distributed over N/L data periods, with the data periods also able to be referred to as data blocks or data sections.

Costa-782 at 0037.

	The particular advantage of the combination of a spread matrix formed by a Fourier Transformation FFT in combination with the equidistant distribution on the frequency axis lies in the fact that, after the inverse Fourier Transformation in the uplink a timing signal with a constant encapsulator and in the downlink a timing signal with a peak value which is much-reduced by contrast with a conventional OFDM system is produced. This constant encapsulator is produced since the peak to average value ratio (PAR) is far lower than with other generation methods for OFDM symbols. If a PSK modulation were to be used here, the PAR=1 Costa-782 at 0038. To assist understanding it is formally pointed out that a general linear transformation is involved here, that is even with the use of a Fourier Transformation to transform or spread the user-specific data no direct relationship of a frequency area to a period exists, as would be the case for normal considerations of Fourier Transformations. Costa-782 at 0039.

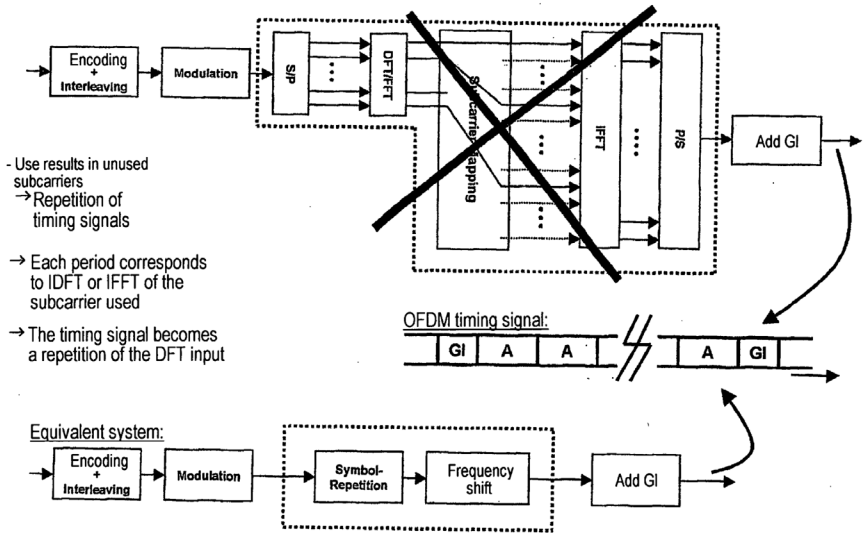


FIG 4: OFDM-FDMA Uplink (only one user sending)

Costa-782 at Fig. 4.

In accordance with a further developed embodiment, for the case of the consideration of a Fourier Transformation as spreading matrix and a subsequent Inverse Fourier Transformation to transmit the individual frequency subcarriers on a timing data sequence it can be established that purely theoretically the two Fourier Transformations cancel each other out. As a consequence a particularly preferred embodiment for generating OFDM symbols can be used, as is shown for example in FIG. 4 for example for a transmission in the uplink direction from a user station to a network-side station if only one single user is sending, in which case the transformations cancel each other out.

Through the canceling-out effect of the series of transformations of a Fourier Transformation FFT and after the distribution to the individual subcarriers f1 . . . fN of an Inverse Fourier Transformation IFFT this block can be omitted in the conversion or replaced by a repetition of the symbol

	sequence in accordance with the number of the assigned, now fictitious, subcarriers and subsequent frequency shifting for a distribution of the input data to the output data. A repeat of the timing signals is produced by the subcarriers which are not assigned to the user remaining unmodulated. Each individual period of the OFDM signal then corresponds in the final analysis to the inverse discrete Fourier Transformation of the subcarriers used. Thus, with ideal conversion and later error-free transmission over the interface the received OFDM then theoretically contains on the receiver side, behind the guard interval GI, a number of periods with the same data sequence in each case. The timing signals would thus correspond to a repeating sequence of the original inputs in the discrete Fourier Transformation which would be undertaken initially in accordance with the exemplary embodiment of FIG. 2. As can be seen from the bottom area of FIG. 4, this produces an equivalent system in which the blocks with the conversions of serial into parallel data, the subscriber-specific Fourier Transformations, the mapping or transmission on the subcarriers, the inverse Fourier Transformation and the conversion of parallel into serial data can be replaced by a series of repeating symbols and a corresponding frequency shift to be performed. Costa-782 at 0040-43. 12. A method for generating an OFDM symbol as a send signal in a communication system, comprising: mapping a complete data sequence from a data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 12.

	13. A method in accordance with claim 12, further comprising before said mapping encoding the complete data sequence from the data source to produce encoded data; and modulating the encoded data on the orthogonal subcarriers. Costa-782, claim 13. 15. A method for generating OFDM symbols for send signals in a communication system, comprising: mapping data from at least one data source to a plurality of orthogonal subcarriers, by transforming the data from the data sources; and assigning transformed data to the orthogonal subcarriers in a data source-specific manner independently of how the data is transformed. Costa-782, claim 15. 16. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by an orthogonal matrix. Costa-782, claim 16. 17. A method in accordance with claim 15, wherein said transforming is undertaken as spreading by a Fourier Transformation. Costa-782, claim 17. 22. A communication device coupled to at least one data source, comprising: at least one interface receiving input data from the at least one data source;

	at least one of a memory device and at least one processing module temporary storing and processing, respectively, the input data from the at least one data source; and a control device controlling operation of said communication device and mapping a complete data sequence from each data source to a plurality of orthogonal subcarriers of a carrier to form a chronological OFDM symbol in blocks after a guard interval, with each of the blocks including the complete data sequence. Costa-782, claim 22.
[Claim 17] The apparatus of claim 11, further comprising adding a cyclic prefix to the time-domain waveform.	StarTAC, alone or in combination with one or more other prior art references, renders obvious the apparatus of claim 11, as set forth above with respect to claim 11. *See, e.g.*, claim elements 11PRE, 11A, 11B, 11C, 11D, 11E, 11F, 11H. StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality: For example, Kaiser-1998 discloses: This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to

	MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. OFDM with guard interval is applied in SS-MC-MA systems in the same way as in MC-CDMA systems, cf. Section 3.1.1. In order to perform coherent data detection at the receiver and to guarantee robust time and frequency synchronization, pilot symbols are multiplexed in the transmitted data. Kaiser-1998 at 133. In the following, the performance of an SS-MC-MA mobile radio system in the uplink is presented. Table B.1 shows the SS-MC-MA system

	parameters used in the uplink. These parameters are chosen such that they correspond as far as possible with the MC-CDMA system parameters for the downlink presented in Table 6.1. The SS-MC-MA system parameters described in the following differ from those of the MC-CDMA system presented in Chapter 6. The SS-MC-MA system transmits only on 256 subcarriers. Since the channel estimation in the considered SS-MC-MA system is based on a 1-D filtering in time direction which should fulfill two-times oversampling of the time-variant fading process, the overhead due to pilot symbols can be reduced with decreasing OFDM symbol durations. However, it has to be taken into account that with decreasing OFDM symbol duration the loss in bandwidth efficiency due to the guard interval increases. The used TDMA frame structure consisting of 4 time slots. A time slot corresponds to an OFDM frame consisting of 31 OFDM symbols as illustrated in Fig. B.4. Each user exclusively transmits on 8 subcarriers, where 3 of the 8 subcarriers used by the kth user are depicted. Hence, per user, a block of 8 serial data symbols is parallel converted and spread with orthogonal Walsh Hadamard codes of length L equal to 8, resulting after superposition in the transmission sequence $\underline{s}^{(k)}$, cf. (B.3). Note that in contrast to Fig. B.2, an additional interleaver is applied which scrambles 192 components of 24 transmission sequences $\underline{s}^{(k)}$ with the intention to increase the diversity potential of the system. Per OFDM symbol, 8 randomly interleaved components are mapped on 8 subcarriers exclusively used by the kth user. The 8 user specific subcarriers are distributed over the whole bandwidth. The receiver applies an MLSSE for data detection. The channel coding part is identical to that of the MC-CDMA system presented in Chapter 6. Kaiser-1998 at 133-135.

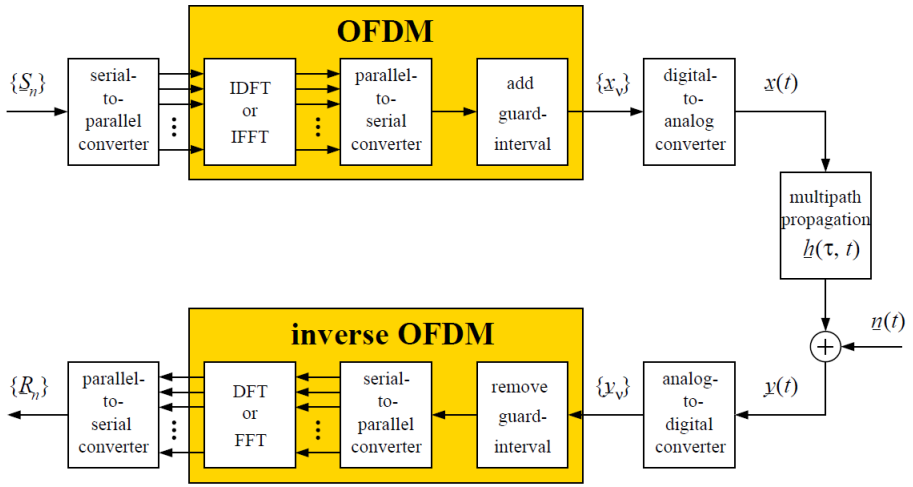


Figure 3.2: MC transmission system with OFDM

Kaiser-1998 at Fig. 3.2.

When the number of subcarriers increases, the OFDM symbol duration T_s becomes large compared to the duration of the impulse response τ_{max} of the channel and the amount of ISI reduces. However, to completely avoid the effect of ISI and, thus, to maintain the orthogonality between the signals on the N_c subcarriers, i.e., also to avoid ICI, a guard interval of duration

$$T_g \geq \tau_{max} \tag{3.7}$$

has to be inserted between adjacent OFDM symbols [Ail87, Bin90, Pro95]. The guard interval is a cyclic prefix added to each OFDM symbol which is obtained by extending the duration of an OFDM symbol to

$$T_s' = T_g + T_s. \tag{3.8}$$

Kaiser-1998 at 33.

[Claim 19] The apparatus of claim 11, wherein modulating comprises selecting one of a set of subcarrier frequency spacings.	StarTAC, alone or in combination with one or more other prior art references, renders obvious the apparatus of claim 11, as set forth above with respect to claim 11. *See, e.g.*, claim elements 11PRE, 11A, 11B, 11C, 11D, 11E, 11F, 11H. StarTAC had a non-transitory memory coupled to the processor, the non-transitory memory including a set of instructions stored therein and executable by the processor. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include memory that included instructions to perform the claimed functionality. A POSA would have been aware of developments seeking to add data and higher transmission rates and overall network throughput in cellular and other wireless communications technologies. Such technologies were designed to improve on the technology underlying the transmitter used in, for example, StarTAC. A POSA thus would have found it obvious to modify StarTAC using the technologies described in one or more of the following references and arrive at the claimed subject matter and implement them in instructions stored on a medium/in memory such that when they were executed by a processor, they executed the claimed functionality: For example, Kaiser-1998 discloses: > This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA

transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users.

Kaiser-1998 at 130-131.

Between SS-MC-MA and MC-CDMA systems exist the following similarities:

• SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers.

• Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems.

• ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques.

Kaiser-1998 at 131.

Between SS-MC-MA and MC-CDMA systems exist the following differences:

• In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA

scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme.

• MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user.

• In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

• In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity.

Kaiser-1998 at 131.

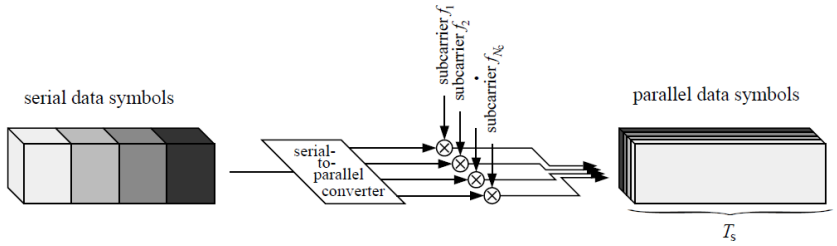


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

	The progress in wireless communications entails a demand for higher data rates and, thus, shorter symbol durations. However, if the duration of the transmitted symbol becomes smaller than the time dispersion of the multipath channel, the performance of the wireless communication system suffers from ISI. This is a crucial problem since the receiver complexity is related to the amount of ISI. An approach to prevent ISI is offered by parallel data transmission [Cha66, Sal67, WeE71], referred to as MC communications. The principle of MC modulation, depicted in Fig. 1.3, is to convert a high rate data stream into $N_c$low-rate substreams, where N_c is the number of subcarriers used for data transmission. Each substream is modulated on its assigned subcarrier $f_n, n = 1, \dots, N_c$. Thus, the available channel bandwidth is subdivided into N_c narrow subbands, which ideally appear frequency non-selective. The data symbol rate per subcarrier is reduced by a factor N_c and with that, the ISI is reduced. A common realization of MC communications is conventional frequency division multiplexing where the subbands are completely separated in the frequency domain. However, due to finite steepness of the filter roll-offs, the subchannel spacing has to be greater than the Nyquist bandwidth to avoid inter-subchannel interference (ICI). This inefficient use of the available spectrum can be overcome by permitting spectral overlap between adjacent subchannels [Cha66, Sal67]. ICI can be avoided by guaranteeing orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s, known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbols of duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate 1 = T_s. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B. Kaiser-1998 at 5-6. 3.1.1 Orthogonal Frequency Division Multiplexing

	The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{S_n\}$ consisting of N_c complex-valued source symbols $S_n, n = 1, \dots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $S_n, n = 1, \dots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{S_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{S_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{S_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to

$$\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$$

According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of

$$F_s = \frac{1}{T_s}. \quad (3.2)$$

to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $S_n, n = 1, \ldots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form

$$x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} S_n \ \mathrm{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$$

Kaiser-1998 at 31-32.

The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be transmitted over the radio channel is taken from the complex data symbol alphabet

$$\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \ldots, \underline{v}_{d,M_d}\} \quad (3.24)$$

of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data

symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

$$\underline{c}^{(k)} = \left(\underline{C}_1^{(k)}, \underline{C}_2^{(k)}, \dots, \underline{C}_L^{(k)}\right)^{\mathrm{T}} \tag{3.25}$$

of the kth user. The chips $\underline{C}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet

$$\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \tag{3.26}$$

of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is

$$\frac{1}{T_c} = \frac{L}{T_d} \tag{3.27}$$

and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector

$$\underline{s}^{(k)} = \underline{d}^{(k)}\underline{c}^{(k)} = \left(\underline{S}_1^{(k)}, \underline{S}_2^{(k)}, \dots, \underline{S}_L^{(k)}\right)^{\mathrm{T}}. \tag{3.28}$$

The rate of the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{S}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is

$$T_s' = T_g + N_c T_c. \tag{3.29}$$

The transmission of one data symbol per user per OFDM symbol requires

$$N_c = L \tag{3.30}$$

subcarriers. In this case, the OFDM symbol duration including the guard interval is

$$T_s' = T_g + T_d. \tag{3.31}$$

Kaiser-1998 at 39-40.

M-Modification: The intention of the *M*-Modification is to increase the number of subcarriers while maintaining constant the spreading code length and the maximum number of active users. Consequently, the OFDM symbol duration increases and the loss in bandwidth efficiency due to the guard interval decreases. Moreover, the tighter subcarrier spacing enables one to guarantee flat fading per subchannel in propagation scenarios with decreased coherence bandwidth. With the *M*-Modification, each user transmits simultaneously M greater than 1 data symbols per OFDM symbol. The total number of subcarriers of the modified MC-CDMA system is

$$N_c = ML. \tag{3.34}$$

Each user exploits the total of N_c subcarriers for data transmission. The OFDM symbol duration including the guard interval increases to

$$T_s' = T_g + MLT_c, \tag{3.35}$$

where it can be observed that the loss in bandwidth efficiency due to the guard interval decreases with increasing M. The maximum number of active users is still defined according to (3.32). The assigned MC-CDMA transmitter is shown in Fig. 3.8. The data symbol index $m, m = 1, \ldots, M$, is introduced in Fig. 3.8 to distinguish the M simultaneously transmitted data symbols $\underline{d}_m^{(k)}, m = 1, \ldots, M$, of the kth user. The number M is upper limited by the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), since the symbol duration T_s', which increases with increasing M, has to be smaller

	than $(\Delta t)_c$ to guarantee that the channel is time-invariant during one OFDM symbol duration. To optimally exploit frequency diversity, the components of the sequences $\underline{s}_m, m = 1, \ldots, M$, transmitted in the same OFDM symbol are interleaved over the frequency. Subcarriers used for the transmission of $\underline{s}_m$ should have a spacing greater than the coherence bandwidth of the channel. Thus, the components of one sequence $\underline{s}_m$ are affected independently, reducing the probability that $\underline{s}_m$ is completely located in a deep fade. The interleaving is carried out prior to OFDM. The frequency interleaver can be a block interleaver which guarantees the maximum frequency separation between the components of $\underline{s}_m$. However, due to a possible periodicity of the fading process in frequency, the block interleaver can fail if the periodicity is similar to the frequency separation between adjacent components. This effect can be reduced if a pseudo-random frequency interleaver is used. Kaiser-1998 at 41-42. The OFDM symbol duration including the guard interval is $$T_s' = T_g + QLT_c. \quad (3.40)$$ Kaiser-1998 at 44. *M*&*Q*-Modification: The *M*&*Q*-Modification is a combination of the *M*- and the *Q*-Modification, resulting in an MC-CDMA system with adjustable number of subcarriers and receiver complexity, keeping constant the maximum number of active users. The transmission of *M* data symbols per user and, additionally, the splitting of the users in Q independent user groups according to the *M*&*Q*-Modification is illustrated in Fig. 3.10. The total number of subcarriers used by the MC-CDMA system with *M*&*Q*-Modification is $$N_c = QML, \quad (3.41)$$

	where each user only exploits a subset of $M\,L$ subcarriers for data transmission due to the FDMA component introduced by the Q-Modification. The maximum number of active users is given by (3.38). The total OFDM symbol duration including the guard interval results with the $M\&Q$-Modification in $$T_s' = T_g + QMLT_c. \quad (3.42)$$ Kaiser-1998 at 44. R1-021246, which discloses: The sub-carrier spacing should be large enough to provide robustness against frequency offset and phase noise, but it also has to be small enough such that each sub-carrier experiences flat fading. Normally, the tone (or sub-carrier) spacing can be selected by first fixing a maximum delay spread from all possible channel conditions, calculating the coherence bandwidth and then using it as an upper bound for the sub-carrier spacing. From [3], the Pedestrian A, Pedestrian B, and Vehicular A channel model, have maximum delay spread at 410ns, 3.7usec and 2.5usec, respectively. We suggest that a maximum delay spread of 10 usec be considered for the design of the OFDM system. The 10-usec suggestion takes into account only the cyclic prefix, some extra guard time should be added to allow some ramp-up and ramp-down period for the power amplifier. Time domain filtering maybe necessary to avoid the spurious effect due to the possible sudden transition between the consecutive OFDM symbols. In order to reduce the out of band emissions effectively, a raise cosine window with roll-off factor equal to one should be allowed. Note that it is observed that in a simulcast environment, the signal coming from the other cell is most likely the dominant multi-path which has longer delay than the non-simulcast signal. Therefore, larger delay spread should be considered if multicast and simulcast services are of interest. Table 2 shows some parameters for coherence bandwidth based on various definitions stated in [2].

R1-021246 at 2.

FFT Size

From Table 1., assuming the nominal UE speed is less than 120 km/hr, we can choose the OFDM symbol duration up to 805.5 usec as long as it does not violate the coherence bandwidth dictated by Table 2. To keep the time domain overhead, i.e. the cyclic prefix and guard time, small, it is desirable to limit the amount of time overhead to be less than 10% of the time domain symbol duration. Table 3. summarized the number of sub-carried allowed under 5, 10, and 15% time domain overhead (T_g) assumptions, and the number of FFT points required to implement it. Note that T_u is the useful/signal part of the symbol, and T_g is the guard time. The number sub-carriers can be supported in a 5MHz bandwidth is given by $\lfloor 5MHz/T_u \rfloor$, where the numbers are rounded to the nearest integers from below.

R1-021246 at 2.

No. Sym/TS	OFDM Symbol period (T_u+T_g)	No of tones w/ 5% time overhead	No. of FFT points	No of tones w/ 10% time overhead	No. of FFT points	No of tones w/ 15% time overhead	No. of FFT points
1	667 usec	3166	4096	3000	4096	2833	4096
2	333 usec	1583	2048	1500	2048	1416	2048
3	222 usec	1055	2048	1000	1024	944	1024
4	167 usec	791	1024	750	1024	708	1024
5	133 usec	644	1024	600	1024	566	1024

6	111 usec	527	1024	500	512	472	512
7	95.2 usec	452	512	428	512	404	512
8	83.3 usec	395	512	375	512	354	512
9	74.1 usec	351	512	333	512	314	512
10	66.7 usec	316	512	300	512	283	512
11	60.6 usec	287	512	272	512	257	512
12	55.6 usec	263	512	250	256	236	256
13	51.3 usec	243	256	230	256	217	256
14	47.6 usec	226	256	214	256	202	256
15	44.4 usec	211	256	200	256	188	256
16	41.7 usec	197	256	187	256	177	256

Table 3. Number of Symbols per Time slot vs. Number of possible sub-carriers over 5MHz bandwidth vs. Number of FFT points needed

R1-021246 at Table 3.

> It can be seen that with less than 10% time overhead, the most efficient choices of the FFT operations are 1024, 512, and 256 at 3, 6, and 12 symbols per time slot. To guarantee the highest data rate, all 1024, 512 or 256 sub-carriers should be used to transmit. The smaller the number of sub-carriers is, the wider the subcarrier spacing becomes which leads to robustness against frequency offset and phase noise.

R1-021246 at 3.

> Based on the above discussion, we would like propose a baseline system with multiple configurations suitable for different channel conditions. Some benefit of having multiple configurations are:
>
> > (1) To allow shorter symbol durations when the multipath is less severe, this would result in wider subcarrier spacing which would make the system more immune to frequency offset
> >
> > (2) To use shorter symbol duration which makes the system less susceptible to high Doppler and hence reduces the ICI
> >
> > (3) To use smaller size FFT which lowers the power consumption and the UE complexity.

	These multiple configurations have the same sampling frequency, which will simplify the receiver implementation while allowing UE to switch smoothly to different configurations supported by the Node Bs in different multipath environments. R1-021246 at 3-5. Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a 1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system's resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations. R1-021246 at 5.

System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

R1-021246 at Table 4.

> We have suggested an OFDM system with multiple configurations that can be deployed in different environments. The system is designed to fit into the current UMTS time slot structure. If agreed upon, the system will be used as a baseline for future OFDM study.

R1-021246 at 7.

Böhnke-501, which discloses:

> According to the present invention, a number of subcarriers of an OFDM/TDMA-system is allocated to each GSM-frequency channel so that a multiple of one resulting OFDM/TDMA-timeslot matches with one or a multiple of one GSM-timeslot. The spacing between two adjacent GSM-frequency channels is 200 kHz, and the length of a GSM-timeslot is 15/26 ms. According to the present invention, one GSM-frequency channel is

	divided into a number of subcarriers. The number of subcarriers is chosen, so that a multiple of one resulting OFDM/TDMA-timeslot fits well in one or a multiple of one GSM-timeslot. The transformation of one subcarrier from the frequency domain into the time domain results in an OFDM/TDMA-time burst, which builds the largest part of the resulting OFDM/TDMA-timeslot. In FIG. 7, the basic structure of an OFDM/TDMA-timeslot is shown as containing an OFDM/TDMA-time burst, whereby the length of the OFDM/TDMA-timeburst T_{OFDM} corresponds to the effective Modulation Period and depends on the subcarrier-spacing (1/subcarrier-spacing). The subcarrier spacing depends on the number of subcarriers allocated to one GSM-frequency channel of 200 kHz. A guard time TG (or pre-guard time) is disposed in advance of the OFDM/TDMA-time burst T_{OFDM}. In FIG. 8, the detailed structure of an OFDM/TDMA-timeslot is shown. The length of the OFDM/TDMA-timeslot corresponds to the modulation period and has a length of a μs. After the transformation of the subcarriers into the time domain, whereby the OFDM/TDMA-timebursts are produced, a guard time consisting of the pre-guard time of length c μs and a post-guard time is of length e μs is added to the OFDM-TDMA-timebursts. The OFDM/TDMA-timebursts correspond to the effective modulation period and have a length b μs. Then, before transmitting, the ramp of the time domain signal is shaped according to a raised cosine function, as shown in FIG. 8, to reduce spurious emissions. As can be seen In FIG. 8, the ramp time in the front part and the back part of the OFDM/TDMA-timeslot, respectively, has a length d μs and overlaps partially with the pre-guard time and the post-guard time, respectively. The length of the post-guard time can be o μs. At the beginning of the OFDM/TDMA-timeslot there is located a pre-idle time in advance of the ramp time and at the end of the OFDM/TDMA-timeslot there is located a post-idle time behind the ramp time. The length of each of the pre-idle time and the post-idle time is f μs. Therefore, the resulting OFDM/TDMA-timeslot is composed of the OFDM/TDMA-timeburst (effective modulation period), the guard time consisting of the pre-guard time and the

	post-guard time, the ramp times and the pre-idle time and the post-idle time. The length b of the OFDM/TDMA-timeburst depends on the subcarrier spacing (b=1/f_{SCS}), where f_{SCS} is the subcarrier in Hz. According to the present invention, the length a of one OFDM/TDMA-timeslot can for example correspond to 1, ½, ⅓ or ¼ GSM-timeslot. Böhnke-501 at 4:14-67. In a 1st embodiment, the total number of subcarriers is 48, whereby one or more subcarriers on the borders can be left unmodulated to reduce interference to adjacent frequency slots. The resulting subcarrier spacing is 200 kHz/48=4.166 Hz, which leads to an OFDM/TDMA-time burst T_{OFDM} of 48/200 kHz=240 µs. The symbol duration (240 µs) is therefore very long compared to the GSM-symbol duration (range of µs), which has the advantage of avoiding inter-symbol interference due to the radio channel delay profile. The guard time (pre-guard time and post-guard time) in the first embodiment is set to 30 µs, whereby it has to be noted that the guard time has to be set according to the expected channel delay profile (multipath environment). The ramp time is set to 10 to 20 µs, so that the total OFDM/TDMA-timeslot T_s has a length of 280 to 290 µs. This fits very well into ½ of the basic GSM-timeslot of 576 923 µs. Therefore, in the 1st embodiment, two OFDM/TDMA-timeslots are mapped into one GSM-timeslot with an adaptation time guard, if necessary. The basic clock is 240 µs/64=3.75 µs. The guard time (pre- and post guard time) can be set to 30 µs (pre-guard: 22.5 µs=6 samples, post-guard: 7.5 µs=2 samples) and the ramp time can be set to 15.0 µs (=4 samples) which leads to a total symbol time of (250 µs/64)*(64+6+2+4)=285 µs. Böhnke-501 at 6:7-31. In the 2nd embodiment, the total number of subcarriers is chosen to be 32, wherein one or more subcarriers at the borders can be left unmodulated to

	reduce interference to adjacent frequency slots. The subcarrier spacing is 200 kHz/32=6.25 kHz, which leads to an OFDM/TDMA-burst of 1/6.25 kHz=160 µs. The guard time (pre- and post guard time) can be set to 20 µs and the ramp time can be set to 10.0 µs, which leads to a total OFDM/TDMA-timeslot of 190 µs. 3 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. In other words, one OFDM/TDMA-timeslot T_s is mapped into ⅓ of a GSM-timeslot. The basic clock is set to 160 µs/32=5 µs. To be more precise, the guard time (pre- and post guard time) can be set to 20 µs (pre-guard: 15.0 µs=3 samples, post-guard: 5 µs=1 sample) and the ramp time can be set to 10.0 µs (=2 samples) which leads to a total symbol time of (160 µs/32)*(32+3+1+2)=190 µs. Böhnke-501 at 6:48-65. In the 3rd embodiment, the total number of subcarriers is chosen to be 24, wherein one or more subcarriers at the borders can be left unmodulated to reduce interference to adjacent frequency slots. The subcarrier spacing is 200 kHz/24=8.33 kHz, which leads to an OFDM/TDMA-burst of 1/8.33 kHz=120 µs. The guard time (pre- and post guard time) can be set to 15 µs and the ramp time can be set to 9 µs, which leads to a total OFDM/TDMA-timeslot of 144 µs. 4 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. The scheme according to the 3rd embodiment is very advantageous for fast varying channel environments. In other words, one OFDM/TDMA-timeslot T_s is mapped into ¼ of one GSM-timeslot. The basic clock is set to 120 µs/32=3.75 µs. to be more precise, the guard time (pre- and post guard time) can be set to 15 µs (pre-guard: 11.25 µs=3 samples, post-guard: 3.75 µs=1 sample) and the ramp time can be set to 7.5 µs (=2 samples) which leads to a total symbol time of (120 µs/32)*(32+3+1+2)=142.5 µs.

	Böhnke-501 at 7:9-27. In the 4th embodiment, the total number of subcarriers is chosen to be 104, wherein one or more subcarriers at the borders can be left unmodulated to reduce interference to adjacent frequency slots. The subcarrier spacing is 200 kHz/104=1.923 kHz, which leads to an OFDM/TDMA-burst of 1/1.923 kHz=520 µs. The guard time (pre- and post guard time) can be set to 25 µs and the ramp time can be set to 15 µs, which leads to a total OFDM/TDMA-timeslot of 560 µs. One OFDM/TDMA-timeslot is mapped into one GSM timeslot with an adaptation guard of 17 µs. The basic clock is set to 520 µs/128=4.0625 µs. To be more precise, the guard time (pre- and post guard time) can be set to 28.4375 µs (pre-guard: 20.3125 µs=5 samples, post-guard: 8.125 µs=2 sample) and the ramp time can be set to 12.1875 µs (=3 samples) which leads to a total symbol time of (520 µs/128)*(128+5+2+3)=560 625 µs. Böhnke-501 at 7:39-54. Dolle-010, which discloses: The subcarrier spacings of the OFDM system can be identical in the first transmission frequency band and the second transmission frequency band. The subcarrier spacings of the OFDM system in the first transmission frequency band and the second transmission frequency band alternatively can satisfy the following equation: $\Delta F_1/\Delta F_2 = k * 2^i$, wherein ΔF_1 and ΔF_2 are the subcarrier spacings used in the OFDM systems in the first transmission frequency band and the second transmission frequency band, respectively, and k is a positive integer value and i is a negative or positive integer value including zero.

This selection allows an effective implementation of the baseband block to process the OFDM signals and/or symbols.

Dolle-010 at 3:25-41.

As has been already been set forth above, the advantage of the transceiver 10 as shown in FIG. 1 is that the transmission frequency f_{C1} operates at the same time as the intermediate frequency 4 f_{C2}This allows the system to operate in two different frequency ranges with different propagation properties and thus fulfills a wide range of application requirements. In addition the structure allows interoperability between different systems (system 1 and system 2, for example), which are not only distinguished by its different transmission frequencies but also by its different channel bandwidth. To achieve the interoperability, the air interface channel of the system 1 has to be mapped properly to the air interface channel structure of the system 2.

According to the present invention, a channel mapping solution particularly for an OFDM system is provided. Thereby a solution is proposed for an OFDM system trans mitting a dual frequency band and providing interoperability with a coexisting OFDM system. The following system parameters thereby are taken into account:

total number of subcarriers: N_1, N_2

channel bandwidth: B_{C1}, B_{C2}, and

subcarrier spacings: ΔF_1, ΔF_2

Between the above parameters the following relation exists:

$$\Delta F = \frac{B_C}{N}$$

According to the present invention ΔF_1 can be equal to ΔF_2, which means the same subcarrier spacing in both frequency ranges and/or systems is used. Therefore

	$\frac{B_{C1}}{N_1} = \frac{B_{C2}}{N_2}$ or $B_{C1} \times N_2 = B_{C2} \times N_1$. The above equations can be rewritten $B_{C1} \times n = B_{C2} \times m$ and $N_1 \times n = N_2 \times m$, wherein the ratio n/m satisfies the following equation: $n/m = k \times 2_{\mathrm{i}}$, wherein k is a positive integer value and i is a negative or positive integer value including zero. The above selection of the ratios n/m is particularly advantageous for the effective implementation of the FFT algorithm generating the OFDM symbols. In FIG. 3 the two OFDM systems channel mapping is depicted. In the example shown in FIG. 3 n = 8 and m = 1, which means ideally 8 channels of the OFDM system (system 1) operating in the lower frequency band can be mapped to one channel of the OFDM system (system 2) operating in the dual frequency bands. Depending on the required guard band ($F_{\mathrm{guard\ 2}}$) between the channels in the upper frequency band the actual mapping of the system 1 channels could be limited to channel 2 through channel 7. The same subcarrier spacings are kept for both systems and/or frequency bands, thereby giving the highest efficiency of interoperability. In general the ratio of $\Delta F_1/\Delta F_2$ is selected to satisfy the following equation: $\frac{\Delta F_1}{\Delta F_2} = k \times 2^i$, wherein k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implement of the base-band block to process the OFDM signals and/or symbols. Dolle-010 at 5:28-6:56.

Exhibit G-19

Invalidity of U.S. Patent No. 11,381,285 in View of Motorola StarTAC 7868 ("StarTAC")

Samsung v. GenghisComm
IPR2025-00792, 11,381,285
GC EX2024