

Exhibit D-20

Invalidity of U.S. Patent No. 11,075,786 in View of Motorola StarTAC 7868 (“StarTAC”)

The asserted claims of U.S. Patent No. 11,075,786 (“the ’786 patent”) are obvious over Motorola StarTAC 7868 (including StarTAC 7868w) in view of the knowledge of the person of ordinary skill in the art and one or more of the following references: “A Low Complexity Transmitter Structure for OFDM-FDMA Uplink Systems” (“Galda-2002”), “On the Duality of Multi-Carrier Spread Spectrum and Single-Carrier Transmission” to Brüninghaus et al. (“Brüninghaus-1997”), “Multi-Carrier CDMA Mobile Radio Systems - Analysis and Optimization of Detection, Decoding, and Channel Estimation” (“Kaiser-1998”), and “Multi-Carrier Spread Spectrum and Its Relationship to Single-Carrier Transmission” to Brüninghaus et al. (“Brüninghaus-1998”).

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).

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).

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-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).

The asserted claims and the alleged priority date of the ’786 patent are identified below:

’786 Patent Asserted Claims	Alleged Priority Date
10, 11, 15, 16, 17, 18	“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.

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Claim Language	Galda-2002 and Other References
[10PRE] An apparatus for communication in a wireless communication network that employs a first set of complex-valued codes to encode data symbols to be transmitted, and employs a second set of complex-valued codes to recover transmitted data symbols from a received signal, the apparatus comprising:	To the extent that the preamble is a limitation, StarTAC is an apparatus for communicating in a mobile radio network. <i>See, e.g.</i>, Motorola CDMA ST7868W Dual Band/Tri Mode, Service Manual Level III, pp. 15-17 (describing the “Transmitter Circuitry” used in the StarTAC). With respect to a wireless communication network that employs a first set of complex-valued codes to encode data symbols to be transmitted, and employs a second set of complex-valued codes to recover transmitted data symbols from a received signal,” StarTAC included a CDMA transmitter that used an earlier generation of wireless communication technology. As such it did not include using complex-valued codes in an OFDM system. 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, Galda-2002 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.

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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.

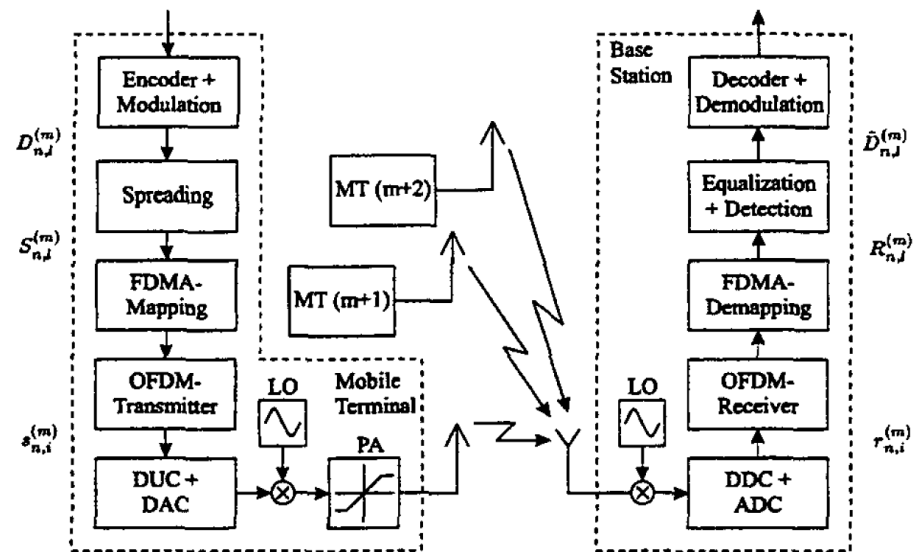
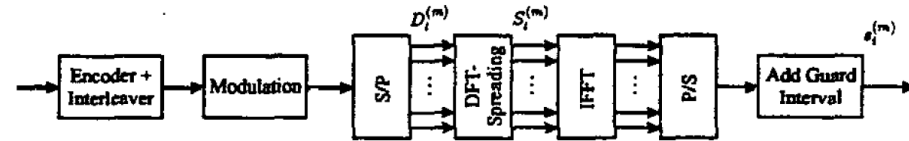


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

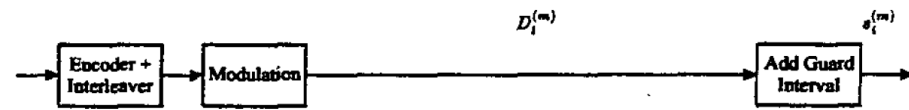
Galda-2002 at Fig. 1.

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(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.

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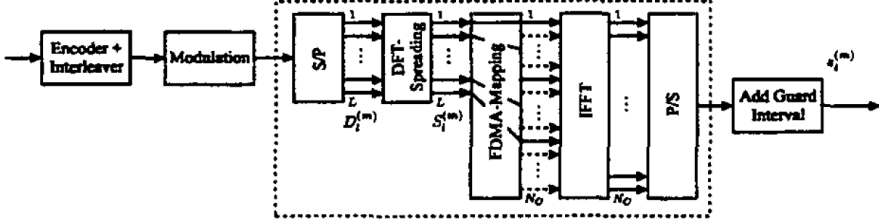
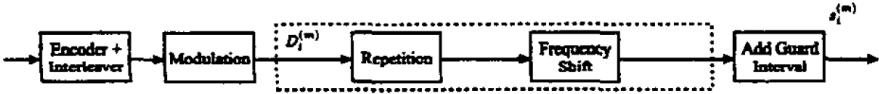
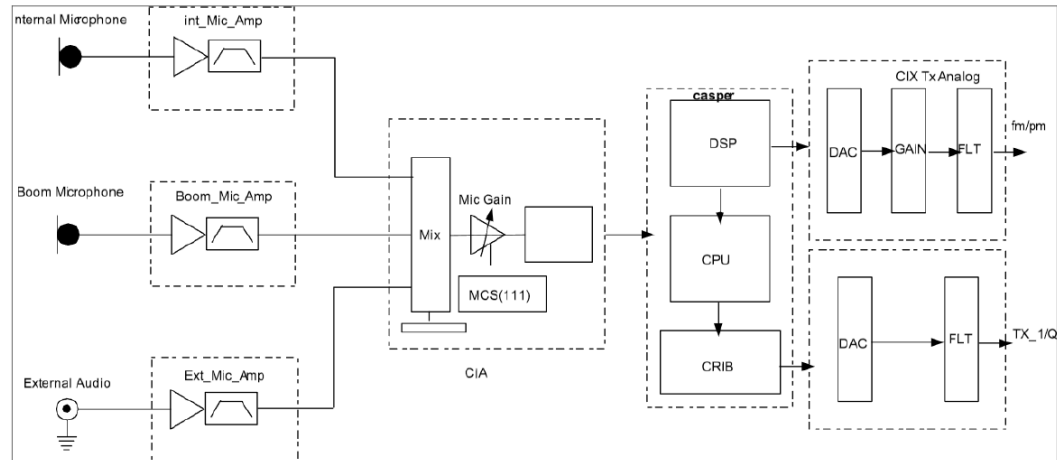
	 (a) OFDM-FDMA transmitter with DFT spreading over equidistant subcarriers  (b) Realistic but simplified OFDM transmitter structure Fig. 6. In an OFDM-FDMA uplink system including DFT spreading matrix applied to a set of equidistant subcarriers the DFT spreading matrix and the OFDM IFFT transformation cancel out each other. Galda-2002 at Fig. 6.
[10A] at least one processor; and	StarTAC included a processor. For example, StarTAC included a processor called "Casper."

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Id., p.19.

Additional prior art references also reveal the presence of a processor for wireless communications.

For example, Galda-2002 discloses or renders obvious (at least based on Plaintiff's apparent interpretation of the claims) a processor.

For example, Galda-2002 discloses:

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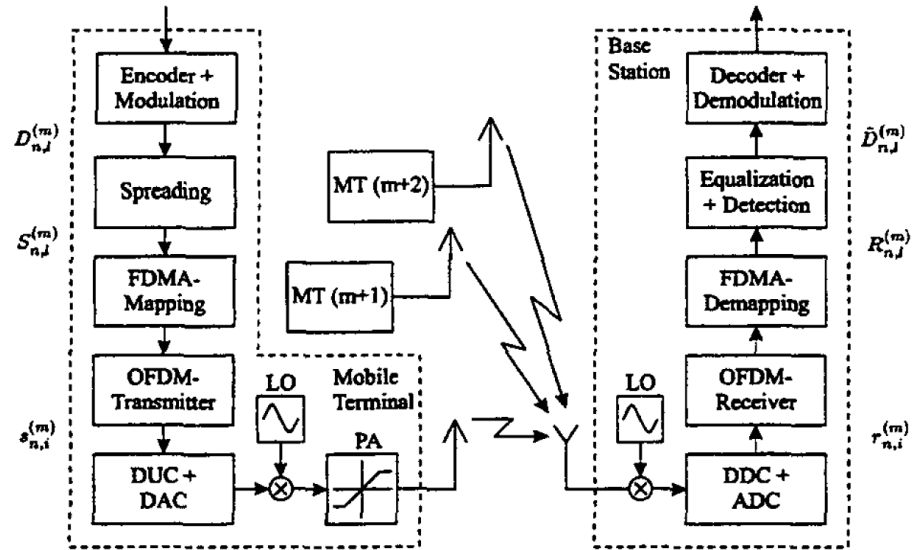
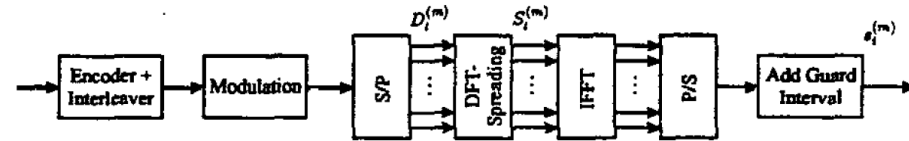


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

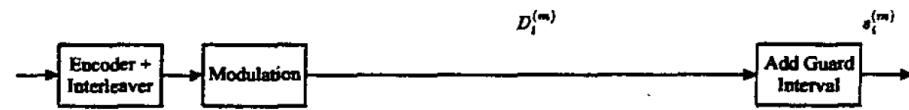
Galda-2002 at Fig. 1.

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(a) OFDM transmitter including DFT spreading over all subcarriers



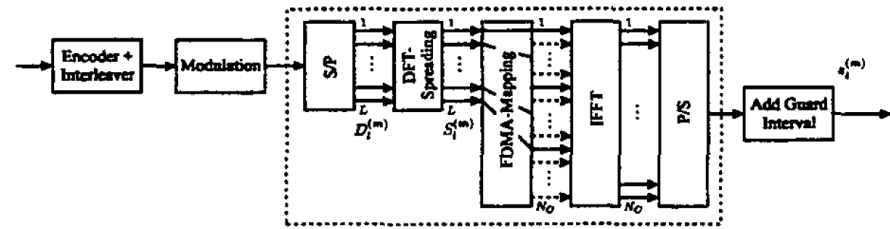
(b) Realistic but simplified OFDM transmitter structure

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.

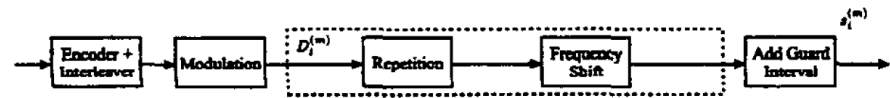
Galda-2002 at Fig. 4.

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(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.

[10B] 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. 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

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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, Galda-2002 discloses or renders obvious (at least based on Plaintiff's apparent interpretation of the claims) 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 example, Galda-2002 discloses:

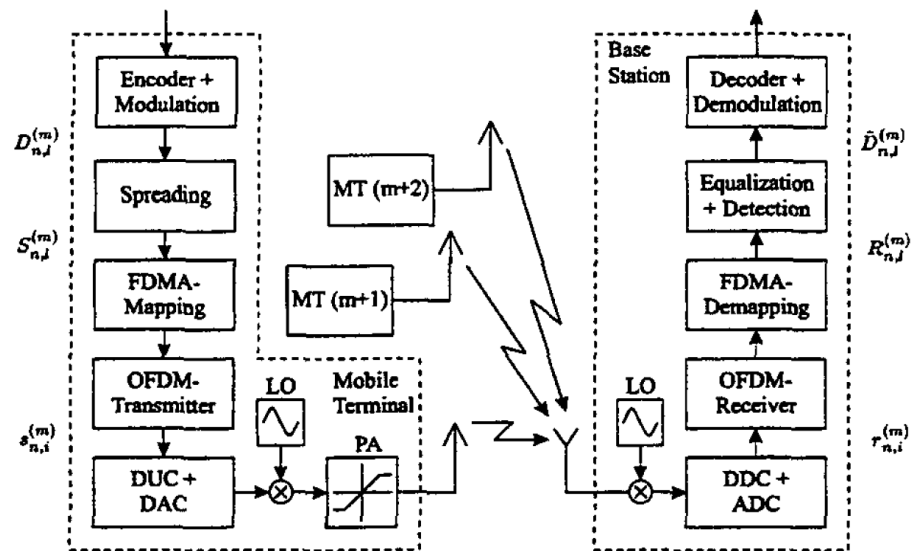
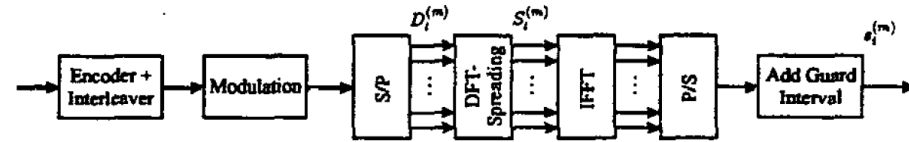


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

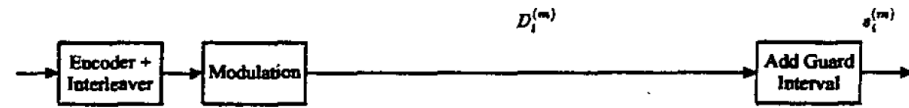
Galda-2002 at Fig. 1.

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(a) OFDM transmitter including DFT spreading over all subcarriers

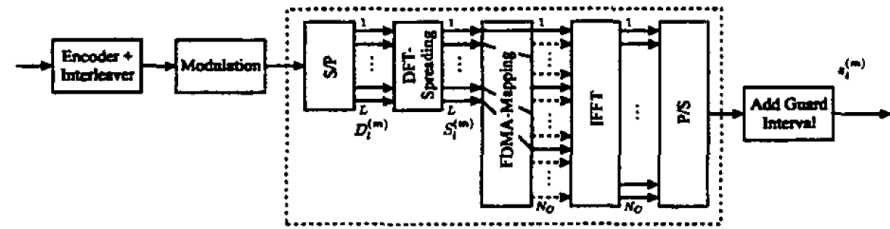


(b) Realistic but simplified OFDM transmitter structure

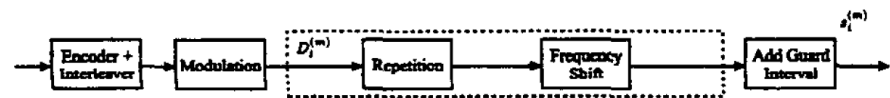
Fig. 4. In an OFDM system including a DFT spreading matrix and an IFFT for the OFDM modulation process both matrices cancel out each other.

Galda-2002 at Fig. 4.

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(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.

[10C] selecting a plurality of subcarriers to be transmitted;

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

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	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, Galda-2002 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
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	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 significantly [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
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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.

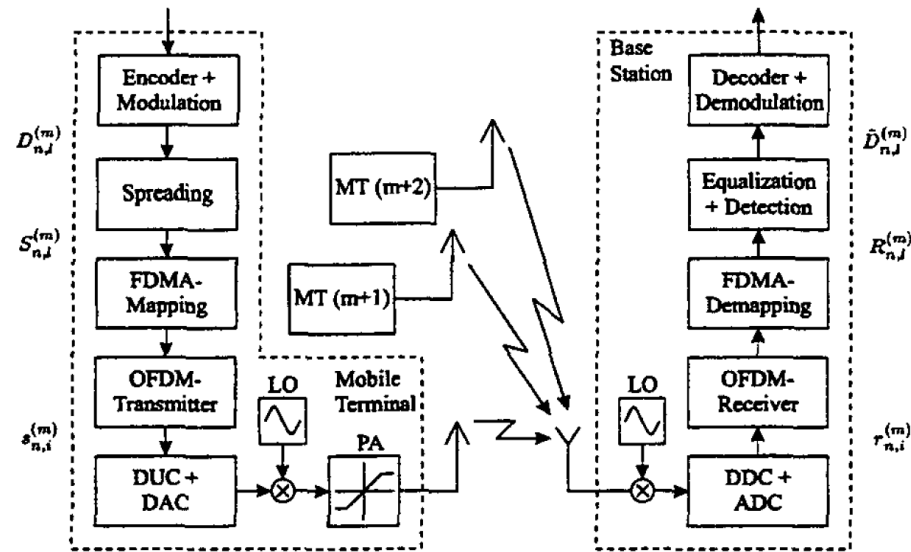


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

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

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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 $\tilde{C}_l = (C_{l,0}, C_{l,1}, \dots, C_{l,L})$ with $l = 0, \dots, L - 1$

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

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.

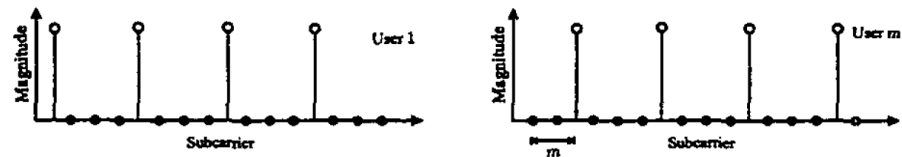


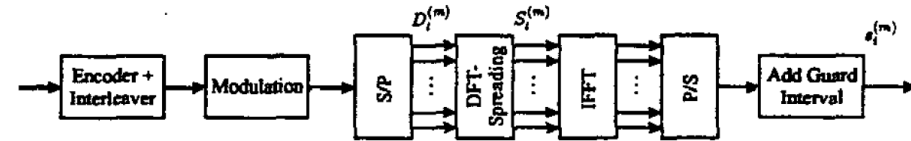
Fig. 2. User m allocates the equidistant subset of subcarriers shift by m subcarriers in the frequency domain

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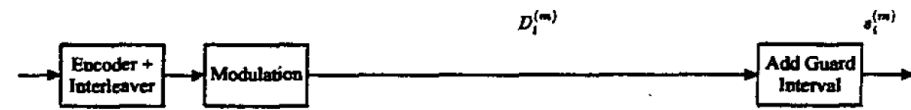
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	Galda-2002 at Fig. 2. If a spreading technique is employed including the user specific subcarriers and the spreading gain should be maximized then the selected subcarrier set should be more or less uncorrelated [4]. Therefore in this paper a subset is considered where the selected subcarrier are placed on equidistant subcarriers over the entire bandwidth, see Fig. 2. In this case the selected subcarrier set can be assumed to be mutually independent which leads to a maximum spreading gain, the subcarrier selection is exclusive for each user, which avoids any MAI, and the signalling overhead is minimized. Furthermore, it is assumed in the sequel that the set of equidistant subcarrier are shifted by m subcarrier in the frequency domain if the subset is assigned to user m. The proposed subcarrier selection and modulation process does not need any radio channel state information in this case. 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 $s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (3)$ where N_G denotes the length of the guard interval which is inserted into the transmit time signal. Galda-2002 at 1738.
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(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.

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 $S_i^{(m)}$ 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

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

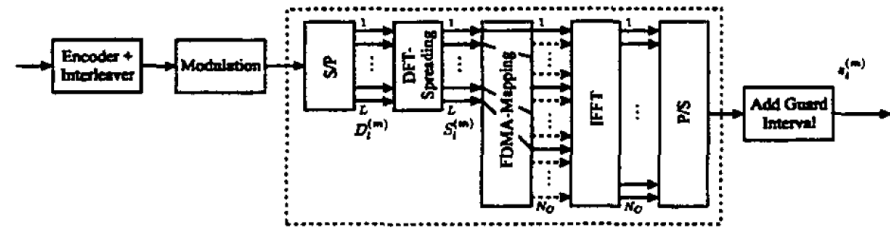
the transmit signal of user m can be written as

$$\begin{aligned} s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\ &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\ &= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \delta_L(\nu-i) \\ s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \end{aligned} \quad (7)$$

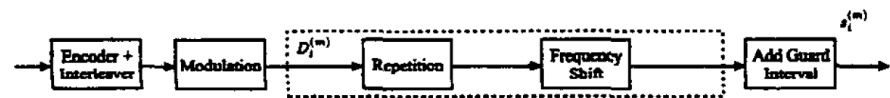
for $i = -N_G, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ 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.

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(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.

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	Galda-2002 at 1740. With the same argumentation the PAR can also be reduced for the OFDM-FDMA downlink even though not the same simple transmitter structure can be used. The PAR of the time signal is in this case determined by the number of users $M = N_C/L$ instead of the number of used subcarrier and will therefore in most cases be lower than for a conventional OFDM-FDMA system without additional spreading. Galda-2002 at 1740. For a sufficiently large number L of used subcarrier per user the time discrete OFDM signal $s_i^{(m)}$ of user m given in Equation (3) has an approximately Gaussian amplitude distribution due to the superposition of statistically independent modulation symbols $S_l^{(m)}$ on all used subcarriers. The maximum peak-to-average ratio (PAR), defined by $PAR = 10 \log_{10} \left(\frac{\max(s(t) ^2)}{\sigma_s^2} \right) [dB] \quad (8)$ where σ_s^2 denotes the average transmit power, occurs only if the identical modulation symbol S_l is transmitted on all used subcarriers. In this case the PAR is determined by the number of used subcarriers L. 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
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	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.
[10D] encoding the data symbols with the first set of complex-valued codes to produce encoded data symbols;	Galda-2002 discloses (at least based on Plaintiff’s apparent interpretation of the claims) instruction for encoding the data symbols with the first set of complex-valued codes to produce encoded data symbols. For example, Galda-2002 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

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	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
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	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 significantly [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.
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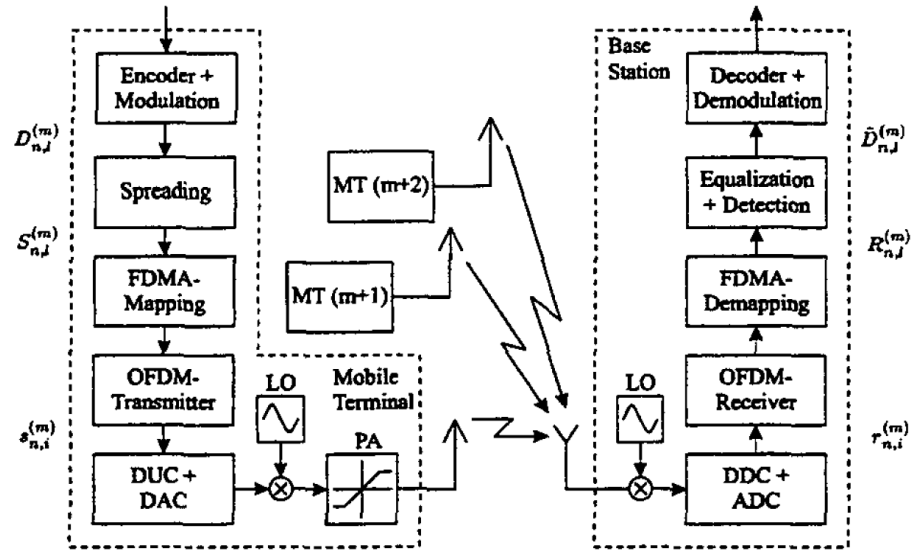


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

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

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	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 $\tilde{C}_l = (C_{l,0}, C_{l,1}, \dots, C_{l,L})$ with $l = 0, \dots, L - 1$ $S_l^{(m)} = \sum_{v=0}^{L-1} C_{l,v} D_v^{(m)} \quad \text{for } l = 0, \dots, L - 1 \quad (2)$ 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 $s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (3)$ where N_G denotes the length of the guard interval which is inserted into the transmit time signal. Galda-2002 at 1738. III. DFT SPREADING
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The spreading matrix $[C]$ of an OFDM-FDMA system is often only characterized by its frequency diversity properties. It therefore is chosen to be unitary in order to make the detection process easier, to distribute the signal energy of the superimposed code symbols uniformly over all subcarrier and not to change the distance of the code vectors. Thus, in many OFDM systems with additional spreading the Walsh-Hadamard (WH) matrix is employed since it has the additional advantage that it only consists of only “+1” and “-1” elements which can reduce the computational complexity. The discrete Fourier matrix is also unitary but additionally has an influence on the PAR of an OFDM transmit signal. In this Section the influence of such an Fourier sp[r]eading matrix on the resulting PAR will be discussed.

Galda-2002 at 1739.

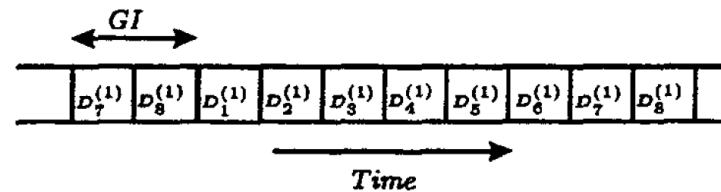


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

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

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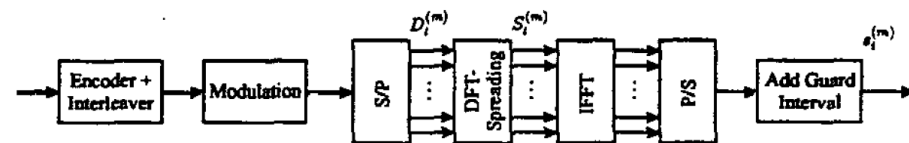
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modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore technically reduced to the serial sequence of complex transmit data symbols D_i to which a guard interval is added in the time domain as a cyclic prefix

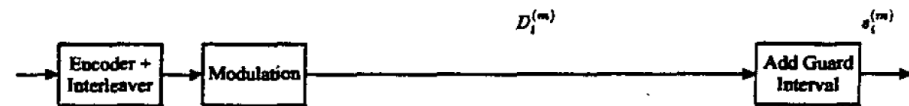
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$$

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-

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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.

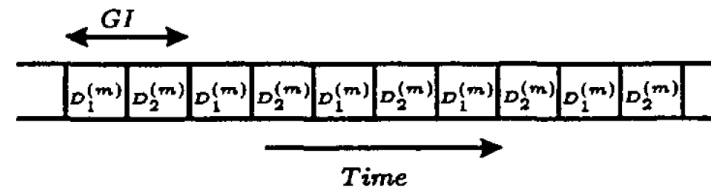


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

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

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

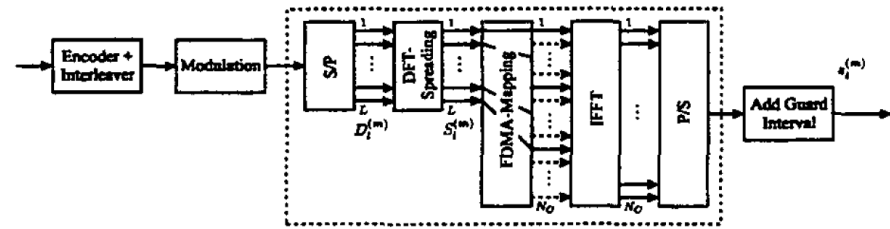
the transmit signal of user m can be written as

$$\begin{aligned} s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\ &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\ &= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \delta_L(\nu-i) \\ s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \end{aligned} \quad (7)$$

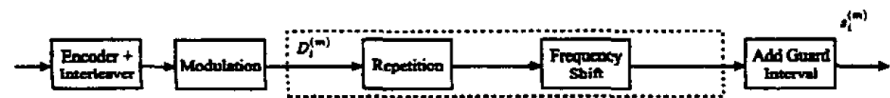
for $i = -N_G, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ 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.

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(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.

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	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
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	interesting alternative for reducing the complexity of the mobile terminal in the broadband radio uplink. Galda-2002 at 1741.
[10E] applying the encoded data symbols to the plurality of subcarriers to produce a spread-Orthogonal Frequency Division Multiplexing (OFDM) signal; 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, Galda-2002 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

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	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 broadband radio channel is characterized by its frequency selective fading due to multi-path propagation. In mobile communications applications the radio channel is additionally time-variant due to the movement of the mobile terminal. The orthogonal frequency division multiplexing (OFDM) transmission technique can cope with the effects of frequency selectivity and time variance with a low implementation and computation complexity. Inter symbol interferences (ISI) as well as inter carrier interferences (ICI) can be completely avoided by dividing the total system bandwidth into a large number of spectrally overlapping but mutually orthogonal non-frequency selective narrow-band subchannels and by introducing an additional guard interval into the OFDM symbol. Even at the output of a frequency-selective channel this orthogonality of the subcarriers can be maintained. The equalization of each subchannel is then reduced to a single complex multiplication per subchannel [1]. 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-
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	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 significantly [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.
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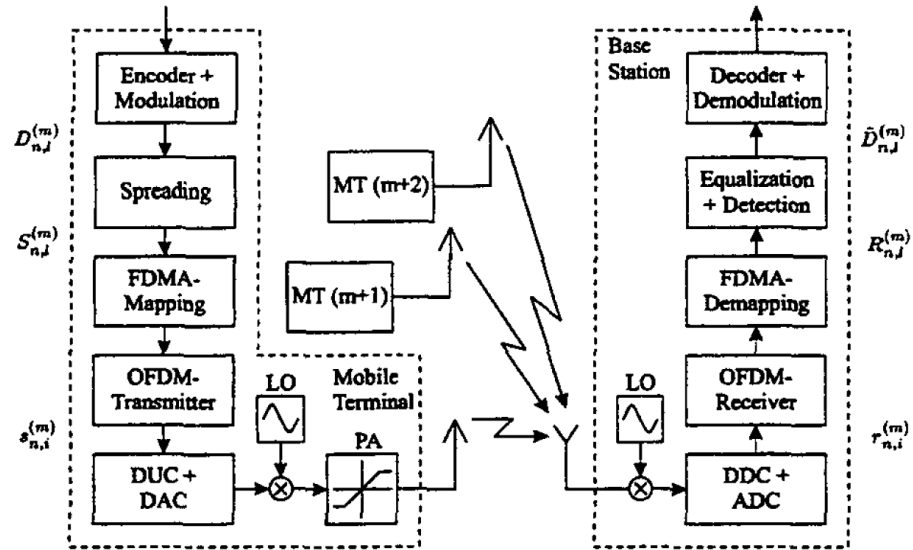


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

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

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	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 $\tilde{C}_l = (C_{l,0}, C_{l,1}, \dots, C_{l,L})$ with $l = 0, \dots, L - 1$ $S_l^{(m)} = \sum_{v=0}^{L-1} C_{l,v} D_v^{(m)} \quad \text{for } l = 0, \dots, L - 1 \quad (2)$ 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 $s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (3)$ where N_G denotes the length of the guard interval which is inserted into the transmit time signal. Galda-2002 at 1738. III. DFT SPREADING
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The spreading matrix $[C]$ of an OFDM-FDMA system is often only characterized by its frequency diversity properties. It therefore is chosen to be unitary in order to make the detection process easier, to distribute the signal energy of the superimposed code symbols uniformly over all subcarrier and not to change the distance of the code vectors. Thus, in many OFDM systems with additional spreading the Walsh-Hadamard (WH) matrix is employed since it has the additional advantage that it only consists of only “+1” and “-1” elements which can reduce the computational complexity. The discrete Fourier matrix is also unitary but additionally has an influence on the PAR of an OFDM transmit signal. In this Section the influence of such an Fourier sp[r]eading matrix on the resulting PAR will be discussed.

Galda-2002 at 1739.

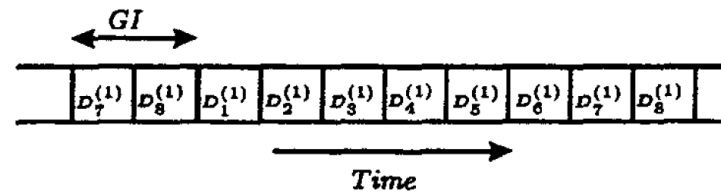


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

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

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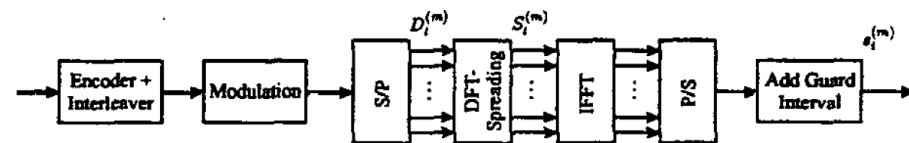
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modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore technically reduced to the serial sequence of complex transmit data symbols D_i to which a guard interval is added in the time domain as a cyclic prefix

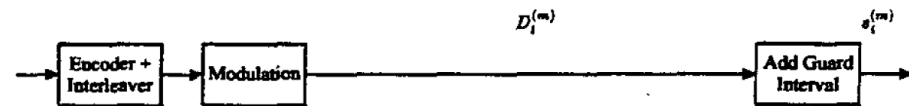
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$$

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-

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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.

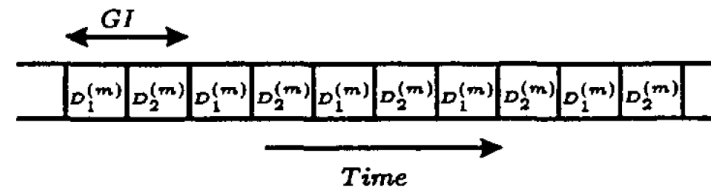


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

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

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

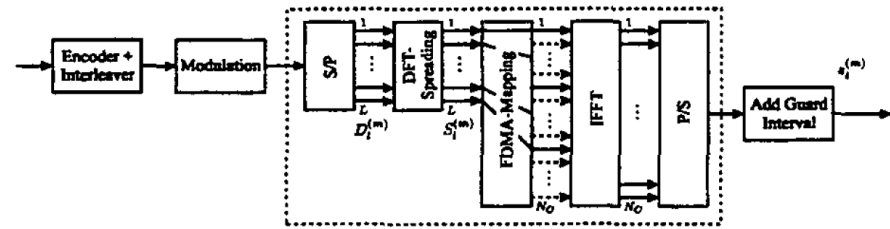
the transmit signal of user m can be written as

$$\begin{aligned} s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\ &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\ &= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \delta_L(\nu-i) \\ s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \end{aligned} \quad (7)$$

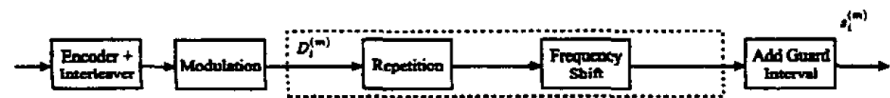
for $i = -N_G, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ 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.

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(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.

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	Galda-2002 at 1740. We consider an OFDM-FDMA system with $N_C = 512$ subcarriers and a guard interval of $N_G = 64$ shared between $M = 16$ users. The continuous-time transmit signal $s(t)$ is simulated by a discrete-time signal oversampled by a factor of $K = 8$ and bandlimited by a root-raised cosine Nyquist filter. The oversampled and filtered signal is then passed through a non-linear device modelled by a soft-limiter as it has been described in Section IV. The distorted signal $\tilde{s}(t)^{(m)}$ is then analyzed by measuring its power spectral density (PSD) and its clipping probability. Since only the transmit signal is analyzed in this paper no assumption about the channel have to be made. Galda-2002 at 1741. 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.
[10F] transmitting the spread-OFDM signal;	Galda-2002 discloses (at least based on Plaintiff’s apparent interpretation of the claims) instruction for transmitting the spread-OFDM signal. For example, Galda-2002 discloses:

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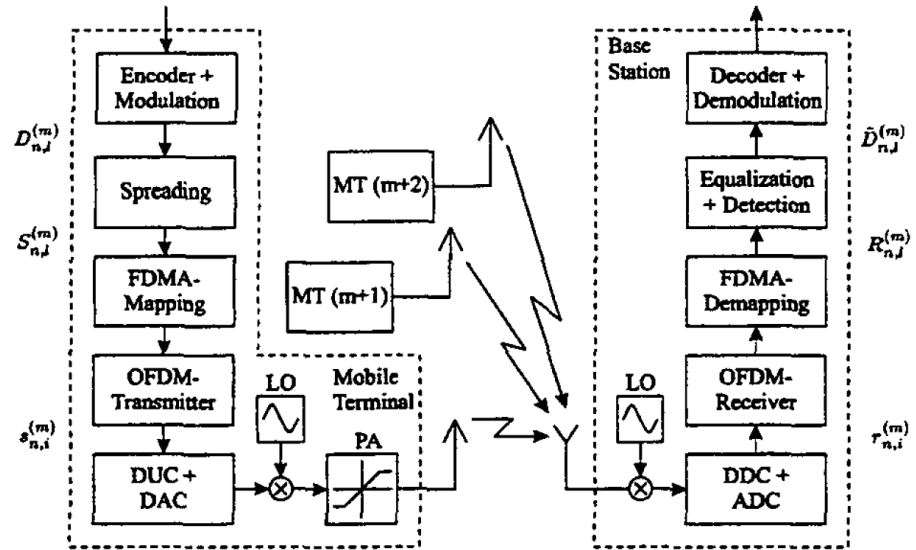
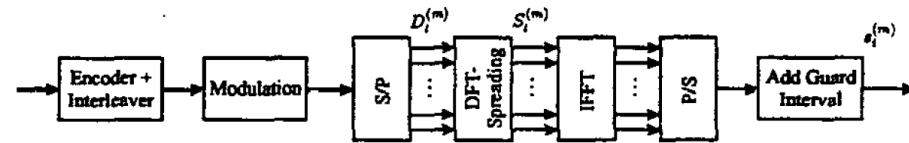


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

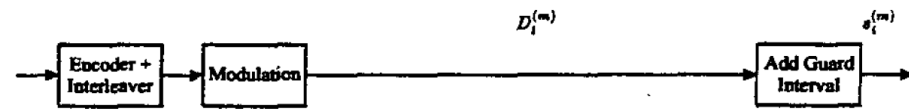
Galda-2002 at Fig. 1.

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(a) OFDM transmitter including DFT spreading over all subcarriers

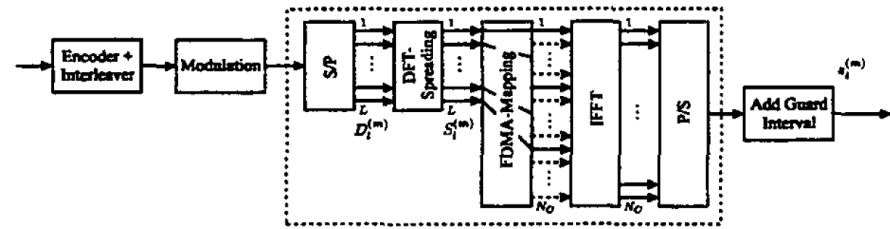


(b) Realistic but simplified OFDM transmitter structure

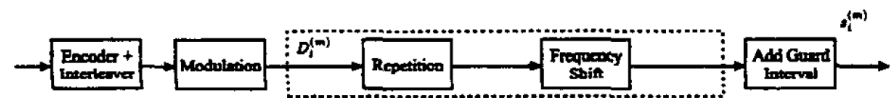
Fig. 4. In an OFDM system including a DFT spreading matrix and an IFFT for the OFDM modulation process both matrices cancel out each other.

Galda-2002 at Fig. 4.

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(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.

[10G] wherein the first set of complex-valued codes are complex conjugates of the second set of complex-valued codes.

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

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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, Galda-2002 discloses:

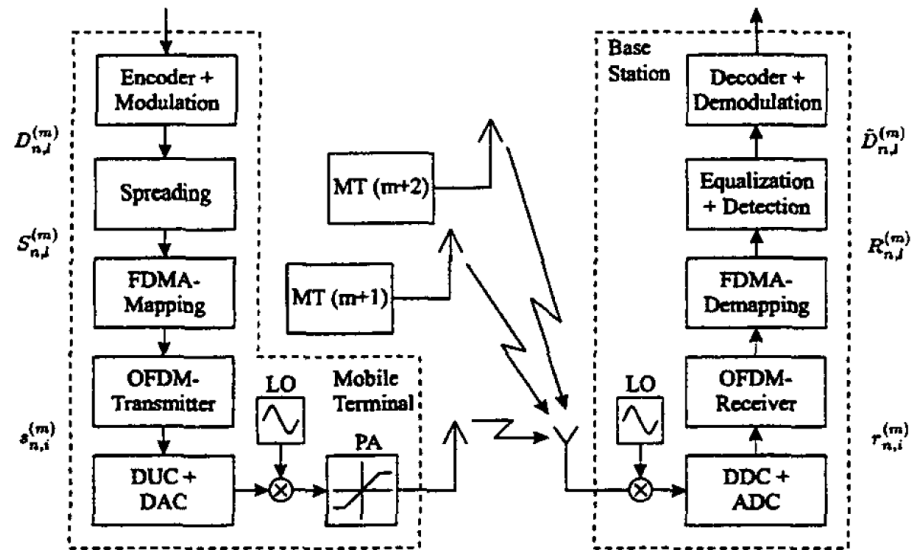


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

Galda-2002 at Fig. 1.

An estimate of data symbols $\tilde{D}_l^{(m)}$ can then be calculated independently for each user by applying any single- or multi-code detection techniques.

Galda-2002 at 1739.

III. DFT SPREADING

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	The spreading matrix $[C]$ of an OFDM-FDMA system is often only characterized by its frequency diversity properties. It therefore is chosen to be unitary in order to make the detection process easier, to distribute the signal energy of the superimposed code symbols uniformly over all subcarrier and not to change the distance of the code vectors. Thus, in many OFDM systems with additional spreading the Walsh-Hadamard (WH) matrix is employed since it has the additional advantage that it only consists of only “+1” and “-1” elements which can reduce the computational complexity. The discrete Fourier matrix is also unitary but additionally has an influence on the PAR of an OFDM transmit signal. In this Section the influence of such an Fourier spreading matrix on the resulting PAR will be discussed. Galda-2002 at 1739. To the extent that Galda-2002 does not disclose that the first set of complex-valued codes are complex conjugates of the second set of complex-valued codes, the first set of complex-valued codes being complex conjugates of the second set of complex-valued codes would have been obvious in view of Galda-2002, either alone or in combination with the knowledge of a POSA, and/or in combination with one or more of the following reference(s): Brüninghaus-1997, which discloses: 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.
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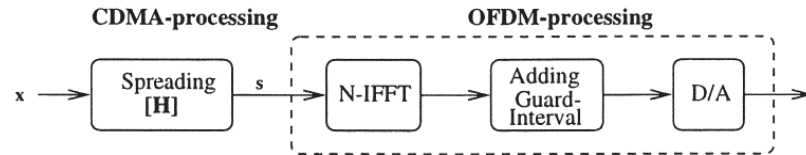


Figure 1: Block diagramm of a MC-CDMA transmitter (downlink)

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 , $1 \leq i \leq M$, 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

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

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. 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.

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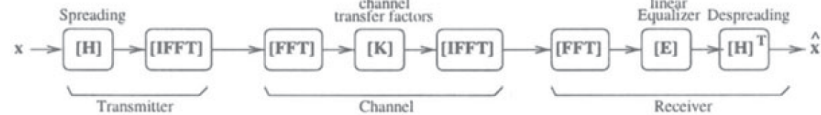


Figure 3: Model of a MC-CDMA transmission system with linear equalization

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.

Kaiser-1998, which discloses:

Any of the SD or MD data detection techniques presented for MC-CDMA systems in Section 3.3 can be applied for the detection of the data of a single user per subsystem in SS-MC-MA systems. However, SS-MC-MA systems offer especially in the downlink the advantage that with JD in one estimation step simultaneously L data symbols of a single user are estimated. Compared to MC-CDMA systems, the complexity of JD per data symbol in SS-MC-MA systems reduces by a factor of L in the downlink. With JD, LLRs can inherently be obtained from the detection algorithm which may also include the symbol demapping, cf. Chapter 4. After deinterleaving and decoding of the LLRs, the detected source bits of the k th user are obtained.

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Kaiser-1998 at 133.

... The symbol $(.)^*$ denotes the complex conjugation.

Kaiser-1998 at 17.

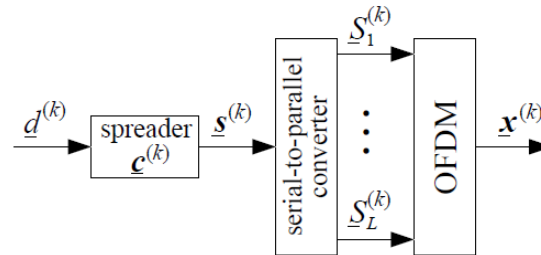


Figure 3.6: MC spread spectrum signal generation

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 k th 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

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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

$$\underline{c}^{(k)} = (\underline{c}_1^{(k)}, \underline{c}_2^{(k)}, \dots, \underline{c}_L^{(k)})^T \quad (3.25)$$

of the k th 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

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

Kaiser-1998 at 39-40.

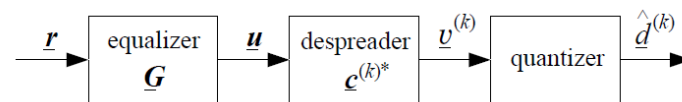


Figure 3.12: SD scheme

Kaiser-1998 at Fig. 3.12.

The diagonal equalizer matrix

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$$\underline{G} = \begin{pmatrix} \underline{G}_1 & 0 & \cdots & 0 \\ 0 & \underline{G}_2 & \cdots & 0 \\ \vdots & \ddots & \cdots & \vdots \\ 0 & 0 & \cdots & \underline{G}_L \end{pmatrix} \quad (3.55)$$

of dimension $L \times L$ represents the L complex-valued equalizer coefficients of the subcarriers where $\underline{s}$ was transmitted on. The complex-valued output $\underline{u}$ of the equalizer is despread by correlating it with the conjugate complex user specific spreading code $\underline{c}^{(k)*}$, cf. (3.25). The complex-valued soft decided value at the output of the despreader is

$$\underline{v}^{(k)} = \underline{c}^{(k)*} \underline{u}^T. \quad (3.56)$$

Kaiser-1998 at 49.

$\underline{c}^{(k)}$ MC-CDMA spreading code vector of the k th user

Kaiser-1998 at 138.

$(\cdot)^*$ complex conjugation

Kaiser-1998 at 143.

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 arbitrary spreading matrix are described and discussed.

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Brüninghaus-1998 at 2329.

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.

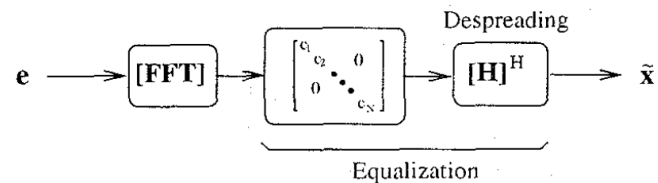


Fig. 4. Model of an OFDM-CDM receiver with linear equalization

Brüninghaus-1998 at 2330.

[Claim 11] The apparatus of claim 10, wherein selecting is responsive to spectrum allocation or is configured to provide 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. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation

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orthogonal frequency division multiple access.	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. Galda-2002 discloses or renders obvious the apparatus recited in claim 10, as set forth above with respect to claim 10. <i>See, e.g.</i>, claim elements 10PRE, 10A, 10B, 10C, 10D, 10E, 10F, 10G. Galda-2002 further discloses (at least based on Plaintiff’s apparent interpretation of the claims) that selecting is responsive to spectrum allocation or is configured to provide for orthogonal frequency division multiple access. For example, Galda-2002 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
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	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. Recently, the combination between the classical multiple access schemes "TDMA", "FDMA" and "CDMA" and the OFDM transmission technique have been intensively discussed [2]. For the synchronous downlink MC-CDMA or OFDM-CDMA can offer a good performance but due to the loss of orthogonality of the used codes in a frequency selective radio channel the receiver of a mobile terminal has to cope with MAI by single or multi user detection (SUD, MUD) scheme. The effect of MAI is even increased if OFDM-CDMA is used in the uplink due to the independent channels which affect the transmission of different mobile terminals. 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
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	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 significantly [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.
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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.

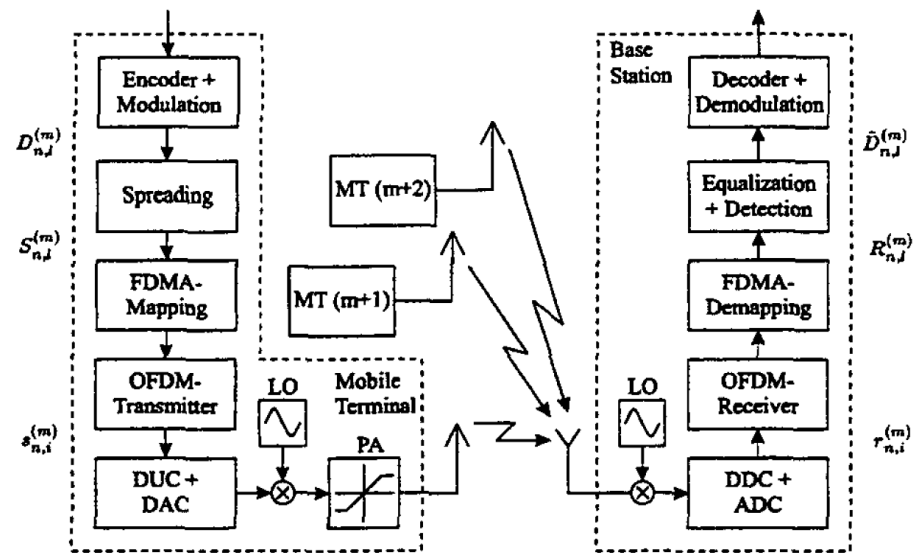


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

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	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 $\tilde{C}_l = (C_{l,0}, C_{l,1}, \dots, C_{l,l})$ with $l = 0, \dots, L - 1$ $S_l^{(m)} = \sum_{v=0}^{L-1} C_{l,v} D_v^{(m)} \quad \text{for } l = 0, \dots, L - 1 \quad (2)$ 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.
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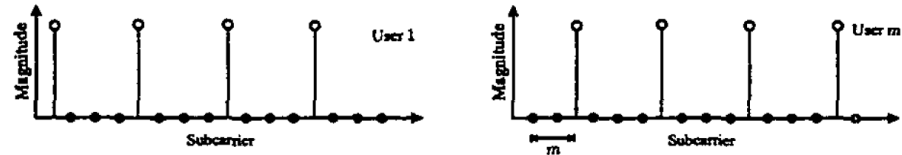


Fig. 2. User m allocates the equidistant subset of subcarriers shift by m subcarriers in the frequency domain

Galda-2002 at Fig. 2.

If a spreading technique is employed including the user specific subcarriers and the spreading gain should be maximized then the selected subcarrier set should be more or less uncorrelated [4]. Therefore in this paper a subset is considered where the selected subcarrier are placed on equidistant subcarriers over the entire bandwidth, see Fig. 2. In this case the selected subcarrier set can be assumed to be mutually independent which leads to a maximum spreading gain, the subcarrier selection is exclusive for each user, which avoids any MAI, and the signalling overhead is minimized. Furthermore, it is assumed in the sequel that the set of equidistant subcarrier are shifted by m subcarrier in the frequency domain if the subset is assigned to user m . The proposed subcarrier selection and modulation process does not need any radio channel state information in this case.

Galda-2002 at 1738.

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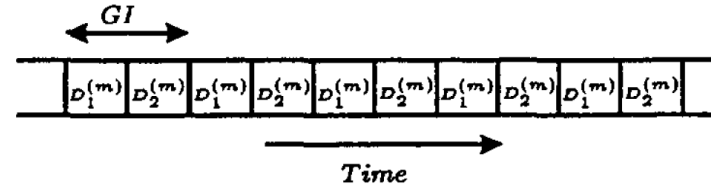


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8$, $M = 4$)

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

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

the transmit signal of user m can be written as

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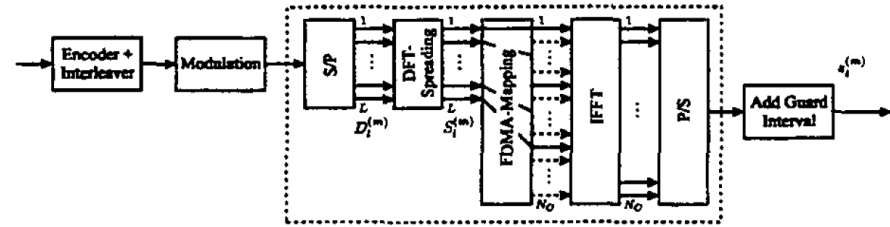
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$$\begin{aligned}
 s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L} \\
 &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\
 &= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu-i) \\
 s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \tag{7}
 \end{aligned}$$

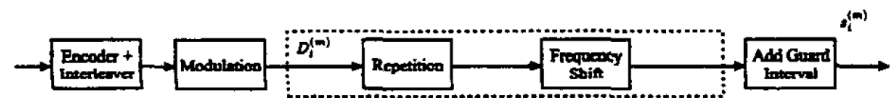
for $i = -N_G, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ 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.

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(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.

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	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.
[Claim 15] The apparatus of claim 10, wherein the plurality of subcarriers are contiguous subcarriers or interleaved subcarriers.	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. Galda-2002 discloses or renders obvious the apparatus recited in claim 10, as set forth above with respect to claim 10.

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	<i>See, e.g.</i>, claim elements 10PRE, 10A, 10B, 10C, 10D, 10E, 10F, 10G. Galda-2002 further discloses (at least based on Plaintiff’s apparent interpretation of the claims) that the plurality of subcarriers are contiguous subcarriers or interleaved subcarriers. For example, Galda-2002 discloses: 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. 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 $N_c =$
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$L \cdot M$. 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 $\tilde{C}_l = (C_{l,0}, C_{l,1}, \dots, C_{l,L})$ with $l = 0, \dots, L - 1$

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

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.

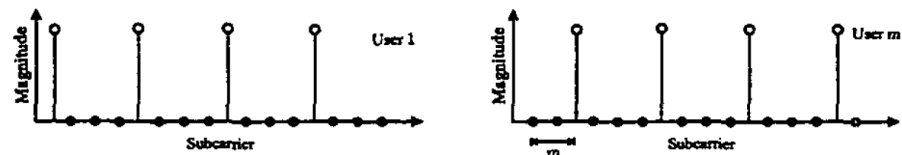


Fig. 2. User m allocates the equidistant subset of subcarriers shift by m subcarriers in the frequency domain

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Galda-2002 at Fig. 2.

If a spreading technique is employed including the user specific subcarriers and the spreading gain should be maximized then the selected subcarrier set should be more or less uncorrelated [4]. Therefore in this paper a subset is considered where the selected subcarrier are placed on equidistant subcarriers over the entire bandwidth, see Fig. 2. In this case the selected subcarrier set can be assumed to be mutually independent which leads to a maximum spreading gain, the subcarrier selection is exclusive for each user, which avoids any MAI, and the signalling overhead is minimized. Furthermore, it is assumed in the sequel that the set of equidistant subcarrier are shifted by m subcarrier in the frequency domain if the subset is assigned to user m . The proposed subcarrier selection and modulation process does not need any radio channel state information in this case.

Galda-2002 at 1738.

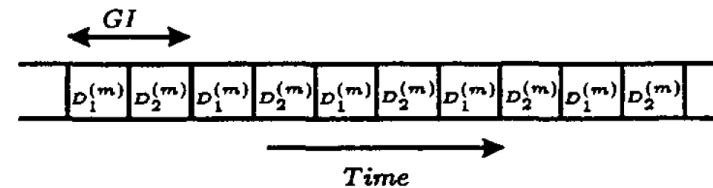


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

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

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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

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

the transmit signal of user m can be written as

$$\begin{aligned} s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L} \\ &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\ &= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu - i) \\ s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \end{aligned} \quad (7)$$

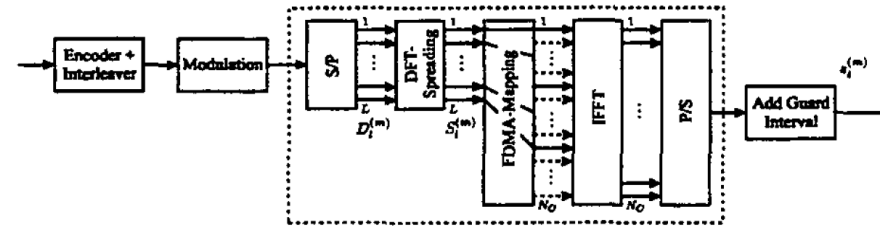
for $i = -N_G, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ 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

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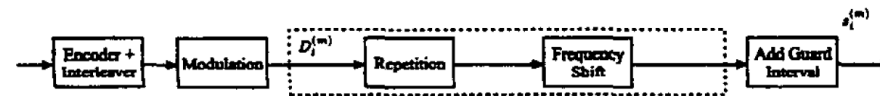
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the complete allocated subcarrier set. The number of periods inside a single OFDM symbol is equal to the spacing M of the subcarriers allocated to user m .

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

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	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 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.
[Claim 16] The apparatus of claim 10, wherein encoding comprises multiplying a vector or matrix of data symbols with a vector or matrix comprising the first set of complex-valued codes.	Galda-2002 discloses or renders obvious the apparatus recited in claim 10, as set forth above with respect to claim 10. <i>See, e.g.,</i> claim elements 10PRE, 10A, 10B, 10C, 10D, 10E, 10F, 10G. Galda-2002 further discloses (at least based on Plaintiff’s apparent interpretation of the claims) that encoding comprises multiplying a vector or matrix of data symbols with a vector or matrix comprising the first set of complex-valued codes. For example, Galda-2002 discloses: Abstract- The orthogonal frequency division multiplex (OFDM) transmission technique can efficiently deal with the effects of multi-path

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	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. 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 significantly [3].
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	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. 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
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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 $\tilde{C}_l = (C_{l,0}, C_{l,1}, \dots, C_{l,L})$ with $l = 0, \dots, L - 1$

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

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.

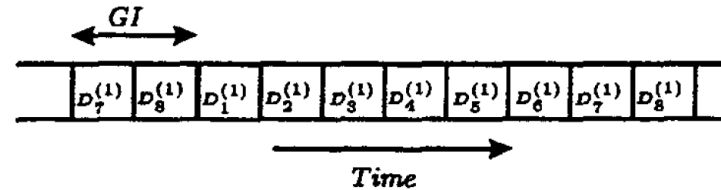


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

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

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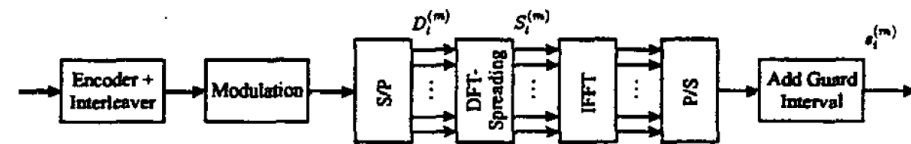
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system. If a single user is assumed in this OFDM system the spreading operation includes all subcarrier within the entire bandwidth. In this case the DFT spreading matrix and the IDFT operation in the OFDM modulation process cancel out each other. 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

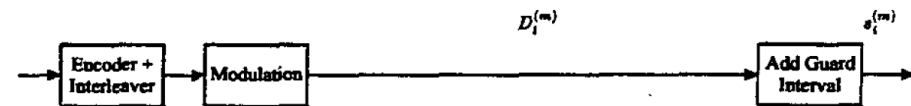
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$$

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.

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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.

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

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

the transmit signal of user m can be written as

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$$\begin{aligned}
s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L} \\
&= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\
&= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu-i) \\
s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \tag{7}
\end{aligned}$$

for $i = -N_G, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. 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.

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

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	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.
[Claim 17] The apparatus of claim 10, wherein applying comprises modulating the encoded data symbols onto the plurality of subcarriers.	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. Galda-2002 discloses or renders obvious the apparatus recited in claim 10, as set forth above with respect to claim 10. <i>See, e.g.</i>, claim elements 10PRE, 10A, 10B, 10C, 10D, 10E, 10F, 10G. Galda-2002 further discloses (at least based on Plaintiff’s apparent interpretation of the claims) that applying comprises modulating the encoded data symbols onto the plurality of subcarriers. For example, Galda-2002 discloses:

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	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 broadband radio channel is characterized by its frequency selective fading due to multi-path propagation. In mobile communications applications the radio channel is additionally time-variant due to the movement of the mobile terminal. The orthogonal frequency division multiplexing (OFDM) transmission technique can cope with the effects of frequency selectivity and time variance with a low implementation and computation complexity. Inter symbol interferences (ISI) as well as inter carrier interferences (ICI) can be completely avoided by dividing the total system bandwidth into a large number of spectrally overlapping but mutually orthogonal non-frequency selective narrow-band subchannels and by introducing an additional guard interval into the OFDM symbol. Even at the output of a frequency-selective channel this orthogonality of the subcarriers can be maintained. The equalization of each subchannel is then reduced to a single complex multiplication per subchannel [1].
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	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 significantly [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
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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.

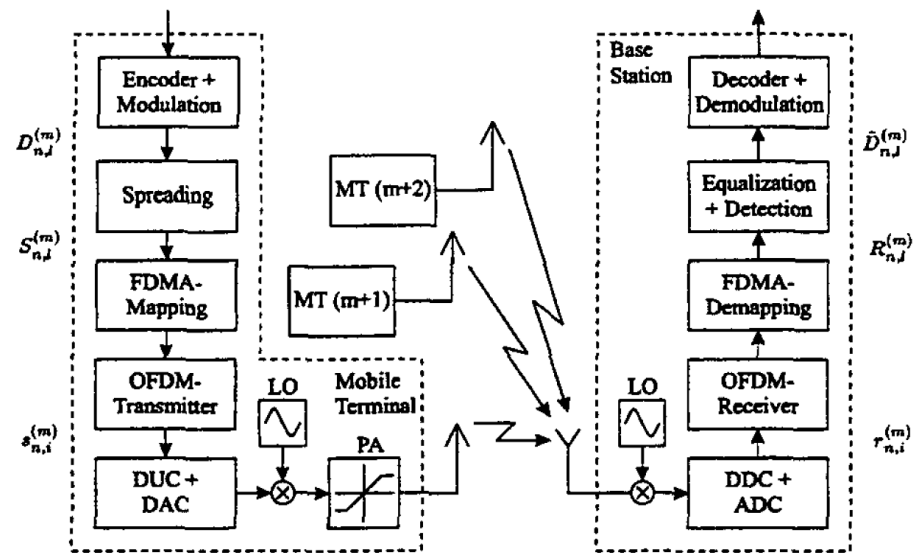


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

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 $N_C =$

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$L \cdot M$. 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 $\tilde{C}_l = (C_{l,0}, C_{l,1}, \dots, C_{l,L})$ with $l = 0, \dots, L - 1$

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

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

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

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

Galda-2002 at 1738.

III. DFT SPREADING

The spreading matrix $[C]$ of an OFDM-FDMA system is often only characterized by its frequency diversity properties. It therefore is chosen to be unitary in order to make the detection process easier, to distribute the signal energy of the superimposed code symbols uniformly over all subcarrier and not to change the distance of the code vectors. Thus, in many OFDM systems with additional spreading the Walsh-Hadamard (WH) matrix is employed since it has the additional advantage that it only consists of only “+1” and “-1” elements which can reduce the computational complexity. The discrete Fourier matrix is also unitary but additionally has an influence on the PAR of an OFDM transmit signal. In this Section the influence of such an Fourier sp[r]eading matrix on the resulting PAR will be discussed.

Galda-2002 at 1739.

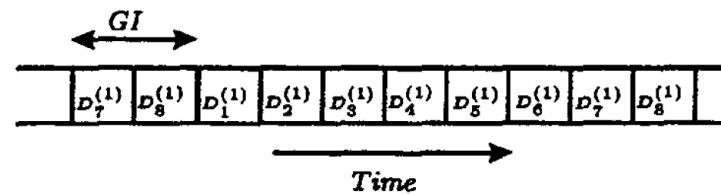


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

Galda-2002 at Fig. 3.

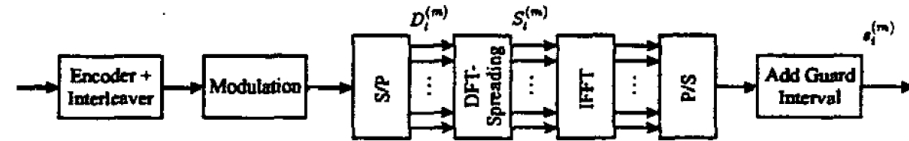
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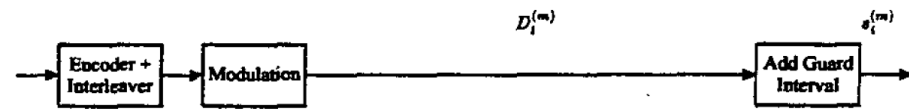
	A. OFDM-TDMA with DFT Spreading In [3] the Discrete Fourier Transformation (DFT) matrix has been used for spreading the vector $\vec{D}$ of length $L = N_C$ over all subcarriers of an OFDM system. If a single user is assumed in this OFDM system the spreading operation includes all subcarrier within the 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 $s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$ where <i>mod</i> denotes the modulo operation, as shown in Fig. 3. Galda-2002 at 1739.
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(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.

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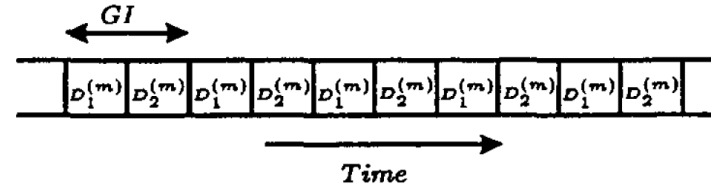


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8$, $M = 4$)

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

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

the transmit signal of user m can be written as

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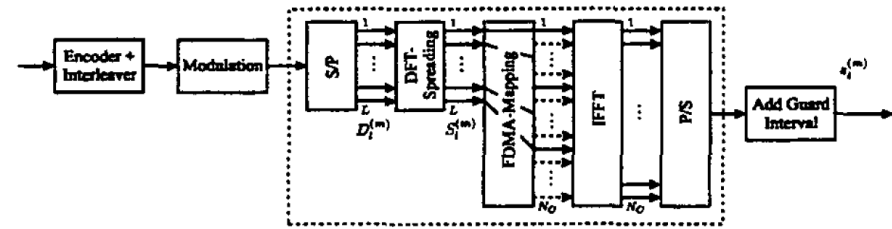
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$$\begin{aligned}
 s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\
 &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\
 &= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \delta_L(\nu-i) \\
 s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \tag{7}
 \end{aligned}$$

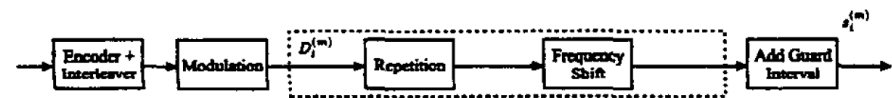
for $i = -N_G, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ 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.

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(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.

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	Galda-2002 at 1740. We consider an OFDM-FDMA system with $N_C = 512$ subcarriers and a guard interval of $N_G = 64$ shared between $M = 16$ users. The continuous-time transmit signal $s(t)$ is simulated by a discrete-time signal oversampled by a factor of $K = 8$ and bandlimited by a root-raised cosine Nyquist filter. The oversampled and filtered signal is then passed through a non-linear device modelled by a soft-limiter as it has been described in Section IV. The distorted signal $\tilde{s}(t)^{(m)}$ is then analyzed by measuring its power spectral density (PSD) and its clipping probability. Since only the transmit signal is analyzed in this paper no assumption about the channel have to be made. Galda-2002 at 1741. 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.
[Claim 18] The apparatus of claim 10, wherein the non-transitory computer-readable memory further includes instructions stored thereon and executable by the 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. Nevertheless, StarTAC included a CDMA transmitter that used an earlier generation

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adding a cyclic prefix to the spread-OFDM signal before transmitting the spread-OFDM signal.	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. Galda-2002 discloses or renders obvious the apparatus recited in claim 10, as set forth above with respect to claim 10. <i>See, e.g.</i>, claim elements 10PRE, 10A, 10B, 10C, 10D, 10E, 10F, 10G. Galda-2002 further discloses (at least based on Plaintiff’s apparent interpretation of the claims) instructions stored thereon and executable by the processor for adding a cyclic prefix to the spread-OFDM signal before transmitting the spread-OFDM signal. For example, Galda-2002 discloses: The broadband radio channel is characterized by its frequency selective fading due to multi-path propagation. In mobile communications applications the radio channel is additionally time-variant due to the movement of the mobile terminal. The orthogonal frequency division multiplexing (OFDM) transmission technique can cope with the effects of frequency selectivity and time variance with a low implementation and computation complexity. Inter symbol interferences (ISI) as well as inter carrier interferences (ICI) can be completely avoided by dividing the total system bandwidth into a large number of spectrally overlapping but mutually orthogonal non-frequency selective narrow-band subchannels and by introducing an additional guard interval into the OFDM symbol. Even at the output of a frequency-selective channel this orthogonality of
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	the subcarriers can be maintained. The equalization of each subchannel is then reduced to a single complex multiplication per subchannel [1]. 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 significantly [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.
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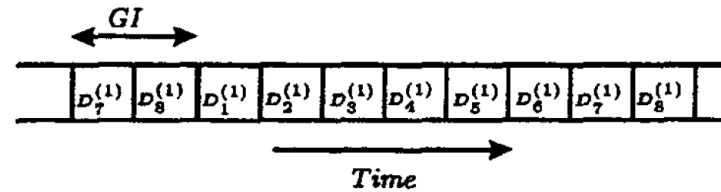


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

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

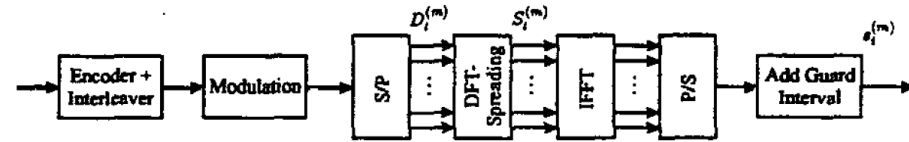
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$$

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

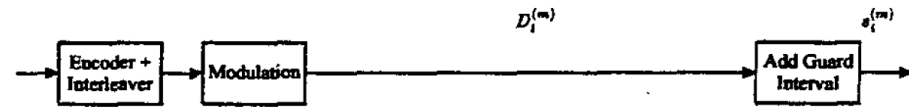
Galda-2002 at 1739.

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(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.

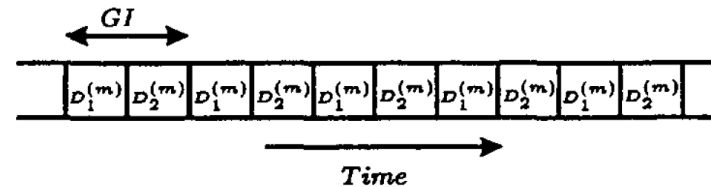


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

Galda-2002 at Fig. 5.

B. OFDM-FDMA with DFT Spreading

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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

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

the transmit signal of user m can be written as

$$\begin{aligned} s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_\nu^{(m)} e^{-j2\pi il/L} \\ &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\ &= e^{j2\pi im/N_C} \sum_{\nu=0}^{L-1} D_\nu^{(m)} \delta_L(\nu-i) \\ s_i^{(m)} &= e^{j2\pi im/N_C} D_{i \bmod L}^{(m)} \end{aligned} \quad (7)$$

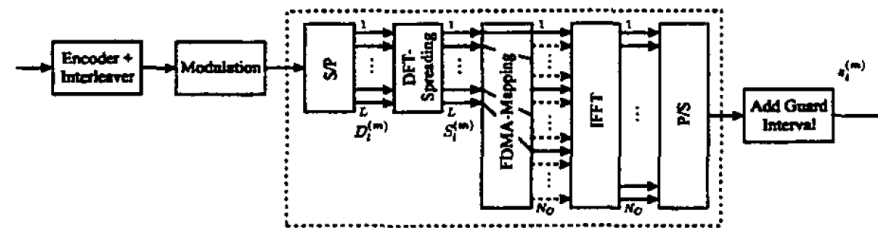
for $i = -N_C, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ sequence

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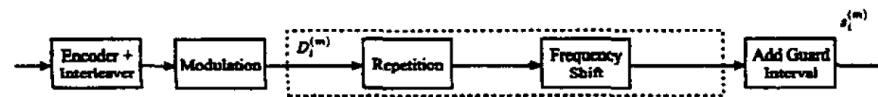
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including an added guard interval as cyclic prefix, shown in Fig. 5. This periodic data sequence is multiplied by a user specific complex signal $e^{j2\pi im/N_c}$ due to the user individual frequency shift by m subcarriers of the complete allocated 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.