

Exhibit E-21

Invalidity of U.S. Patent No. 11,223,508 in View Motorola StarTAC 7868 (“StarTAC”)

The asserted claims of U.S. Patent No. 11,223,508 (“the ’508 patent”) are obvious in view of Motorola StarTAC 7868 (including StarTAC 7868w) (“StarTAC”) in view of the knowledge of the period 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”), “Multi-Carrier CDMA Mobile Radio Systems - Analysis and Optimization of Detection, Decoding, and Channel Estimation” (“Kaiser-1998”), “Proposed Baseline OFDM Systems for Study” (“R1-021246”), U.S. Patent No. 6,535,501 to Böhnke (“Böhnke-501”), and U.S. Patent No. 6,609,010 to Dolle et al. (“Dolle-010”).

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

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).

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).

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

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

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

The asserted claims and the alleged priority date of the ’508 patent are identified below:

’508 Patent Asserted Claims	Alleged Priority Date
17, 18, 19, 20, 21, 22	“August 2, 2004” (ACICS at 8)

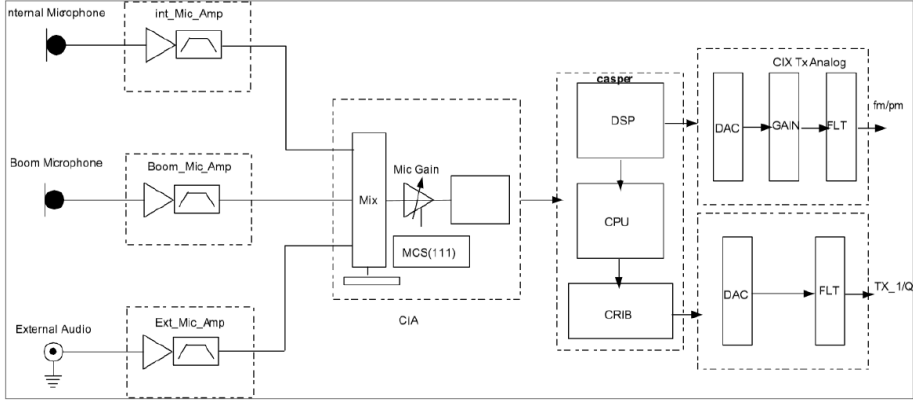
The Court has not yet construed the claims and therefore the meaning of the terms in the claims has yet to be resolved by the Court. The support identified herein may be responsive at least in part to Plaintiff’s infringement contentions, with which Defendant does not necessarily agree. As such, nothing 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.

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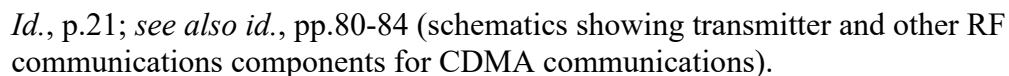
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Where Defendant cites a particular figure, such citation should be understood to encompass the caption and description of the figure, in addition to the figure itself. Conversely, where a cited portion of text refers to a figure, the citation should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

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

Claim Language	StarTAC and Other References
[17PRE] An apparatus for communicating in a mobile radio communications network, 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).  <i>Id.</i>, p.19.

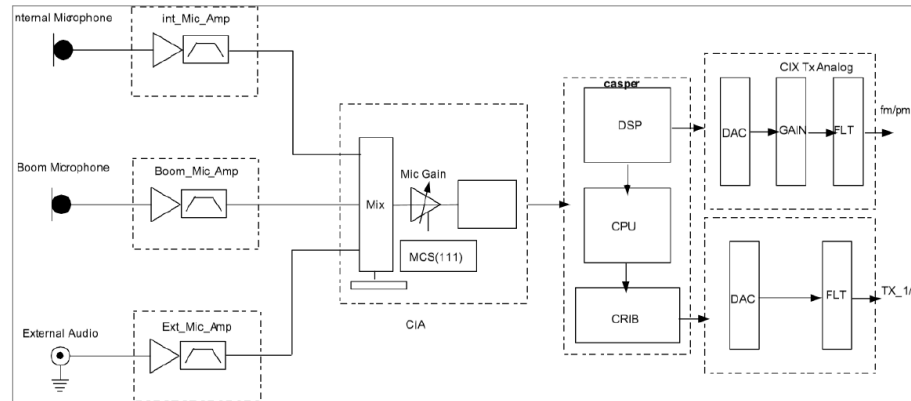
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StarTAC includes transceiver-control circuitry. *See, e.g.*, Motorola CDMA ST7868W Dual Band/Tri Mode, Service Manual Level III, pp. 15-17 (describing the “Transmitter Circuitry” used in the StarTAC).

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Id., p.19.

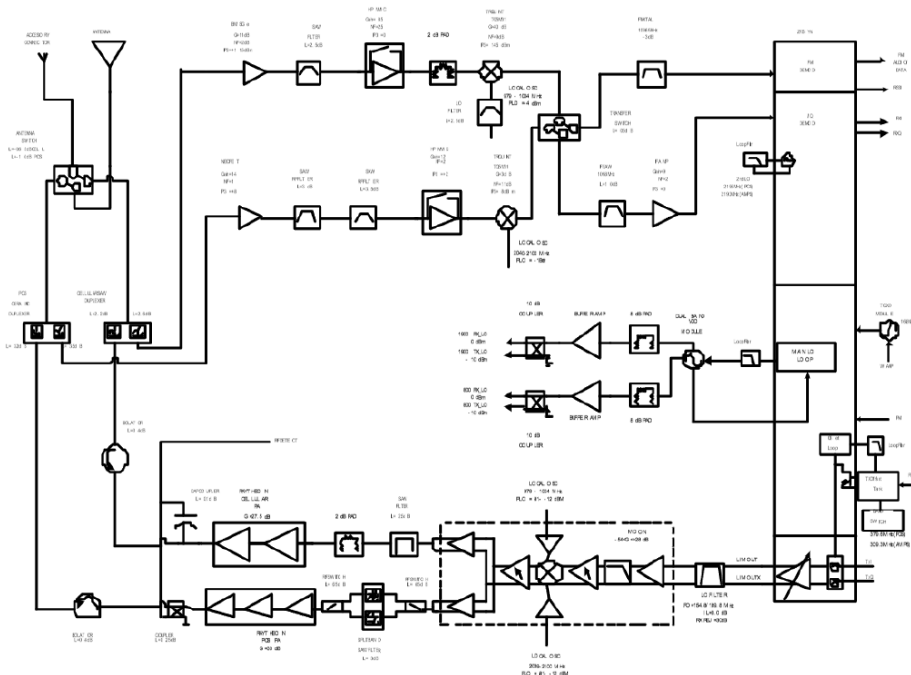


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	<i>Id.</i> , p.21; <i>see also id.</i> , pp.80-84 (schematics showing transmitter and other RF communications components for CDMA communications).
[17Ai] provisioning a consecutive series of Orthogonal Frequency Division Multiplexing (OFDM) subcarriers for uplink or downlink communications;	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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: 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

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	scheme. By allocating distinct sets of subcarriers to different users the available bandwidth can be flexibly shared between different mobile terminals while avoiding any multiple access interferences (MAI) between different users. The FDMA multiple access scheme offers not only a high flexibility for the radio resource management (RRM) but can also increase the bandwidth efficiency of the complete system by avoiding the use of highly attenuated subcarriers for specific users based on the knowledge of the channel transfer function [2]. Moreover, the OFDM-FDMA multiple access scheme can be adapted to the measured radio channel knowledge at the transmitter site using bit-loading techniques. If channel state information is not available the performance can be increased using an additional spreading over the subcarriers assigned to one user. The resulting computation complexity of the total system can by this means be adopted to the given system requirements which is especially of importance for the mobile terminal and in the uplink case. The alternative OFDM-FDMA multiple access scheme is therefore of importance for the uplink case and can be advantageous over OFDM-CDMA schemes because of its ability to avoid MAI if ideal carrier synchronization is assumed for all mobile terminals and the base station. Galda-2002 at 1737. Since the OFDM transmit signal results from the superposition of a large number of independent data symbols the envelope of the complex baseband time signal has in general a large peak-to-average ratio (PAR). The largest output power value of the amplifier will limit the maximum amplitude of the signal in the transmitter. Therefore, non-linear distortions due to clipping and amplification effects in the transmit signal will lead to both in-band and out-of-band emissions. In the past different techniques for reducing the PAR by changing the transmit signal independently from knowledge of other parts of the OFDM transmitter have been developed. But the PAR of the transmit signal envelope which employs an OFDM-FDMA multiple access scheme can significantly be reduced if additional spreading techniques are applied which spread the user data over the allocated subcarrier only. In this case an appropriate spreading technique must be designed reducing the PAR to a
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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.

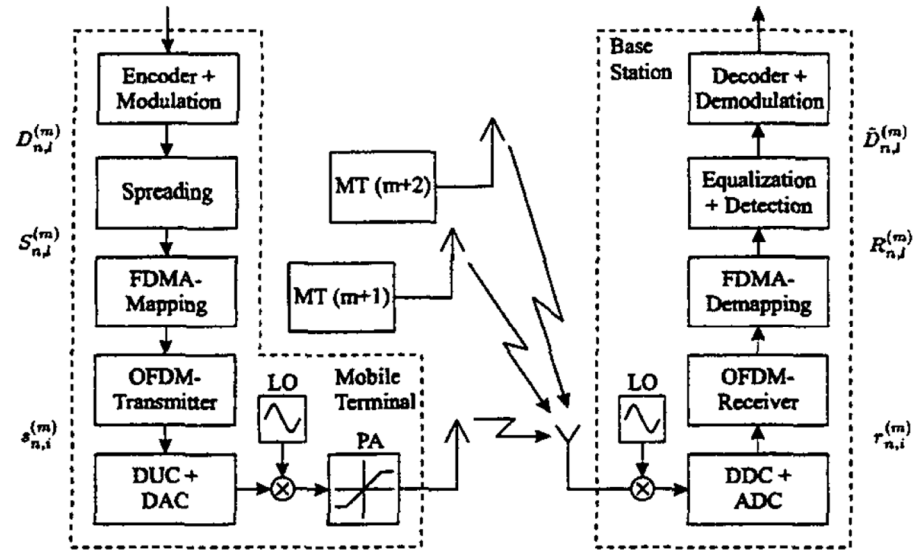


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

Galda-2002 at Fig. 1.

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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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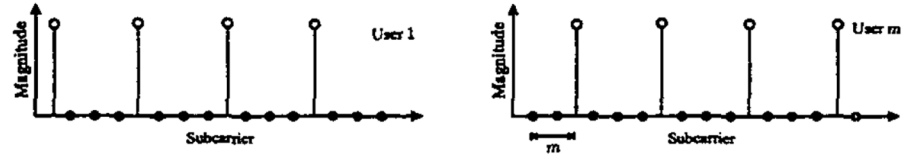


Fig. 2. User m allocates the equidistant subset of subcarriers shift by m subcarriers in the frequency domain

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.

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

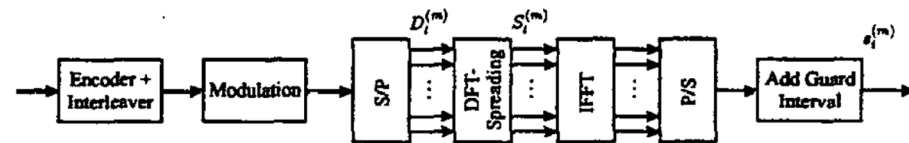
$$S_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for } i = -N_C, \dots, 0, \dots, N_C \quad (3)$$

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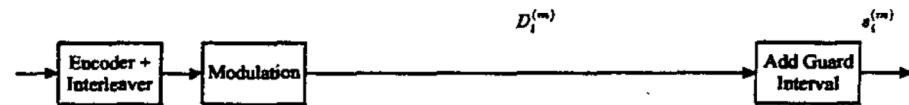
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where N_G denotes the length of the guard interval which is inserted into the transmit time signal.

Galda-2002 at 1738.



(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 $S_l^{(m)}$ 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

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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

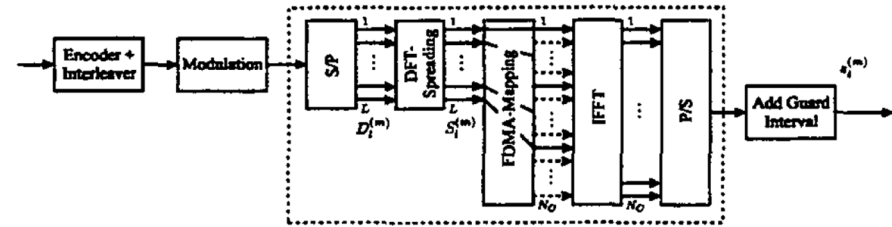
$$\begin{aligned} s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\ &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\ &= e^{j2\pi im/N_C}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

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 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 .

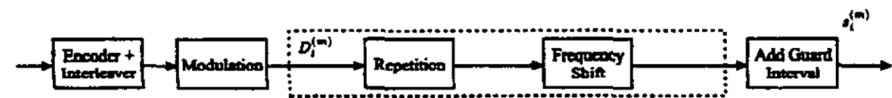
Galda-2002 at 1739-40.

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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 which can limit the
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	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.
[17Aii] provisioning a plurality of different selectable subcarrier spacings for the consecutive series of OFDM subcarriers; and	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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: For example, Galda-2002 discloses: 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

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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.

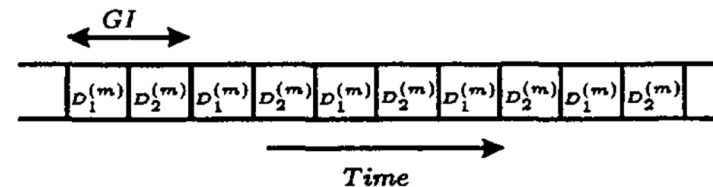


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

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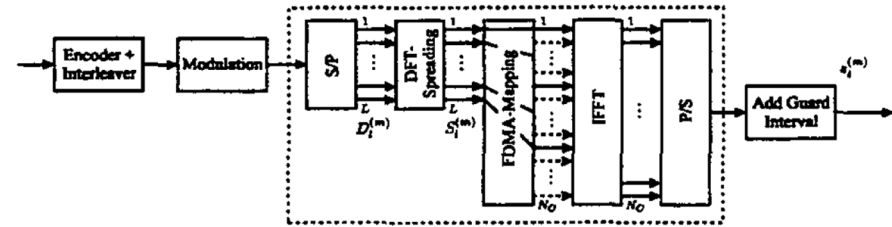
$$\begin{aligned} s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\ &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\ &= e^{j2\pi im/N_C}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

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 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 .

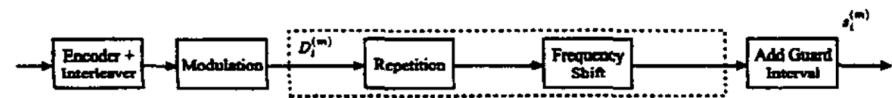
Galda-2002 at 1739-40.

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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. Since the time signal of the OFDM-FDMA uplink with DFT spreading is identical to a single carrier transmission additional techniques to reduce the PAR originally developed for single carrier systems like the $\pi/4$-QPSK can be employed. 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.
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	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. Kaiser-1998, which discloses: This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA
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	systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers. • Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques. Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme. • MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink
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has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

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

Kaiser-1998 at 131.

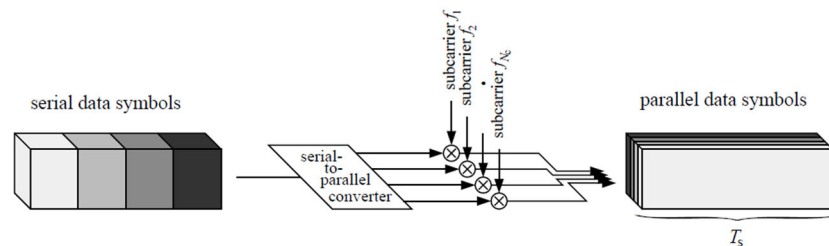


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

The progress in wireless communications entails a demand for higher data rates and, thus, shorter symbol durations. However, if the duration of the transmitted symbol becomes smaller than the time dispersion of the multipath channel, the performance of the wireless communication system suffers from ISI. This is a crucial problem since the receiver complexity is related to the amount of ISI. An approach to prevent ISI is offered by parallel data transmission [Cha66, Sal67, WeE71], referred to as MC communications. The principle of MC modulation, depicted in Fig. 1.3, is to convert a high rate data stream into N_c low-rate substreams, where N_c is the number of subcarriers used for data transmission. Each substream is modulated on its assigned subcarrier $f_n, n = 1, \dots, N_c$. Thus, the available channel bandwidth is subdivided into N_c narrow subbands, which ideally appear frequency non-selective. The data

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	symbol rate per subcarrier is reduced by a factor N_c and with that, the ISI is reduced. A common realization of MC communications is conventional frequency division multiplexing where the subbands are completely separated in the frequency domain. However, due to finite steepness of the filter roll-offs, the subchannel spacing has to be greater than the Nyquist bandwidth to avoid inter-subchannel interference (ICI). This inefficient use of the available spectrum can be overcome by permitting spectral overlap between adjacent subchannels [Cha66, Sal67]. ICI can be avoided by guaranteeing orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s, known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbols of duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1/T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B. Kaiser-1998 at 5-6. 3.1.1 Orthogonal Frequency Division Multiplexing The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be
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	smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{S_n\}$ consisting of N_c complex-valued source symbols $S_n, n = 1, \dots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $S_n, n = 1, \dots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{S_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{S_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{S_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to $\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$ According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of $F_s = \frac{1}{T_s}. \quad (3.2)$ to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $S_n, n = 1, \dots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form
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$$x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} S_n \operatorname{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$$

Kaiser-1998 at 31-32.

The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the 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 symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

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

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

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	$\frac{1}{T_c} = \frac{L}{T_d} \quad (3.27)$ and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector $\underline{s}^{(k)} = \underline{d}^{(k)} \underline{c}^{(k)} = \left(\underline{s}_1^{(k)}, \underline{s}_2^{(k)}, \dots, \underline{s}_L^{(k)} \right)^T. \quad (3.28)$ The rate of the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is $T'_s = T_g + N_c T_c. \quad (3.29)$ The transmission of one data symbol per user per OFDM symbol requires $N_c = L \quad (3.30)$ subcarriers. In this case, the OFDM symbol duration including the guard interval is $T'_s = T_g + T_d. \quad (3.31)$ Kaiser-1998 at 39-40. <i>M</i>-Modification: The intention of the <i>M</i>-Modification is to increase the number of subcarriers while maintaining constant the spreading code length and the maximum number of active users. Consequently, the OFDM symbol duration increases and the loss in bandwidth efficiency due to the guard
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	interval decreases. Moreover, the tighter subcarrier spacing enables one to guarantee flat fading per subchannel in propagation scenarios with decreased coherence bandwidth. With the M-Modification, each user transmits simultaneously M greater than 1 data symbols per OFDM symbol. The total number of subcarriers of the modified MC-CDMA system is $N_c = ML. \quad (3.34)$ Each user exploits the total of N_c subcarriers for data transmission. The OFDM symbol duration including the guard interval increases to $T'_s = T_g + MLT_c, \quad (3.35)$ where it can be observed that the loss in bandwidth efficiency due to the guard interval decreases with increasing M. The maximum number of active users is still defined according to (3.32). The assigned MC-CDMA transmitter is shown in Fig. 3.8. The data symbol index $m, m = 1, \dots, M$, is introduced in Fig. 3.8 to distinguish the M simultaneously transmitted data symbols $\underline{d}_m^{(k)}, m = 1, \dots, M$, of the kth user. The number M is upper limited by the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), since the symbol duration T'_s, which increases with increasing M, has to be smaller than $(\Delta t)_c$ to guarantee that the channel is time-invariant during one OFDM symbol duration. To optimally exploit frequency diversity, the components of the sequences $\underline{s}_m, m = 1, \dots, M$, transmitted in the same OFDM symbol are interleaved over the frequency. Subcarriers used for the transmission of $\underline{s}_m$ should have a spacing greater than the coherence bandwidth of the channel. Thus, the components of one sequence $\underline{s}_m$ are affected independently, reducing the probability that $\underline{s}_m$ is completely located in a deep fade. The interleaving is carried out prior to OFDM. The frequency interleaver can be a block interleaver which guarantees the maximum frequency separation between the components of $\underline{s}_m$. However, due to a possible periodicity of the fading process in frequency, the block interleaver can fail if the periodicity is
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	similar to the frequency separation between adjacent components. This effect can be reduced if a pseudo-random frequency interleaver is used. Kaiser-1998 at 41-42. The OFDM symbol duration including the guard interval is $T'_s = T_g + QLT_c. \quad (3.40)$ Kaiser-1998 at 44. <i>M&Q</i>-Modification: The <i>M&Q</i>-Modification is a combination of the <i>M</i>- and the <i>Q</i>-Modification, resulting in an MC-CDMA system with adjustable number of subcarriers and receiver complexity, keeping constant the maximum number of active users. The transmission of <i>M</i> data symbols per user and, additionally, the splitting of the users in <i>Q</i> independent user groups according to the <i>M&Q</i>-Modification is illustrated in Fig. 3.10. The total number of subcarriers used by the MC-CDMA system with <i>M&Q</i>-Modification is $N_c = QML, \quad (3.41)$ where each user only exploits a subset of <i>M L</i> subcarriers for data transmission due to the FDMA component introduced by the <i>Q</i>-Modification. The maximum number of active users is given by (3.38). The total OFDM symbol duration including the guard interval results with the <i>M&Q</i>-Modification in $T'_s = T_g + QMLT_c. \quad (3.42)$ Kaiser-1998 at 44. R1-021246, which discloses: The sub-carrier spacing should be large enough to provide robustness against frequency offset and phase noise, but it also has to be small enough such that each sub-carrier experiences flat fading. Normally, the tone (or sub-carrier) spacing can be selected by first fixing a maximum delay spread from all
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	possible channel conditions, calculating the coherence bandwidth and then using it as an upper bound for the sub-carrier spacing. From [3], the Pedestrian A, Pedestrian B, and Vehicular A channel model, have maximum delay spread at 410ns, 3.7usec and 2.5usec, respectively. We suggest that a maximum delay spread of 10 usec be considered for the design of the OFDM system. The 10-usec suggestion takes into account only the cyclic prefix, some extra guard time should be added to allow some ramp-up and ramp-down period for the power amplifier. Time domain filtering maybe necessary to avoid the spurious effect due to the possible sudden transition between the consecutive OFDM symbols. In order to reduce the out of band emissions effectively, a raise cosine window with roll-off factor equal to one should be allowed. Note that it is observed that in a simulcast environment, the signal coming from the other cell is most likely the dominant multi-path which has longer delay than the non-simulcast signal. Therefore, larger delay spread should be considered if multicast and simulcast services are of interest. Table 2 shows some parameters for coherence bandwidth based on various definitions stated in [2]. R1-021246 at 2. FFT Size From Table 1., assuming the nominal UE speed is less than 120 km/hr, we can choose the OFDM symbol duration up to 805.5 usec as long as it does not violate the coherence bandwidth dictated by Table 2. To keep the time domain overhead, i.e. the cyclic prefix and guard time, small, it is desirable to limit the amount of time overhead to be less than 10% of the time domain symbol duration. Table 3. summarized the number of sub-carried allowed under 5, 10, and 15% time domain overhead (T_g) assumptions, and the number of FFT points required to implement it. Note that T_u is the useful/signal part of the symbol, and T_g is the guard time. The number sub-carriers can be supported in a 5MHz bandwidth is given by $\lfloor 5MHz/T_u \rfloor$, where the numbers are rounded to the nearest integers from below.
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R1-021246 at 2.

No. Sym/TS	OFDM Symbol period (T_u+T_g)	No of tones w/ 5% time overhead	No. of FFT points	No of tones w/ 10% time overhead	No. of FFT points	No of tones w/ 15% time overhead	No. of FFT points
1	667 usec	3166	4096	3000	4096	2833	4096
2	333 usec	1583	2048	1500	2048	1416	2048
3	222 usec	1055	2048	1000	1024	944	1024
4	167 usec	791	1024	750	1024	708	1024
5	133 usec	644	1024	600	1024	566	1024

6	111 usec	527	1024	500	512	472	512
7	95.2 usec	452	512	428	512	404	512
8	83.3 usec	395	512	375	512	354	512
9	74.1 usec	351	512	333	512	314	512
10	66.7 usec	316	512	300	512	283	512
11	60.6 usec	287	512	272	512	257	512
12	55.6 usec	263	512	250	256	236	256
13	51.3 usec	243	256	230	256	217	256
14	47.6 usec	226	256	214	256	202	256
15	44.4 usec	211	256	200	256	188	256
16	41.7 usec	197	256	187	256	177	256

Table 3. Number of Symbols per Time slot vs. Number of possible sub-carriers over 5MHz bandwidth vs. Number of FFT points needed

R1-021246 at Table 3.

It can be seen that with less than 10% time overhead, the most efficient choices of the FFT operations are 1024, 512, and 256 at 3, 6, and 12 symbols per time slot. To guarantee the highest data rate, all 1024, 512 or 256 sub-carriers should be used to transmit. The smaller the number of sub-carriers is, the wider the subcarrier spacing becomes which leads to robustness against frequency offset and phase noise.

R1-021246 at 3.

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	Based on the above discussion, we would like propose a baseline system with multiple configurations suitable for different channel conditions. Some benefit of having multiple configurations are: (1) To allow shorter symbol durations when the multipath is less severe, this would result in wider subcarrier spacing which would make the system more immune to frequency offset (2) To use shorter symbol duration which makes the system less susceptible to high Doppler and hence reduces the ICI (3) To use smaller size FFT which lowers the power consumption and the UE complexity. These multiple configurations have the same sampling frequency, which will simplify the receiver implementation while allowing UE to switch smoothly to different configurations supported by the Node Bs in different multipath environments. R1-021246 at 3-5. Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a 1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system’s resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations. R1-021246 at 5.
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System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

R1-021246 at Table 4.

We have suggested an OFDM system with multiple configurations that can be deployed in different environments. The system is designed to fit into the current UMTS time slot structure. If agreed upon, the system will be used as a baseline for future OFDM study.

R1-021246 at 7.

Böhnke-501, which discloses:

According to the present invention, a number of subcarriers of an OFDM/TDMA-system is allocated to each GSM-frequency channel so that a multiple of one resulting OFDM/TDMA-timeslot matches with one or a multiple of one GSM-timeslot. The spacing between two adjacent GSM-frequency channels is 200 kHz, and the length of a GSM-timeslot is 15/26 ms. According to the present invention, one GSM-frequency channel is

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	divided into a number of subcarriers. The number of subcarriers is chosen, so that a multiple of one resulting OFDM/TDMA-timeslot fits well in one or a multiple of one GSM-timeslot. The transformation of one subcarrier from the frequency domain into the time domain results in an OFDM/TDMA-time burst, which builds the largest part of the resulting OFDM/TDMA-timeslot. In FIG. 7, the basic structure of an OFDM/TDMA-timeslot is shown as containing an OFDM/TDMA-time burst, whereby the length of the OFDM/TDMA-timeburst T_{OFDM} corresponds to the effective Modulation Period and depends on the subcarrier-spacing (1/subcarrier-spacing). The subcarrier spacing depends on the number of subcarriers allocated to one GSM-frequency channel of 200 kHz. A guard time TG (or pre-guard time) is disposed in advance of the OFDM/TDMA-time burst T_{OFDM}. In FIG. 8, the detailed structure of an OFDM/TDMA-timeslot is shown. The length of the OFDM/TDMA-timeslot corresponds to the modulation period and has a length of a μs. After the transformation of the subcarriers into the time domain, whereby the OFDM/TDMA-timebursts are produced, a guard time consisting of the pre-guard time of length c μs and a post-guard time is of length e μs is added to the OFDM-TDMA-timebursts. The OFDM/TDMA-timebursts correspond to the effective modulation period and have a length b μs. Then, before transmitting, the ramp of the time domain signal is shaped according to a raised cosine function, as shown in FIG. 8, to reduce spurious emissions. As can be seen In FIG. 8, the ramp time in the front part and the back part of the OFDM/TDMA-timeslot, respectively, has a length d μs and overlaps partially with the pre-guard time and the post-guard time, respectively. The length of the post-guard time can be o μs. At the beginning of the OFDM/TDMA-timeslot there is located a pre-idle time in advance of the ramp time and at the end of the OFDM/TDMA-timeslot there is located a post-idle time behind the ramp time. The length of each of the pre-idle time and the post-idle time is f μs. Therefore, the resulting OFDM/TDMA-timeslot is composed of the OFDM/TDMA-timeburst (effective modulation period), the guard time consisting of the pre-guard time and the post-guard time, the ramp times and the pre-idle time and the post-idle time. The length b of the
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	OFDM/TDMA-timeburst depends on the subcarrier spacing ($b=1/f_{SCS}$), where f_{SCS} is the subcarrier in Hz. According to the present invention, the length a of one OFDM/TDMA-timeslot can for example correspond to 1, $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$ GSM-timeslot. Böhnke-501 at 4:14-67. In a 1st embodiment, the total number of subcarriers is 48, whereby one or more subcarriers on the borders can be left unmodulated to reduce interference to adjacent frequency slots. The resulting subcarrier spacing is $200 \text{ kHz}/48=4.166 \text{ Hz}$, which leads to an OFDM/TDMA-time burst T_{OFDM} of $48/200 \text{ kHz}=240 \mu\text{s}$. The symbol duration ($240 \mu\text{s}$) is therefore very long compared to the GSM-symbol duration (range of μs), which has the advantage of avoiding inter-symbol interference due to the radio channel delay profile. The guard time (pre-guard time and post-guard time) in the first embodiment is set to $30 \mu\text{s}$, whereby it has to be noted that the guard time has to be set according to the expected channel delay profile (multipath environment). The ramp time is set to 10 to $20 \mu\text{s}$, so that the total OFDM/TDMA-timeslot T_s has a length of 280 to $290 \mu\text{s}$. This fits very well into $\frac{1}{2}$ of the basic GSM-timeslot of $576 \text{ } 923 \mu\text{s}$. Therefore, in the 1st embodiment, two OFDM/TDMA-timeslots are mapped into one GSM-timeslot with an adaptation time guard, if necessary. The basic clock is $240 \mu\text{s}/64=3.75 \mu\text{s}$. The guard time (pre- and post guard time) can be set to $30 \mu\text{s}$ (pre-guard: $22.5 \mu\text{s}=6$ samples, post-guard: $7.5 \mu\text{s}=2$ samples) and the ramp time can be set to $15.0 \mu\text{s}$ ($=4$ samples) which leads to a total symbol time of $(250 \mu\text{s}/64)*(64+6+2+4)=285 \mu\text{s}$. Böhnke-501 at 6:7-31. In the 2nd embodiment, the total number of subcarriers is chosen to be 32, wherein one or more subcarriers at the borders can be left unmodulated to reduce interference to adjacent frequency slots. The subcarrier spacing is $200 \text{ kHz}/32=6.25 \text{ kHz}$, which leads to an OFDM/TDMA-burst of $1/6.25 \text{ kHz}=160$
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	μs. The guard time (pre- and post guard time) can be set to 20 μs and the ramp time can be set to 10.0 μs, which leads to a total OFDM/TDMA-timeslot of 190 μs. 3 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. In other words, one OFDM/TDMA-timeslot T_s is mapped into $\frac{1}{3}$ of a GSM-timeslot. The basic clock is set to $160 \mu s / 32 = 5 \mu s$. To be more precise, the guard time (pre- and post guard time) can be set to 20 μs (pre-guard: $15.0 \mu s = 3$ samples, post-guard: $5 \mu s = 1$ sample) and the ramp time can be set to 10.0 μs (=2 samples) which leads to a total symbol time of $(160 \mu s / 32) * (32 + 3 + 1 + 2) = 190 \mu s$. Böhnke-501 at 6:48-65. In the 3rd embodiment, the total number of subcarriers is chosen to be 24, wherein one or more subcarriers at the borders can be left unmodulated to reduce interference to adjacent frequency slots. The subcarrier spacing is $200 \text{ kHz} / 24 = 8.33 \text{ kHz}$, which leads to an OFDM/TDMA-burst of $1 / 8.33 \text{ kHz} = 120 \mu s$. The guard time (pre- and post guard time) can be set to 15 μs and the ramp time can be set to 9 μs, which leads to a total OFDM/TDMA-timeslot of 144 μs. 4 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. The scheme according to the 3rd embodiment is very advantageous for fast varying channel environments. In other words, one OFDM/TDMA-timeslot T_s is mapped into $\frac{1}{4}$ of one GSM-timeslot. The basic clock is set to $120 \mu s / 32 = 3.75 \mu s$. to be more precise, the guard time (pre- and post guard time) can be set to 15 μs (pre-guard: $11.25 \mu s = 3$ samples, post-guard: $3.75 \mu s = 1$ sample) and the ramp time can be set to 7.5 μs (=2 samples) which leads to a total symbol time of $(120 \mu s / 32) * (32 + 3 + 1 + 2) = 142.5 \mu s$. Böhnke-501 at 7:9-27. In the 4th embodiment, the total number of subcarriers is chosen to be 104, wherein one or more subcarriers at the borders can be left unmodulated to
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	reduce interference to adjacent frequency slots. The subcarrier spacing is 200 kHz/104=1.923 kHz, which leads to an OFDM/TDMA-burst of 1/1.923 kHz=520 μs. The guard time (pre- and post guard time) can be set to 25 μs and the ramp time can be set to 15 μs, which leads to a total OFDM/TDMA-timeslot of 560 μs. One OFDM/TDMA-timeslot is mapped into one GSM timeslot with an adaptation guard of 17 μs. The basic clock is set to 520 μs/128=4.0625 μs. To be more precise, the guard time (pre- and post guard time) can be set to 28.4375 μs (pre-guard: 20.3125 μs=5 samples, post-guard: 8.125 μs=2 sample) and the ramp time can be set to 12.1875 μs (=3 samples) which leads to a total symbol time of (520 μs/128)*(128+5+2+3)=560 625 μs. Böhnke-501 at 7:39-54. Dolle-010, which discloses: The subcarrier spacings of the OFDM system can be identical in the first transmission frequency band and the second transmission frequency band. The subcarrier spacings of the OFDM system in the first transmission frequency band and the second transmission frequency band alternatively can satisfy the following equation: $\Delta F_1 / \Delta F_2 = k * 2^i,$ wherein ΔF_1 and ΔF_2 are the subcarrier spacings used in the OFDM systems in the first transmission frequency band and the second transmission frequency band, respectively, and k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implementation of the baseband block to process the OFDM signals and/or symbols. Dolle-010 at 3:25-41.
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As has been already been set forth above, the advantage of the transceiver 10 as shown in FIG. 1 is that the transmission frequency f_{C1} operates at the same time as the intermediate frequency $4 f_{C2}$. This allows the system to operate in two different frequency ranges with different propagation properties and thus fulfills a wide range of application requirements. In addition the structure allows interoperability between different systems (system 1 and system 2, for example), which are not only distinguished by its different transmission frequencies but also by its different channel bandwidth. To achieve the interoperability, the air interface channel of the system 1 has to be mapped properly to the air interface channel structure of the system 2.

According to the present invention, a channel mapping solution particularly for an OFDM system is provided. Thereby a solution is proposed for an OFDM system transmitting a dual frequency band and providing interoperability with a coexisting OFDM system. The following system parameters thereby are taken into account:

total number of subcarriers: N_1, N_2

channel bandwidth: B_{C1}, B_{C2} , and

subcarrier spacings: $\Delta F_1, \Delta F_2$

Between the above parameters the following relation exists:

$$\Delta F = \frac{B_C}{N}$$

According to the present invention ΔF_1 can be equal to ΔF_2 , which means the same subcarrier spacing in both frequency ranges and/or systems is used. Therefore

$$\frac{B_{C1}}{N_1} = \frac{B_{C2}}{N_2} \quad \text{or} \quad B_{C1} \times N_2 = B_{C2} \times N_1.$$

The above equations can be rewritten

$$B_{C1} \times n = B_{C2} \times m \quad \text{and} \quad N_1 \times n = N_2 \times m,$$

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	wherein the ratio n/m satisfies the following equation: $n/m = k \times 2^i,$ wherein k is a positive integer value and i is a negative or positive integer value including zero. The above selection of the ratios n/m is particularly advantageous for the effective implementation of the FFT algorithm generating the OFDM symbols. In FIG. 3 the two OFDM systems channel mapping is depicted. In the example shown in FIG. 3 $n = 8$ and $m = 1$, which means ideally 8 channels of the OFDM system (system 1) operating in the lower frequency band can be mapped to one channel of the OFDM system (system 2) operating in the dual frequency bands. Depending on the required guard band ($F_{\text{guard } 2}$) between the channels in the upper frequency band the actual mapping of the system 1 channels could be limited to channel 2 through channel 7. The same subcarrier spacings are kept for both systems and/or frequency bands, thereby giving the highest efficiency of interoperability. In general the ratio of $\Delta F_1/\Delta F_2$ is selected to satisfy the following equation: $\frac{\Delta F_1}{\Delta F_2} = k \times 2^i,$ wherein k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implement of the base-band block to process the OFDM signals and/or symbols. Dolle-010 at 5:28-6:56.
[17Aiii] performing discrete Fourier transform (DFT) coding on a plurality of data symbols to produce DFT coded symbols; and	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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

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	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. Since the DFT spreading operation and the IDFT operation used as a part of the OFDM modulation scheme cancel out each other the complexity of the transmitter structure for an OFDM-FDMA uplink can be greatly reduced. Galda-2002 at 1737. The subdivision of the transmission bandwidth into a set of orthogonal subcarriers can additionally be exploited by an OFDM-FDMA multiple access scheme. By allocating distinct sets of subcarriers to different users the available bandwidth can be flexibly shared between different mobile terminals while avoiding any multiple access interferences (MAI) between different users. The FDMA multiple access scheme offers not only a high flexibility for the radio resource management (RRM) but can also increase the bandwidth efficiency of the complete system by avoiding the use of highly attenuated subcarriers for specific users based on the knowledge of the channel transfer
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	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 an additional guard interval in this specific case which helps
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	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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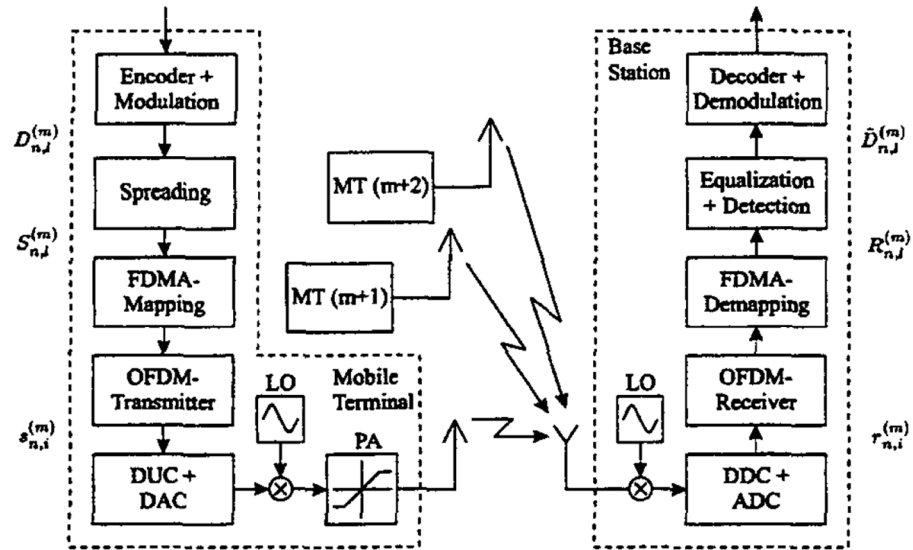


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

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 $[C]$

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	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 $s_i^{(m)} = e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} S_l^{(m)} e^{-j2\pi il/L} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (3)$ 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 spreading matrix on the resulting PAR will be discussed.

Galda-2002 at 1739.

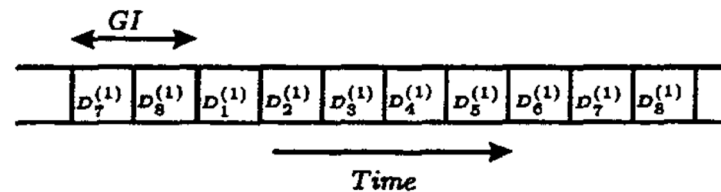


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

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 modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore technically reduced to the serial sequence of

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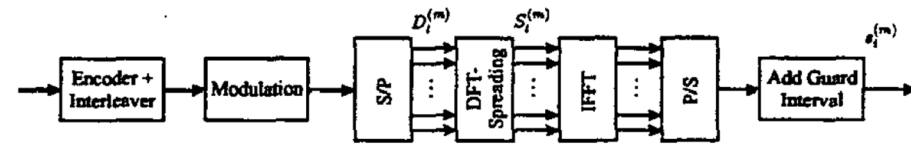
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complex transmit data symbols D_i to which a guard interval is added in the time domain as a cyclic prefix

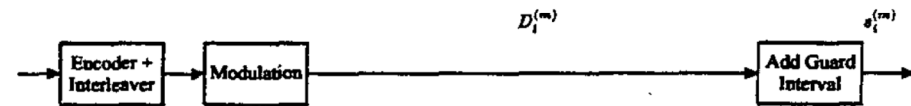
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$$

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-CDMA receiver structures. The same bit error rate (BER) performance compared to a system using a Walsh-Hadamard spreading matrix can therefore be achieved

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if a DFT spreading matrix is considered instead. But in case of a DFT spreading matrix the resulting PAR is significantly reduced. The general structure of an OFDM transmitter including DFT spreading is shown in Fig. 4.

Galda-2002 at 1739.

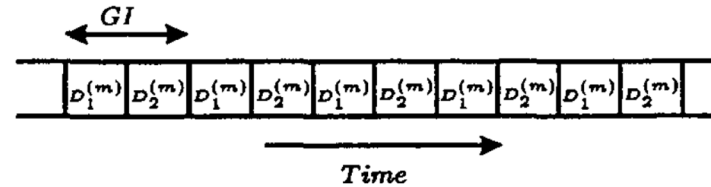


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

Galda-2002 at Fig. 5.

B. OFDM-FDMA with DFT Spreading

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

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

the transmit signal of user m can be written as

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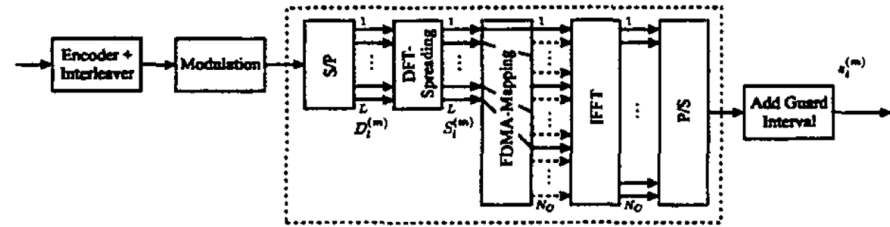
$$\begin{aligned}
 s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\
 &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)} \\
 &= e^{j2\pi im/N_C}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

for $i = -N_C, \dots, 0, \dots, N_C$ 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 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 .

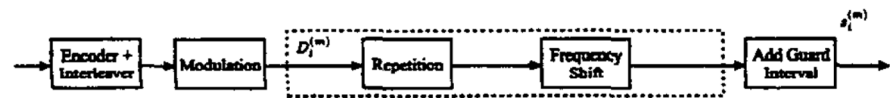
Galda-2002 at 1739-40.

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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 interesting alternative for reducing the complexity of the mobile terminal in the broadband radio uplink.
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	Galda-2002 at 1741.
[17B] an OFDM transceiver communicatively coupled to the transceiver-control circuitry and configured for:	While StarTAC has a transceiver coupled to control circuitry, <i>see</i> Motorola CDMA ST7868W Dual Band/Tri Mode, Service Manual Level III, pp.15-17, 80-84 (describing the “Transmitter Circuitry” used in the StarTAC). StarTAC is not an OFDM product, and thus does not have an OFDM transceiver circuitry communicatively coupled to the transceiver-control circuitry that can 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: For example, Galda-2002 discloses:

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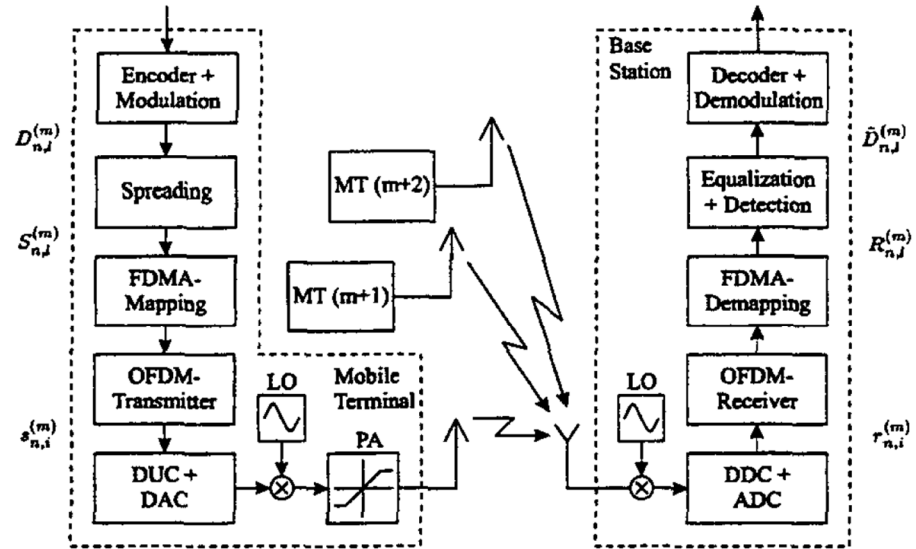
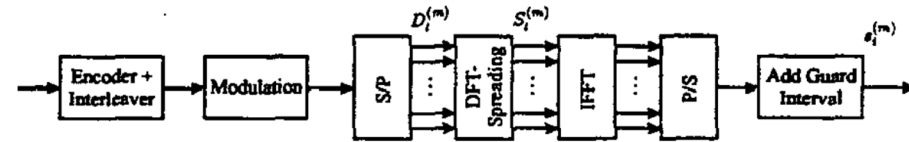


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

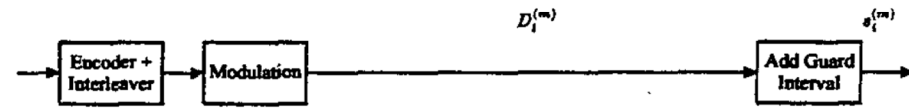
Galda-2002 at Fig. 1.

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(a) OFDM transmitter including DFT spreading over all subcarriers



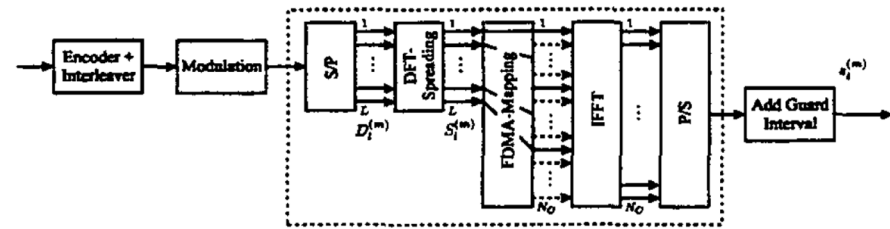
(b) Realistic but simplified OFDM transmitter structure

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.

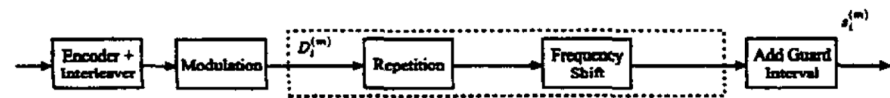
Galda-2002 at Fig. 4.

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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.

[17Bi] performing an inverse-DFT on the coded symbols to produce a single-carrier frequency division multiple access signal that comprises a sum of the consecutive series of OFDM subcarriers; and

While StarTAC has a transmitter, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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:

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 [I].
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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 access scheme and is
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extended to an OFDM-FDMA system in a separate subsection. The general topic of non-linearities in an OFDM system is reviewed in Section IV. Quantitative results are given in Section V and Section VI summarizes the papers content.

Galda-2002 at 1738.

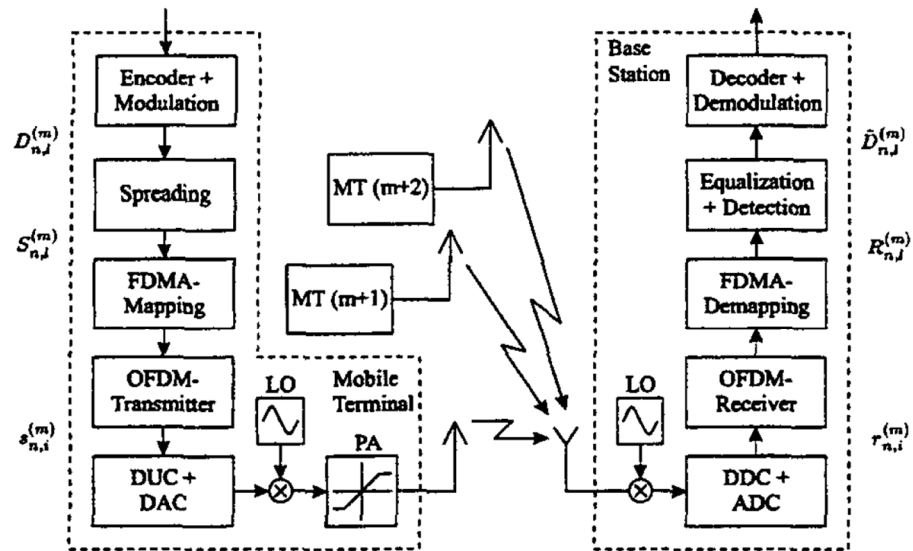


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

Galda-2002 at Fig. 1.

The baseband system model of an OFDM-FDMA uplink with individual spreading of user data is shown in Fig. 1. In this case M different users are considered and each user allocates L different subcarrier exclusively. The total number of subcarrier in the considered transmission system is $N_C = L \cdot M$. The input data stream for each mobile user $m, m = 0, \dots, M - 1$, is

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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

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

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

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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 spreading matrix on the resulting PAR will be discussed.

Galda-2002 at 1739.

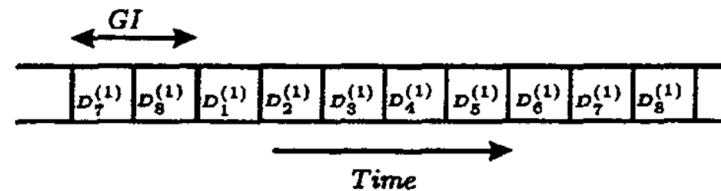


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

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

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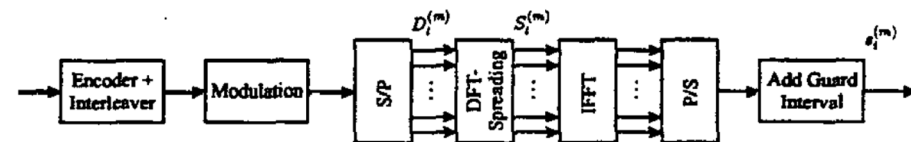
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operation includes all subcarrier within the entire bandwidth. In this case the DFT spreading matrix and the IDFT operation in the OFDM modulation process cancel out each other. The OFDM transmitter structure with DFT spreading matrix is therefore 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

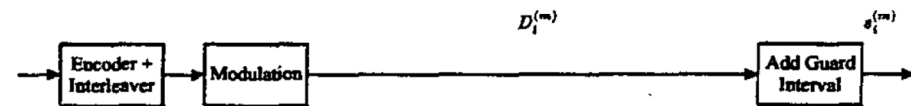
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$$

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 IDFT 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.

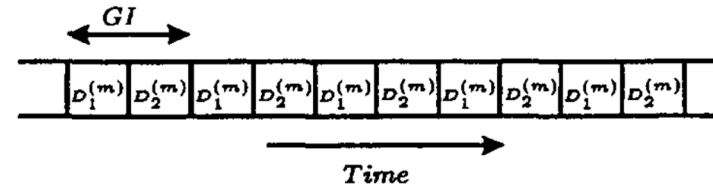


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

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

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inserting Equation (2) into Equation (3) using the elements of the discrete Fourier matrix

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

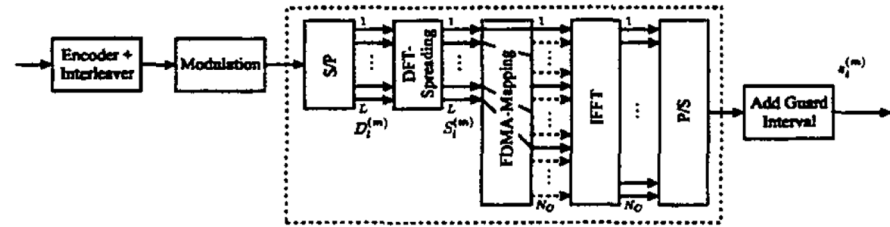
the transmit signal of user m can be written as

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

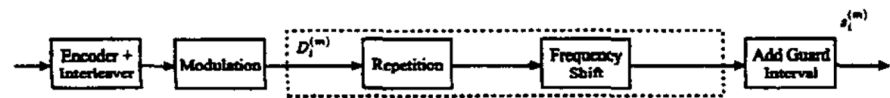
for $i = -N_C, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ sequence 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.
[17Bii] transmitting the single-carrier frequency division multiple access signal in the mobile radio communications network;	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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

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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:

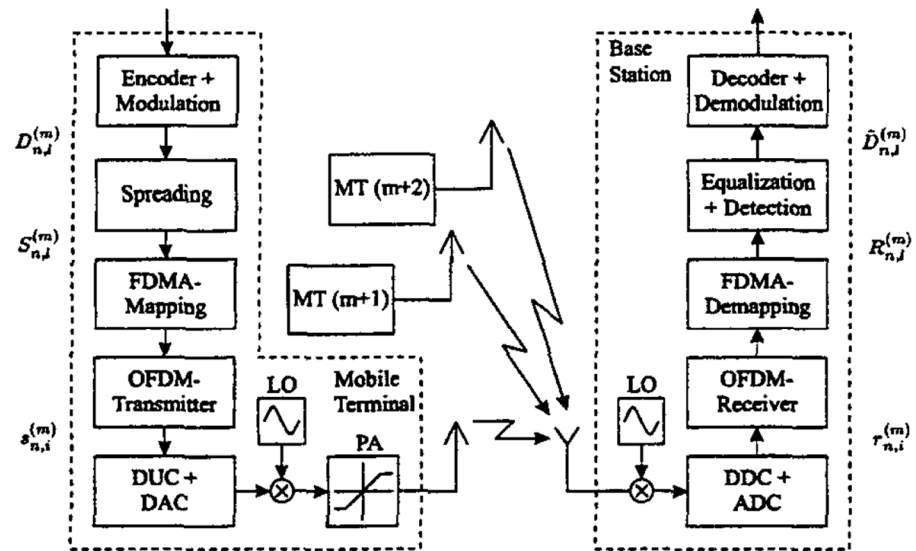
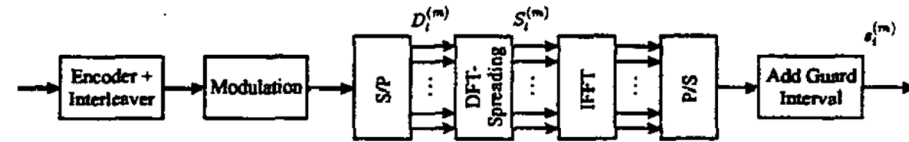


Fig. 1. Baseband system model for the OFDM-FDMA uplink with individual spreading of user data

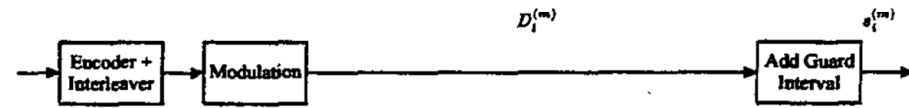
Galda-2002 at Fig. 1.

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(a) OFDM transmitter including DFT spreading over all subcarriers



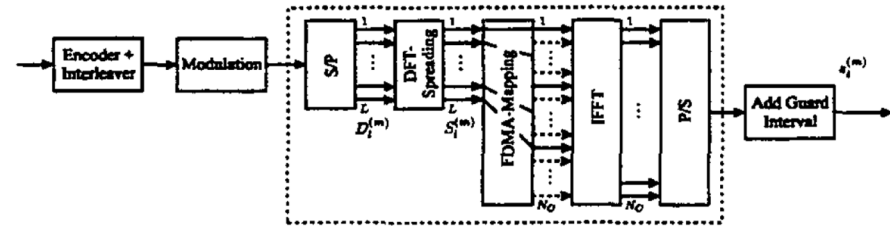
(b) Realistic but simplified OFDM transmitter structure

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.

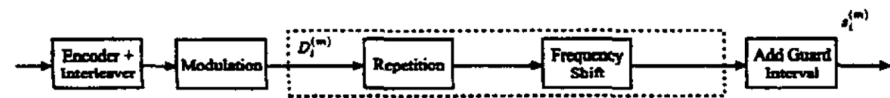
Galda-2002 at Fig. 4.

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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.

[17C] wherein provisioning the plurality of different selectable subcarrier spacings comprises providing the single-carrier frequency division multiple access signal with a particular one of a set of different symbol periods by selecting one of the plurality of different selectable subcarrier spacings.

While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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:

For example, Galda-2002 discloses:

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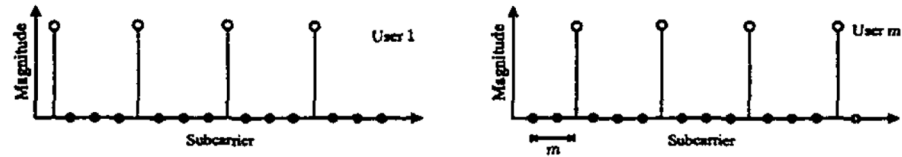


Fig. 2. User m allocates the equidistant subset of subcarriers shift by m subcarriers in the frequency domain

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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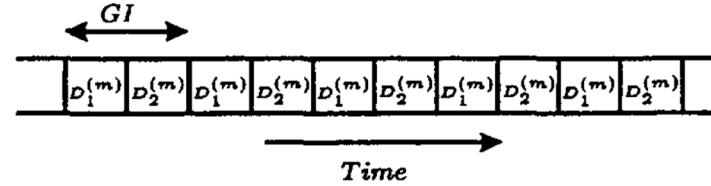


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

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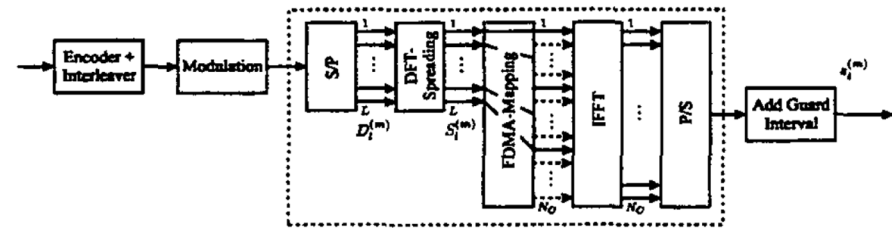
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$$\begin{aligned}
 s_i^{(m)} &= e^{j2\pi im/N_C} \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} \sum_{\nu=0}^{L-1} C_{l,\nu} D_{\nu}^{(m)} e^{-j2\pi il/L} \\
 &= e^{j2\pi im/N_C} \frac{1}{L} \sum_{\nu=0}^{L-1} D_{\nu}^{(m)} \underbrace{\sum_{l=0}^{L-1} e^{j2\pi(\nu-i)l/L}}_{=L\delta_L(\nu-i)}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

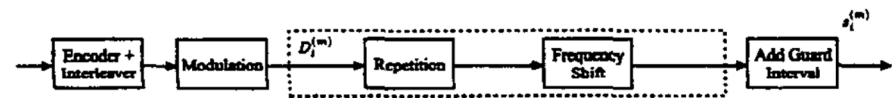
for $i = -N_C, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol $D_l^{(m)}$ sequence 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. Since the time signal of the OFDM-FDMA uplink with DFT spreading is identical to a single carrier transmission additional techniques to reduce the PAR originally developed for single carrier systems like the $\pi/4$-QPSK can be employed. 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.
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	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. Kaiser-1998, which discloses: This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA
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	systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers. • Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques. Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme. • MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink
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has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

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

Kaiser-1998 at 131.

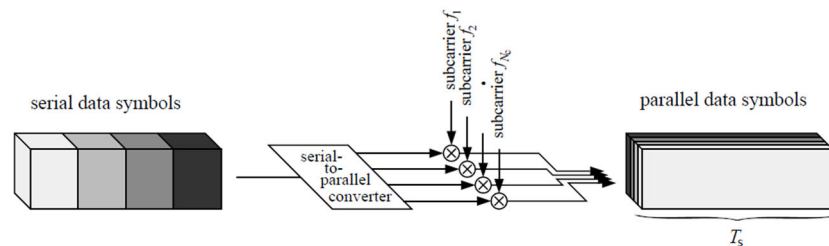


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

The progress in wireless communications entails a demand for higher data rates and, thus, shorter symbol durations. However, if the duration of the transmitted symbol becomes smaller than the time dispersion of the multipath channel, the performance of the wireless communication system suffers from ISI. This is a crucial problem since the receiver complexity is related to the amount of ISI. An approach to prevent ISI is offered by parallel data transmission [Cha66, Sal67, WeE71], referred to as MC communications. The principle of MC modulation, depicted in Fig. 1.3, is to convert a high rate data stream into N_c low-rate substreams, where N_c is the number of subcarriers used for data transmission. Each substream is modulated on its assigned subcarrier $f_n, n = 1, \dots, N_c$. Thus, the available channel bandwidth is subdivided into N_c narrow subbands, which ideally appear frequency non-selective. The data

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symbol rate per subcarrier is reduced by a factor N_c and with that, the ISI is reduced. A common realization of MC communications is conventional frequency division multiplexing where the subbands are completely separated in the frequency domain. However, due to finite steepness of the filter roll-offs, the subchannel spacing has to be greater than the Nyquist bandwidth to avoid inter-subchannel interference (ICI). This inefficient use of the available spectrum can be overcome by permitting spectral overlap between adjacent subchannels [Cha66, Sal67]. ICI can be avoided by guaranteeing orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s , known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbols of duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1/T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B.

Kaiser-1998 at 5-6.

3.1.1 Orthogonal Frequency Division Multiplexing

The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be

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	smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{S_n\}$ consisting of N_c complex-valued source symbols $S_n, n = 1, \dots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $S_n, n = 1, \dots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{S_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{S_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{S_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to $\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$ According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of $F_s = \frac{1}{T_s}. \quad (3.2)$ to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $S_n, n = 1, \dots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form
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$$x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} S_n \text{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$$

Kaiser-1998 at 31-32.

The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the 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 symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

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

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

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	$\frac{1}{T_c} = \frac{L}{T_d} \quad (3.27)$ and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector $\underline{s}^{(k)} = \underline{d}^{(k)} \underline{c}^{(k)} = \left(\underline{s}_1^{(k)}, \underline{s}_2^{(k)}, \dots, \underline{s}_L^{(k)} \right)^T. \quad (3.28)$ The rate of the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is $T'_s = T_g + N_c T_c. \quad (3.29)$ The transmission of one data symbol per user per OFDM symbol requires $N_c = L \quad (3.30)$ subcarriers. In this case, the OFDM symbol duration including the guard interval is $T'_s = T_g + T_d. \quad (3.31)$ Kaiser-1998 at 39-40. <i>M-Modification:</i> The intention of the <i>M-Modification</i> is to increase the number of subcarriers while maintaining constant the spreading code length and the maximum number of active users. Consequently, the OFDM symbol duration increases and the loss in bandwidth efficiency due to the guard
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interval decreases. Moreover, the tighter subcarrier spacing enables one to guarantee flat fading per subchannel in propagation scenarios with decreased coherence bandwidth. With the M -Modification, each user transmits simultaneously M greater than 1 data symbols per OFDM symbol. The total number of subcarriers of the modified MC-CDMA system is

$$N_c = ML. \quad (3.34)$$

Each user exploits the total of N_c subcarriers for data transmission. The OFDM symbol duration including the guard interval increases to

$$T'_s = T_g + MLT_c, \quad (3.35)$$

where it can be observed that the loss in bandwidth efficiency due to the guard interval decreases with increasing M . The maximum number of active users is still defined according to (3.32). The assigned MC-CDMA transmitter is shown in Fig. 3.8. The data symbol index $m, m = 1, \dots, M$, is introduced in Fig. 3.8 to distinguish the M simultaneously transmitted data symbols $\underline{d}_m^{(k)}, m = 1, \dots, M$, of the k th user. The number M is upper limited by the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), since the symbol duration T'_s , which increases with increasing M , has to be smaller than $(\Delta t)_c$ to guarantee that the channel is time-invariant during one OFDM symbol duration.

To optimally exploit frequency diversity, the components of the sequences $\underline{s}_m, m = 1, \dots, M$, transmitted in the same OFDM symbol are interleaved over the frequency. Subcarriers used for the transmission of $\underline{s}_m$ should have a spacing greater than the coherence bandwidth of the channel. Thus, the components of one sequence $\underline{s}_m$ are affected independently, reducing the probability that $\underline{s}_m$ is completely located in a deep fade. The interleaving is carried out prior to OFDM. The frequency interleaver can be a block interleaver which guarantees the maximum frequency separation between the components of $\underline{s}_m$. However, due to a possible periodicity of the fading process in frequency, the block interleaver can fail if the periodicity is

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	similar to the frequency separation between adjacent components. This effect can be reduced if a pseudo-random frequency interleaver is used. Kaiser-1998 at 41-42. The OFDM symbol duration including the guard interval is $T'_s = T_g + QLT_c. \quad (3.40)$ Kaiser-1998 at 44. <i>M&Q</i>-Modification: The <i>M&Q</i>-Modification is a combination of the <i>M</i>- and the <i>Q</i>-Modification, resulting in an MC-CDMA system with adjustable number of subcarriers and receiver complexity, keeping constant the maximum number of active users. The transmission of <i>M</i> data symbols per user and, additionally, the splitting of the users in <i>Q</i> independent user groups according to the <i>M&Q</i>-Modification is illustrated in Fig. 3.10. The total number of subcarriers used by the MC-CDMA system with <i>M&Q</i>-Modification is $N_c = QML, \quad (3.41)$ where each user only exploits a subset of <i>M L</i> subcarriers for data transmission due to the FDMA component introduced by the <i>Q</i>-Modification. The maximum number of active users is given by (3.38). The total OFDM symbol duration including the guard interval results with the <i>M&Q</i>-Modification in $T'_s = T_g + QMLT_c. \quad (3.42)$ Kaiser-1998 at 44. R1-021246, which discloses: The sub-carrier spacing should be large enough to provide robustness against frequency offset and phase noise, but it also has to be small enough such that each sub-carrier experiences flat fading. Normally, the tone (or sub-carrier) spacing can be selected by first fixing a maximum delay spread from all
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	possible channel conditions, calculating the coherence bandwidth and then using it as an upper bound for the sub-carrier spacing. From [3], the Pedestrian A, Pedestrian B, and Vehicular A channel model, have maximum delay spread at 410ns, 3.7usec and 2.5usec, respectively. We suggest that a maximum delay spread of 10 usec be considered for the design of the OFDM system. The 10-usec suggestion takes into account only the cyclic prefix, some extra guard time should be added to allow some ramp-up and ramp-down period for the power amplifier. Time domain filtering maybe necessary to avoid the spurious effect due to the possible sudden transition between the consecutive OFDM symbols. In order to reduce the out of band emissions effectively, a raise cosine window with roll-off factor equal to one should be allowed. Note that it is observed that in a simulcast environment, the signal coming from the other cell is most likely the dominant multi-path which has longer delay than the non-simulcast signal. Therefore, larger delay spread should be considered if multicast and simulcast services are of interest. Table 2 shows some parameters for coherence bandwidth based on various definitions stated in [2]. R1-021246 at 2. FFT Size From Table 1., assuming the nominal UE speed is less than 120 km/hr, we can choose the OFDM symbol duration up to 805.5 usec as long as it does not violate the coherence bandwidth dictated by Table 2. To keep the time domain overhead, i.e. the cyclic prefix and guard time, small, it is desirable to limit the amount of time overhead to be less than 10% of the time domain symbol duration. Table 3. summarized the number of sub-carried allowed under 5, 10, and 15% time domain overhead (T_g) assumptions, and the number of FFT points required to implement it. Note that T_u is the useful/signal part of the symbol, and T_g is the guard time. The number sub-carriers can be supported in a 5MHz bandwidth is given by $\lfloor 5MHz/T_u \rfloor$, where the numbers are rounded to the nearest integers from below.
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R1-021246 at 2.

No. Sym/TS	OFDM Symbol period ($T_u + T_g$)	No of tones w/ 5% time overhead	No. of FFT points	No of tones w/ 10% time overhead	No. of FFT points	No of tones w/ 15% time overhead	No. of FFT points
1	667 usec	3166	4096	3000	4096	2833	4096
2	333 usec	1583	2048	1500	2048	1416	2048
3	222 usec	1055	2048	1000	1024	944	1024
4	167 usec	791	1024	750	1024	708	1024
5	133 usec	644	1024	600	1024	566	1024

6	111 usec	527	1024	500	512	472	512
7	95.2 usec	452	512	428	512	404	512
8	83.3 usec	395	512	375	512	354	512
9	74.1 usec	351	512	333	512	314	512
10	66.7 usec	316	512	300	512	283	512
11	60.6 usec	287	512	272	512	257	512
12	55.6 usec	263	512	250	256	236	256
13	51.3 usec	243	256	230	256	217	256
14	47.6 usec	226	256	214	256	202	256
15	44.4 usec	211	256	200	256	188	256
16	41.7 usec	197	256	187	256	177	256

Table 3. Number of Symbols per Time slot vs. Number of possible sub-carriers over 5MHz bandwidth vs. Number of FFT points needed

R1-021246 at Table 3.

It can be seen that with less than 10% time overhead, the most efficient choices of the FFT operations are 1024, 512, and 256 at 3, 6, and 12 symbols per time slot. To guarantee the highest data rate, all 1024, 512 or 256 sub-carriers should be used to transmit. The smaller the number of sub-carriers is, the wider the subcarrier spacing becomes which leads to robustness against frequency offset and phase noise.

R1-021246 at 3.

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	Based on the above discussion, we would like propose a baseline system with multiple configurations suitable for different channel conditions. Some benefit of having multiple configurations are: (1) To allow shorter symbol durations when the multipath is less severe, this would result in wider subcarrier spacing which would make the system more immune to frequency offset (2) To use shorter symbol duration which makes the system less susceptible to high Doppler and hence reduces the ICI (3) To use smaller size FFT which lowers the power consumption and the UE complexity. These multiple configurations have the same sampling frequency, which will simplify the receiver implementation while allowing UE to switch smoothly to different configurations supported by the Node Bs in different multipath environments. R1-021246 at 3-5. Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a 1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system’s resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations. R1-021246 at 5.
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System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

R1-021246 at Table 4.

We have suggested an OFDM system with multiple configurations that can be deployed in different environments. The system is designed to fit into the current UMTS time slot structure. If agreed upon, the system will be used as a baseline for future OFDM study.

R1-021246 at 7.

Dolle-010, which discloses:

The subcarrier spacings of the OFDM system can be identical in the first transmission frequency band and the second transmission frequency band.

The subcarrier spacings of the OFDM system in the first transmission frequency band and the second transmission frequency band alternatively can satisfy the following equation:

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	$\Delta F_1 / \Delta F_2 = k * 2^i,$ wherein ΔF_1 and ΔF_2 are the subcarrier spacings used in the OFDM systems in the first transmission frequency band and the second transmission frequency band, respectively, and k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implementation of the baseband block to process the OFDM signals and/or symbols. Dolle-010 at 3:25-41.
[Claim 18] The apparatus of claim 17, wherein at least one of the plurality of different selectable subcarrier spacings equals at least one other of the plurality of different selectable subcarrier spacings multiplied by a scaling factor that is a power of two.	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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: For example, Galda-2002 discloses: 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

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	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. Kaiser-1998, which discloses: This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA
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	systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers. • Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques. Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme. • MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink
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has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

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

Kaiser-1998 at 131.

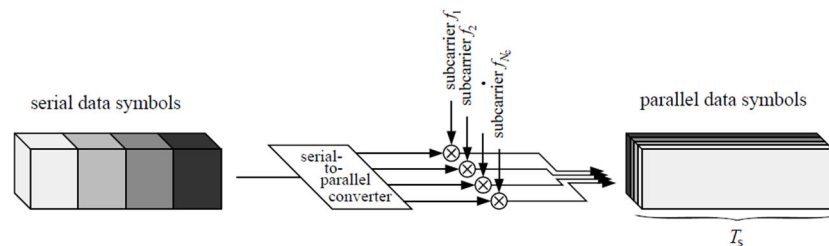


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

The progress in wireless communications entails a demand for higher data rates and, thus, shorter symbol durations. However, if the duration of the transmitted symbol becomes smaller than the time dispersion of the multipath channel, the performance of the wireless communication system suffers from ISI. This is a crucial problem since the receiver complexity is related to the amount of ISI. An approach to prevent ISI is offered by parallel data transmission [Cha66, Sal67, WeE71], referred to as MC communications. The principle of MC modulation, depicted in Fig. 1.3, is to convert a high rate data stream into N_c low-rate substreams, where N_c is the number of subcarriers used for data transmission. Each substream is modulated on its assigned subcarrier $f_n, n = 1, \dots, N_c$. Thus, the available channel bandwidth is subdivided into N_c narrow subbands, which ideally appear frequency non-selective. The data

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symbol rate per subcarrier is reduced by a factor N_c and with that, the ISI is reduced. A common realization of MC communications is conventional frequency division multiplexing where the subbands are completely separated in the frequency domain. However, due to finite steepness of the filter roll-offs, the subchannel spacing has to be greater than the Nyquist bandwidth to avoid inter-subchannel interference (ICI). This inefficient use of the available spectrum can be overcome by permitting spectral overlap between adjacent subchannels [Cha66, Sal67]. ICI can be avoided by guaranteeing orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s , known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbols of duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1/T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B.

Kaiser-1998 at 5-6.

3.1.1 Orthogonal Frequency Division Multiplexing

The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be

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	smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{S_n\}$ consisting of N_c complex-valued source symbols $S_n, n = 1, \dots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $S_n, n = 1, \dots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{S_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{S_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{S_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to $\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$ According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of $F_s = \frac{1}{T_s}. \quad (3.2)$ to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $S_n, n = 1, \dots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form
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	$x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} S_n \operatorname{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$ Kaiser-1998 at 31-32. The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be transmitted over the radio channel is taken from the complex data symbol alphabet $\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \quad (3.24)$ of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $\log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code $\underline{c}^{(k)} = \left(\underline{c}_1^{(k)}, \underline{c}_2^{(k)}, \dots, \underline{c}_L^{(k)} \right)^T \quad (3.25)$ of the kth user. The chips $\underline{c}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet $\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \quad (3.26)$ of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is
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	$\frac{1}{T_c} = \frac{L}{T_d} \quad (3.27)$ and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector $\underline{s}^{(k)} = \underline{d}^{(k)} \underline{c}^{(k)} = \left(\underline{s}_1^{(k)}, \underline{s}_2^{(k)}, \dots, \underline{s}_L^{(k)} \right)^T. \quad (3.28)$ The rate of the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is $T'_s = T_g + N_c T_c. \quad (3.29)$ The transmission of one data symbol per user per OFDM symbol requires $N_c = L \quad (3.30)$ subcarriers. In this case, the OFDM symbol duration including the guard interval is $T'_s = T_g + T_d. \quad (3.31)$ Kaiser-1998 at 39-40. <i>M-Modification:</i> The intention of the <i>M-Modification</i> is to increase the number of subcarriers while maintaining constant the spreading code length and the maximum number of active users. Consequently, the OFDM symbol duration increases and the loss in bandwidth efficiency due to the guard
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interval decreases. Moreover, the tighter subcarrier spacing enables one to guarantee flat fading per subchannel in propagation scenarios with decreased coherence bandwidth. With the M -Modification, each user transmits simultaneously M greater than 1 data symbols per OFDM symbol. The total number of subcarriers of the modified MC-CDMA system is

$$N_c = ML. \quad (3.34)$$

Each user exploits the total of N_c subcarriers for data transmission. The OFDM symbol duration including the guard interval increases to

$$T'_s = T_g + MLT_c, \quad (3.35)$$

where it can be observed that the loss in bandwidth efficiency due to the guard interval decreases with increasing M . The maximum number of active users is still defined according to (3.32). The assigned MC-CDMA transmitter is shown in Fig. 3.8. The data symbol index $m, m = 1, \dots, M$, is introduced in Fig. 3.8 to distinguish the M simultaneously transmitted data symbols $\underline{d}_m^{(k)}, m = 1, \dots, M$, of the k th user. The number M is upper limited by the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), since the symbol duration T'_s , which increases with increasing M , has to be smaller than $(\Delta t)_c$ to guarantee that the channel is time-invariant during one OFDM symbol duration.

To optimally exploit frequency diversity, the components of the sequences $\underline{s}_m, m = 1, \dots, M$, transmitted in the same OFDM symbol are interleaved over the frequency. Subcarriers used for the transmission of $\underline{s}_m$ should have a spacing greater than the coherence bandwidth of the channel. Thus, the components of one sequence $\underline{s}_m$ are affected independently, reducing the probability that $\underline{s}_m$ is completely located in a deep fade. The interleaving is carried out prior to OFDM. The frequency interleaver can be a block interleaver which guarantees the maximum frequency separation between the components of $\underline{s}_m$. However, due to a possible periodicity of the fading process in frequency, the block interleaver can fail if the periodicity is

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	similar to the frequency separation between adjacent components. This effect can be reduced if a pseudo-random frequency interleaver is used. Kaiser-1998 at 41-42. The OFDM symbol duration including the guard interval is $T'_s = T_g + QLT_c. \quad (3.40)$ Kaiser-1998 at 44. <i>M&Q</i>-Modification: The <i>M&Q</i>-Modification is a combination of the <i>M</i>- and the <i>Q</i>-Modification, resulting in an MC-CDMA system with adjustable number of subcarriers and receiver complexity, keeping constant the maximum number of active users. The transmission of <i>M</i> data symbols per user and, additionally, the splitting of the users in <i>Q</i> independent user groups according to the <i>M&Q</i>-Modification is illustrated in Fig. 3.10. The total number of subcarriers used by the MC-CDMA system with <i>M&Q</i>-Modification is $N_c = QML, \quad (3.41)$ where each user only exploits a subset of <i>M L</i> subcarriers for data transmission due to the FDMA component introduced by the <i>Q</i>-Modification. The maximum number of active users is given by (3.38). The total OFDM symbol duration including the guard interval results with the <i>M&Q</i>-Modification in $T'_s = T_g + QMLT_c. \quad (3.42)$ Kaiser-1998 at 44. R1-021246, which discloses: Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a
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1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system’s resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations.

R1-021246 at 5.

System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

R1-021246 at Table 4.

Böhnke-501, which discloses:

According to the present invention, a number of subcarriers of an OFDM/TDMA-system is allocated to each GSM-frequency channel so that a multiple of one resulting OFDM/TDMA-timeslot matches with one or a multiple of one GSM-timeslot. The spacing between two adjacent GSM-

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frequency channels is 200 kHz, and the length of a GSM-timeslot is 15/26 ms. According to the present invention, one GSM-frequency channel is divided into a number of subcarriers. The number of subcarriers is chosen, so that a multiple of one resulting OFDM/TDMA-timeslot fits well in one or a multiple of one GSM-timeslot. The transformation of one subcarrier from the frequency domain into the time domain results in an OFDM/TDMA-time burst, which builds the largest part of the resulting OFDM/TDMA-timeslot. In FIG. 7, the basic structure of an OFDM/TDMA-timeslot is shown as containing an OFDM/TDMA-time burst, whereby the length of the OFDM/TDMA-timeburst T_{OFDM} corresponds to the effective Modulation Period and depends on the subcarrier-spacing (1/subcarrier-spacing). The subcarrier spacing depends on the number of subcarriers allocated to one GSM-frequency channel of 200 kHz. A guard time TG (or pre-guard time) is disposed in advance of the OFDM/TDMA-time burst T_{OFDM} .

In FIG. 8, the detailed structure of an OFDM/TDMA-timeslot is shown. The length of the OFDM/TDMA-timeslot corresponds to the modulation period and has a length of a μ s. After the transformation of the subcarriers into the time domain, whereby the OFDM/TDMA-timebursts are produced, a guard time consisting of the pre-guard time of length c μ s and a post-guard time is of length e μ s is added to the OFDM-TDMA-timebursts. The OFDM/TDMA-timebursts correspond to the effective modulation period and have a length b μ s. Then, before transmitting, the ramp of the time domain signal is shaped according to a raised cosine function, as shown in FIG. 8, to reduce spurious emissions. As can be seen In FIG. 8, the ramp time in the front part and the back part of the OFDM/TDMA-timeslot, respectively, has a length d μ s and overlaps partially with the pre-guard time and the post-guard time, respectively. The length of the post-guard time can be o μ s. At the beginning of the OFDM/TDMA-timeslot there is located a pre-idle time in advance of the ramp time and at the end of the OFDM/TDMA-timeslot there is located a post-idle time behind the ramp time. The length of each of the pre-idle time and the post-idle time is f μ s. Therefore, the resulting OFDM/TDMA-timeslot is composed of the OFDM/TDMA-timeburst (effective modulation period),

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	the guard time consisting of the pre-guard time and the post-guard time, the ramp times and the pre-idle time and the post-idle time. The length b of the OFDM/TDMA-timeburst depends on the subcarrier spacing ($b=1/f_{SCS}$), where f_{SCS} is the subcarrier in Hz. According to the present invention, the length a of one OFDM/TDMA-timeslot can for example correspond to 1, $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$ GSM-timeslot. Böhnke-501 at 4:14-67. In a 1st embodiment, the total number of subcarriers is 48, whereby one or more subcarriers on the borders can be left unmodulated to reduce interference to adjacent frequency slots. The resulting subcarrier spacing is $200 \text{ kHz}/48=4.166 \text{ Hz}$, which leads to an OFDM/TDMA-time burst T_{OFDM} of $48/200 \text{ kHz}=240 \text{ }\mu\text{s}$. The symbol duration ($240 \text{ }\mu\text{s}$) is therefore very long compared to the GSM-symbol duration (range of μs), which has the advantage of avoiding inter-symbol interference due to the radio channel delay profile. The guard time (pre-guard time and post-guard time) in the first embodiment is set to $30 \text{ }\mu\text{s}$, whereby it has to be noted that the guard time has to be set according to the expected channel delay profile (multipath environment). The ramp time is set to 10 to $20 \text{ }\mu\text{s}$, so that the total OFDM/TDMA-timeslot T_s has a length of 280 to $290 \text{ }\mu\text{s}$. This fits very well into $\frac{1}{2}$ of the basic GSM-timeslot of $576 \text{ } 923 \text{ }\mu\text{s}$. Therefore, in the 1st embodiment, two OFDM/TDMA-timeslots are mapped into one GSM-timeslot with an adaptation time guard, if necessary. The basic clock is $240 \text{ }\mu\text{s}/64=3.75 \text{ }\mu\text{s}$. The guard time (pre- and post guard time) can be set to $30 \text{ }\mu\text{s}$ (pre-guard: $22.5 \text{ }\mu\text{s}=6 \text{ samples}$, post-guard: $7.5 \text{ }\mu\text{s}=2 \text{ samples}$) and the ramp time can be set to $15.0 \text{ }\mu\text{s}$ ($=4 \text{ samples}$) which leads to a total symbol time of $(250 \text{ }\mu\text{s}/64)*(64+6+2+4)=285 \text{ }\mu\text{s}$. Böhnke-501 at 6:7-31. In the 3rd embodiment, the total number of subcarriers is chosen to be 24, wherein one or more subcarriers at the borders can be left unmodulated to
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	reduce interference to adjacent frequency slots. The subcarrier spacing is $200 \text{ kHz}/24=8.33 \text{ kHz}$, which leads to an OFDM/TDMA-burst of $1/8.33 \text{ kHz}=120 \mu\text{s}$. The guard time (pre- and post guard time) can be set to $15 \mu\text{s}$ and the ramp time can be set to $9 \mu\text{s}$, which leads to a total OFDM/TDMA-timeslot of $144 \mu\text{s}$. 4 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. The scheme according to the 3rd embodiment is very advantageous for fast varying channel environments. In other words, one OFDM/TDMA-timeslot T_s is mapped into $\frac{1}{4}$ of one GSM-timeslot. The basic clock is set to $120 \mu\text{s}/32=3.75 \mu\text{s}$. to be more precise, the guard time (pre- and post guard time) can be set to $15 \mu\text{s}$ (pre-guard: $11.25 \mu\text{s}=3$ samples, post-guard: $3.75 \mu\text{s}=1$ sample) and the ramp time can be set to $7.5 \mu\text{s}$ ($=2$ samples) which leads to a total symbol time of $(120 \mu\text{s}/32)*(32+3+1+2)=142.5 \mu\text{s}$. Böhnke-501 at 7:9-27. Dolle-010, which discloses: The subcarrier spacings of the OFDM system can be identical in the first transmission frequency band and the second transmission frequency band. The subcarrier spacings of the OFDM system in the first transmission frequency band and the second transmission frequency band alternatively can satisfy the following equation: $\Delta F_1/\Delta F_2 = k * 2^i,$ wherein ΔF_1 and ΔF_2 are the subcarrier spacings used in the OFDM systems in the first transmission frequency band and the second transmission frequency band, respectively, and k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implementation of the baseband block to process the OFDM signals and/or symbols.
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	Dolle-010 at 3:25-41. According to the present invention, a channel mapping solution particularly for an OFDM system is provided. Thereby a solution is proposed for an OFDM system transmitting a dual frequency band and providing interoperability with a coexisting OFDM system. The following system parameters thereby are taken into account: total number of subcarriers: N_1, N_2 channel bandwidth: B_{C1}, B_{C2}, and subcarrier spacings: $\Delta F_1, \Delta F_2$ Between the above parameters the following relation exists: $\Delta F = \frac{B_C}{N}$ According to the present invention ΔF_1 can be equal to ΔF_2, which means the same subcarrier spacing in both frequency ranges and/or systems is used. Therefore $\frac{B_{C1}}{N_1} = \frac{B_{C2}}{N_2} \quad \text{or} \quad B_{C1} \times N_2 = B_{C2} \times N_1.$ The above equations can be rewritten $B_{C1} \times n = B_{C2} \times m \quad \text{and} \quad N_1 \times n = N_2 \times m,$ wherein the ratio n/m satisfies the following equation: $n/m = k \times 2_i,$ wherein k is a positive integer value and i is a negative or positive integer value including zero. The above selection of the ratios n/m is particularly advantageous for the effective implementation of the FFT algorithm generating the OFDM symbols. In FIG. 3 the two OFDM systems channel mapping is depicted.
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	In the example shown in FIG. 3 $n = 8$ and $m = 1$, which means ideally 8 channels of the OFDM system (system 1) operating in the lower frequency band can be mapped to one channel of the OFDM system (system 2) operating in the dual frequency bands. Depending on the required guard band ($F_{\text{guard } 2}$) between the channels in the upper frequency band the actual mapping of the system 1 channels could be limited to channel 2 through channel 7. The same subcarrier spacings are kept for both systems and/or frequency bands, thereby giving the highest efficiency of interoperability. In general the ratio of $\Delta F_1/\Delta F_2$ is selected to satisfy the following equation: $\frac{\Delta F_1}{\Delta F_2} = k \times 2^i,$ wherein k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implement of the base-band block to process the OFDM signals and/or symbols. Dolle-010 at 5:56-6:56.
[Claim 19] The apparatus of claim 17, wherein the OFDM transceiver is further configured to add a cyclic prefix to the single-carrier frequency division multiple access signal.	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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: 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

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	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-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
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to reduce the computational complexity of the transmitter of the mobile terminal.

Galda-2002 at 1737-38.

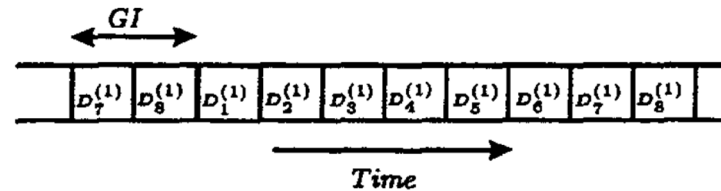


Fig. 3. Time signal of an OFDM-TDMA system with DFT spreading

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

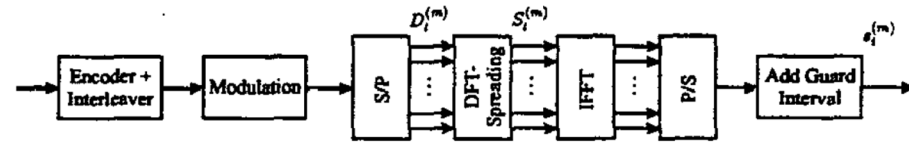
$$s_i^{(1)} = D_{i \bmod N_C} \quad \text{for } i = -N_G, \dots, 0, \dots, N_C \quad (5)$$

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

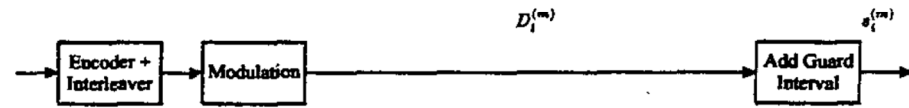
Galda-2002 at 1739.

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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.

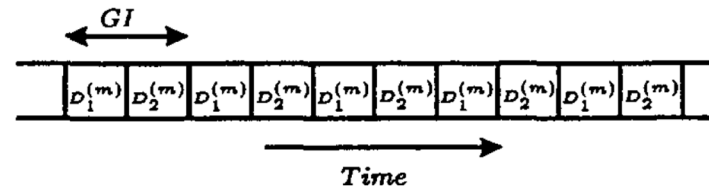


Fig. 5. Time signal of an OFDM-FDMA uplink system with DFT spreading is characterized by a periodic repetition ($N_C = 8, M = 4$)

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

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

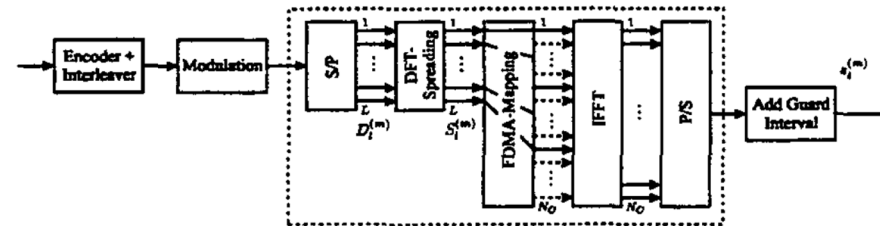
for $i = -N_C, \dots, 0, \dots, N_C$ and the periodic dirac pulse sequence $\delta_L(\cdot)$. The transmit time signal $s_i^{(m)}$ of user m in an OFDM-FDMA uplink using DFT spreading matrix and an equidistant subcarrier allocation results therefore in a periodic repetition of the complex user data symbol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

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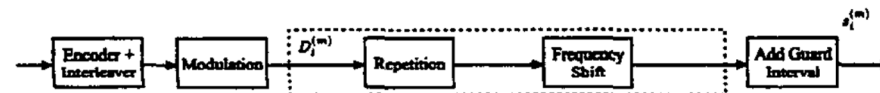
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an added guard interval as cyclic prefix, shown in Fig. 5. This periodic data sequence is multiplied by a user specific complex signal $e^{j2\pi im/N_c}$ due to the user individual frequency shift by m subcarriers of the complete allocated subcarrier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

[Claim 20] The apparatus of claim 17, wherein the plurality of different selectable

While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can perform the claimed

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subcarrier spacings comprise integer multiples of a first subcarrier spacing.

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:

For example, Galda-2002 discloses:

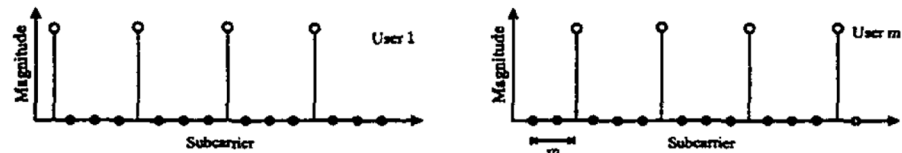


Fig. 2. User m allocates the equidistant subset of subcarriers shift by m subcarriers in the frequency domain

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.

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	Galda-2002 at 1738. Kaiser-1998, which discloses: This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers.
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	• Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques. Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme. • MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation. • In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity.
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Kaiser-1998 at 131.

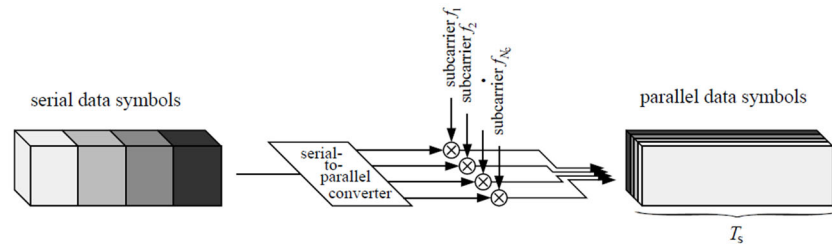


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

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

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	orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s, known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbols of duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1 = T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B. Kaiser-1998 at 5-6. 3.1.1 Orthogonal Frequency Division Multiplexing The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{S_n\}$ consisting of N_c complex-valued source symbols $S_n, n = 1, \dots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $S_n, n = 1, \dots, N_c$,
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	each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{S_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{S_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{S_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to $\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$ According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of $F_s = \frac{1}{T_s}. \quad (3.2)$ to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $S_n, n = 1, \dots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form $x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} S_n \operatorname{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$ Kaiser-1998 at 31-32. The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig.
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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 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

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

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	The rate of the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is $T'_s = T_g + N_c T_c. \quad (3.29)$ The transmission of one data symbol per user per OFDM symbol requires $N_c = L \quad (3.30)$ subcarriers. In this case, the OFDM symbol duration including the guard interval is $T'_s = T_g + T_d. \quad (3.31)$ Kaiser-1998 at 39-40. <i>M</i>-Modification: The intention of the <i>M</i>-Modification is to increase the number of subcarriers while maintaining constant the spreading code length and the maximum number of active users. Consequently, the OFDM symbol duration increases and the loss in bandwidth efficiency due to the guard interval decreases. Moreover, the tighter subcarrier spacing enables one to guarantee flat fading per subchannel in propagation scenarios with decreased coherence bandwidth. With the <i>M</i>-Modification, each user transmits simultaneously M greater than 1 data symbols per OFDM symbol. The total number of subcarriers of the modified MC-CDMA system is $N_c = ML. \quad (3.34)$
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	Each user exploits the total of N_c subcarriers for data transmission. The OFDM symbol duration including the guard interval increases to $T'_s = T_g + MLT_c, \quad (3.35)$ where it can be observed that the loss in bandwidth efficiency due to the guard interval decreases with increasing M. The maximum number of active users is still defined according to (3.32). The assigned MC-CDMA transmitter is shown in Fig. 3.8. The data symbol index $m, m = 1, \dots, M$, is introduced in Fig. 3.8 to distinguish the M simultaneously transmitted data symbols $\underline{d}_m^{(k)}, m = 1, \dots, M$, of the kth user. The number M is upper limited by the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), since the symbol duration T'_s, which increases with increasing M, has to be smaller than $(\Delta t)_c$ to guarantee that the channel is time-invariant during one OFDM symbol duration. To optimally exploit frequency diversity, the components of the sequences $\underline{s}_m, m = 1, \dots, M$, transmitted in the same OFDM symbol are interleaved over the frequency. Subcarriers used for the transmission of $\underline{s}_m$ should have a spacing greater than the coherence bandwidth of the channel. Thus, the components of one sequence $\underline{s}_m$ are affected independently, reducing the probability that $\underline{s}_m$ is completely located in a deep fade. The interleaving is carried out prior to OFDM. The frequency interleaver can be a block interleaver which guarantees the maximum frequency separation between the components of $\underline{s}_m$. However, due to a possible periodicity of the fading process in frequency, the block interleaver can fail if the periodicity is similar to the frequency separation between adjacent components. This effect can be reduced if a pseudo-random frequency interleaver is used. Kaiser-1998 at 41-42. The OFDM symbol duration including the guard interval is $T'_s = T_g + QLT_c. \quad (3.40)$
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	Kaiser-1998 at 44. <i>M&Q</i>-Modification: The <i>M&Q</i>-Modification is a combination of the <i>M</i>- and the <i>Q</i>-Modification, resulting in an MC-CDMA system with adjustable number of subcarriers and receiver complexity, keeping constant the maximum number of active users. The transmission of <i>M</i> data symbols per user and, additionally, the splitting of the users in <i>Q</i> independent user groups according to the <i>M&Q</i>-Modification is illustrated in Fig. 3.10. The total number of subcarriers used by the MC-CDMA system with <i>M&Q</i>-Modification is $N_c = QML, \quad (3.41)$ where each user only exploits a subset of <i>M L</i> subcarriers for data transmission due to the FDMA component introduced by the <i>Q</i>-Modification. The maximum number of active users is given by (3.38). The total OFDM symbol duration including the guard interval results with the <i>M&Q</i>-Modification in $T'_s = T_g + QMLT_c. \quad (3.42)$ Kaiser-1998 at 44. R1-021246, which discloses: Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a 1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system’s resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations.
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R1-021246 at 5.

System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

R1-021246 at Table 4.

Böhnke-501, which discloses:

According to the present invention, a number of subcarriers of an OFDM/TDMA-system is allocated to each GSM-frequency channel so that a multiple of one resulting OFDM/TDMA-timeslot matches with one or a multiple of one GSM-timeslot. The spacing between two adjacent GSM-frequency channels is 200 kHz, and the length of a GSM-timeslot is 15/26 ms. According to the present invention, one GSM-frequency channel is divided into a number of subcarriers. The number of subcarriers is chosen, so that a multiple of one resulting OFDM/TDMA-timeslot fits well in one or a multiple of one GSM-timeslot. The transformation of one subcarrier from the frequency domain into the time domain results in an OFDM/TDMA-time burst, which builds the largest part of the resulting

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	OFDM/TDMA-timeslot. In FIG. 7, the basic structure of an OFDM/TDMA-timeslot is shown as containing an OFDM/TDMA-time burst, whereby the length of the OFDM/TDMA-timeburst T_{OFDM} corresponds to the effective Modulation Period and depends on the subcarrier-spacing (1/subcarrier-spacing). The subcarrier spacing depends on the number of subcarriers allocated to one GSM-frequency channel of 200 kHz. A guard time TG (or pre-guard time) is disposed in advance of the OFDM/TDMA-time burst T_{OFDM}. In FIG. 8, the detailed structure of an OFDM/TDMA-timeslot is shown. The length of the OFDM/TDMA-timeslot corresponds to the modulation period and has a length of a μs. After the transformation of the subcarriers into the time domain, whereby the OFDM/TDMA-timebursts are produced, a guard time consisting of the pre-guard time of length c μs and a post-guard time is of length e μs is added to the OFDM-TDMA-timebursts. The OFDM/TDMA-timebursts correspond to the effective modulation period and have a length b μs. Then, before transmitting, the ramp of the time domain signal is shaped according to a raised cosine function, as shown in FIG. 8, to reduce spurious emissions. As can be seen In FIG. 8, the ramp time in the front part and the back part of the OFDM/TDMA-timeslot, respectively, has a length d μs and overlaps partially with the pre-guard time and the post-guard time, respectively. The length of the post-guard time can be o μs. At the beginning of the OFDM/TDMA-timeslot there is located a pre-idle time in advance of the ramp time and at the end of the OFDM/TDMA-timeslot there is located a post-idle time behind the ramp time. The length of each of the pre-idle time and the post-idle time is f μs. Therefore, the resulting OFDM/TDMA-timeslot is composed of the OFDM/TDMA-timeburst (effective modulation period), the guard time consisting of the pre-guard time and the post-guard time, the ramp times and the pre-idle time and the post-idle time. The length b of the OFDM/TDMA-timeburst depends on the subcarrier spacing ($b=1/f_{SCS}$), where f_{SCS} is the subcarrier in Hz. According to the present invention, the length a of one OFDM/TDMA-timeslot can for example correspond to 1, $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$ GSM-timeslot.
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	Böhnke-501 at 4:14-67. In a 1st embodiment, the total number of subcarriers is 48, whereby one or more subcarriers on the borders can be left unmodulated to reduce interference to adjacent frequency slots. The resulting subcarrier spacing is $200 \text{ kHz}/48=4.166 \text{ Hz}$, which leads to an OFDM/TDMA-time burst T_{OFDM} of $48/200 \text{ kHz}=240 \text{ }\mu\text{s}$. The symbol duration ($240 \text{ }\mu\text{s}$) is therefore very long compared to the GSM-symbol duration (range of μs), which has the advantage of avoiding inter-symbol interference due to the radio channel delay profile. The guard time (pre-guard time and post-guard time) in the first embodiment is set to $30 \text{ }\mu\text{s}$, whereby it has to be noted that the guard time has to be set according to the expected channel delay profile (multipath environment). The ramp time is set to 10 to $20 \text{ }\mu\text{s}$, so that the total OFDM/TDMA-timeslot T_s has a length of 280 to $290 \text{ }\mu\text{s}$. This fits very well into $\frac{1}{2}$ of the basic GSM-timeslot of $576 \text{ } 923 \text{ }\mu\text{s}$. Therefore, in the 1st embodiment, two OFDM/TDMA-timeslots are mapped into one GSM-timeslot with an adaptation time guard, if necessary. The basic clock is $240 \text{ }\mu\text{s}/64=3.75 \text{ }\mu\text{s}$. The guard time (pre- and post guard time) can be set to $30 \text{ }\mu\text{s}$ (pre-guard: $22.5 \text{ }\mu\text{s}=6 \text{ samples}$, post-guard: $7.5 \text{ }\mu\text{s}=2 \text{ samples}$) and the ramp time can be set to $15.0 \text{ }\mu\text{s}$ ($=4 \text{ samples}$) which leads to a total symbol time of $(250 \text{ }\mu\text{s}/64)*(64+6+2+4)=285 \text{ }\mu\text{s}$. Böhnke-501 at 6:7-31. In the 3rd embodiment, the total number of subcarriers is chosen to be 24, wherein one or more subcarriers at the borders can be left unmodulated to reduce interference to adjacent frequency slots. The subcarrier spacing is $200 \text{ kHz}/24=8.33 \text{ kHz}$, which leads to an OFDM/TDMA-burst of $1/8.33 \text{ kHz}=120 \text{ }\mu\text{s}$. The guard time (pre- and post guard time) can be set to $15 \text{ }\mu\text{s}$ and the ramp time can be set to $9 \text{ }\mu\text{s}$, which leads to a total OFDM/TDMA-timeslot of $144 \text{ }\mu\text{s}$. 4 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. The scheme according to the 3rd embodiment is very
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	advantageous for fast varying channel environments. In other words, one OFDM/TDMA-timeslot T_s is mapped into $\frac{1}{4}$ of one GSM-timeslot. The basic clock is set to $120 \mu\text{s}/32=3.75 \mu\text{s}$. to be more precise, the guard time (pre- and post guard time) can be set to $15 \mu\text{s}$ (pre-guard: $11.25 \mu\text{s}=3$ samples, post-guard: $3.75 \mu\text{s}=1$ sample) and the ramp time can be set to $7.5 \mu\text{s}$ ($=2$ samples) which leads to a total symbol time of $(120 \mu\text{s}/32)*(32+3+1+2)=142.5 \mu\text{s}$. Böhnke-501 at 7:9-27. Dolle-010, which discloses: The subcarrier spacings of the OFDM system can be identical in the first transmission frequency band and the second transmission frequency band. The subcarrier spacings of the OFDM system in the first transmission frequency band and the second transmission frequency band alternatively can satisfy the following equation: $\Delta F_1/\Delta F_2 = k * 2^i,$ wherein ΔF_1 and ΔF_2 are the subcarrier spacings used in the OFDM systems in the first transmission frequency band and the second transmission frequency band, respectively, and k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implementation of the baseband block to process the OFDM signals and/or symbols. Dolle-010 at 3:25-41. According to the present invention, a channel mapping solution particularly for an OFDM system is provided. Thereby a solution is proposed for an OFDM system transmitting a dual frequency band and providing interoperability with a coexisting OFDM system. The following system parameters thereby are taken into account:
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total number of subcarriers: N_1, N_2

channel bandwidth: B_{C1}, B_{C2} , and

subcarrier spacings: $\Delta F_1, \Delta F_2$

Between the above parameters the following relation exists:

$$\Delta F = \frac{B_C}{N}$$

According to the present invention ΔF_1 can be equal to ΔF_2 , which means the same subcarrier spacing in both frequency ranges and/or systems is used. Therefore

$$\frac{B_{C1}}{N_1} = \frac{B_{C2}}{N_2} \quad \text{or} \quad B_{C1} \times N_2 = B_{C2} \times N_1.$$

The above equations can be rewritten

$$B_{C1} \times n = B_{C2} \times m \quad \text{and} \quad N_1 \times n = N_2 \times m,$$

wherein the ratio n/m satisfies the following equation:

$$n/m = k \times 2_i,$$

wherein k is a positive integer value and i is a negative or positive integer value including zero.

The above selection of the ratios n/m is particularly advantageous for the effective implementation of the FFT algorithm generating the OFDM symbols. In FIG. 3 the two OFDM systems channel mapping is depicted. In the example shown in FIG. 3 $n = 8$ and $m = 1$, which means ideally 8 channels of the OFDM system (system 1) operating in the lower frequency band can be mapped to one channel of the OFDM system (system 2) operating in the dual frequency bands. Depending on the required guard band ($F_{\text{guard } 2}$) between the channels in the upper frequency band the actual mapping of the system 1 channels could be limited to channel 2 through channel 7.

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	The same subcarrier spacings are kept for both systems and/or frequency bands, thereby giving the highest efficiency of interoperability. In general the ratio of $\Delta F_1/\Delta F_2$ is selected to satisfy the following equation: $\frac{\Delta F_1}{\Delta F_2} = k \times 2^i,$ wherein k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implement of the base-band block to process the OFDM signals and/or symbols. Dolle-010 at 5:56-6:56.
[Claim 21] The apparatus of claim 17, wherein each of the plurality of different selectable subcarrier spacings is configured for one of a plurality of different deployment scenarios, the plurality of different deployment scenarios comprising different system requirements or different channel characteristics.	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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: 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

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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.

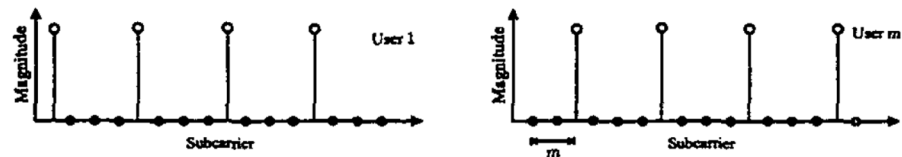


Fig. 2. User m allocates the equidistant subset of subcarriers shift by m subcarriers in the frequency domain

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

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	proposed subcarrier selection and modulation process does not need any radio channel state information in this case. Galda-2002 at 1738. The structure of the OFDM transmitter can be simplified by this approach since both the DFT spreading operation and the IFFT calculation of the conventional OFDM transmitter cancel out and can be removed in the technical realization completely and will be replaced by a simple repetition process of the considered user data $D_l^{(m)}$. The simplified transmitter structure is depicted in Fig. 6. Any equidistant subcarrier allocation can be used with the proposed FDMA scheme since it only influences the number of periods of the transmit signal. Therefore the user data rate can be flexibly adjusted by assigning the required number of subcarriers to each user. Galda-2002 at 1740. In 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. Kaiser-1998, which discloses: This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-
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	CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers. • Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques.
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	Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme. • MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation. • In an MC-CDMA system, M data symbols are spread over $M \cdot L$ subcarriers, whereas in an SS-MC-MA system, L data symbols are spread over the same L subcarriers. Hence, MC-CDMA is able to exploit more frequency diversity. Kaiser-1998 at 131.
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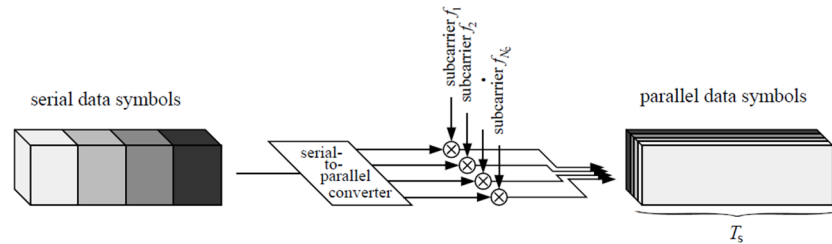


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

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

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	subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s, known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbols of duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1 = T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B. Kaiser-1998 at 5-6. 3.1.1 Orthogonal Frequency Division Multiplexing The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{S_n\}$ consisting of N_c complex-valued source symbols $S_n, n = 1, \dots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $S_n, n = 1, \dots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel
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	coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{S_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{S_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{S_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to $\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$ According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of $F_s = \frac{1}{T_s}. \quad (3.2)$ to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $S_n, n = 1, \dots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form $x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} S_n \operatorname{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$ Kaiser-1998 at 31-32. The generation of an MC spread spectrum signal is illustrated in Fig. 3.6 and is applicable on the transmitter side in both the up- and the down-link. The serial concatenation of DS spreading, cf. Fig. 1.2, and MC modulation, cf. Fig. 1.3, is shown, however, the equivalent realization illustrated in Fig. 1.4 is also applicable. The transmission of a complex-valued data symbol $\underline{d}^{(k)}$ of the kth
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	user is shown in Fig. 3.6. The data symbol $\underline{d}^{(k)}$ to be transmitted over the radio channel is taken from the complex data symbol alphabet $\underline{V}_d = \{\underline{v}_{d,1}, \underline{v}_{d,2}, \dots, \underline{v}_{d,M_d}\} \quad (3.24)$ of size M_d. The data symbol $\underline{d}^{(k)}$ is obtained after symbol mapping, where $\log_2(M_d)$ data bits are mapped into a complex-valued data symbol $\underline{d}^{(k)}$ [Pro95]. The data symbol rate is $1/T_d$. For brevity, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code $\underline{c}^{(k)} = (\underline{c}_1^{(k)}, \underline{c}_2^{(k)}, \dots, \underline{c}_L^{(k)})^T \quad (3.25)$ of the kth user. The chips $\underline{c}_l^{(k)}, l = 1, \dots, L$, are taken from the complex chip alphabet $\underline{V}_c = \{\underline{v}_{c,1}, \underline{v}_{c,2}, \dots, \underline{v}_{c,M_s}\} \quad (3.26)$ of size M_s, where M_s is not necessarily equal to M_d. The chip rate of the serial spreading code $\underline{c}^{(k)}$ before serial-to-parallel conversion is $\frac{1}{T_c} = \frac{L}{T_d} \quad (3.27)$ and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector $\underline{s}^{(k)} = \underline{d}^{(k)} \underline{c}^{(k)} = (\underline{s}_1^{(k)}, \underline{s}_2^{(k)}, \dots, \underline{s}_L^{(k)})^T. \quad (3.28)$ The rate of the components $\underline{s}_l^{(k)}, l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum
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	according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is $T'_s = T_g + N_c T_c. \quad (3.29)$ The transmission of one data symbol per user per OFDM symbol requires $N_c = L \quad (3.30)$ subcarriers. In this case, the OFDM symbol duration including the guard interval is $T'_s = T_g + T_d. \quad (3.31)$ Kaiser-1998 at 39-40. <i>M</i>-Modification: The intention of the <i>M</i>-Modification is to increase the number of subcarriers while maintaining constant the spreading code length and the maximum number of active users. Consequently, the OFDM symbol duration increases and the loss in bandwidth efficiency due to the guard interval decreases. Moreover, the tighter subcarrier spacing enables one to guarantee flat fading per subchannel in propagation scenarios with decreased coherence bandwidth. With the <i>M</i>-Modification, each user transmits simultaneously M greater than 1 data symbols per OFDM symbol. The total number of subcarriers of the modified MC-CDMA system is $N_c = ML. \quad (3.34)$ Each user exploits the total of N_c subcarriers for data transmission. The OFDM symbol duration including the guard interval increases to $T'_s = T_g + MLT_c, \quad (3.35)$
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	where it can be observed that the loss in bandwidth efficiency due to the guard interval decreases with increasing M. The maximum number of active users is still defined according to (3.32). The assigned MC-CDMA transmitter is shown in Fig. 3.8. The data symbol index $m, m = 1, \dots, M$, is introduced in Fig. 3.8 to distinguish the M simultaneously transmitted data symbols $\underline{d}_m^{(k)}, m = 1, \dots, M$, of the kth user. The number M is upper limited by the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), since the symbol duration T'_s, which increases with increasing M, has to be smaller than $(\Delta t)_c$ to guarantee that the channel is time-invariant during one OFDM symbol duration. To optimally exploit frequency diversity, the components of the sequences $\underline{s}_m, m = 1, \dots, M$, transmitted in the same OFDM symbol are interleaved over the frequency. Subcarriers used for the transmission of $\underline{s}_m$ should have a spacing greater than the coherence bandwidth of the channel. Thus, the components of one sequence $\underline{s}_m$ are affected independently, reducing the probability that $\underline{s}_m$ is completely located in a deep fade. The interleaving is carried out prior to OFDM. The frequency interleaver can be a block interleaver which guarantees the maximum frequency separation between the components of $\underline{s}_m$. However, due to a possible periodicity of the fading process in frequency, the block interleaver can fail if the periodicity is similar to the frequency separation between adjacent components. This effect can be reduced if a pseudo-random frequency interleaver is used. Kaiser-1998 at 41-42. The OFDM symbol duration including the guard interval is $T'_s = T_g + QLT_c. \quad (3.40)$ Kaiser-1998 at 44. <i>M&Q-Modification:</i> The <i>M&Q-Modification</i> is a combination of the <i>M</i>- and the <i>Q</i>-Modification, resulting in an MC-CDMA system with adjustable number of subcarriers and receiver complexity, keeping constant the
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	maximum number of active users. The transmission of M data symbols per user and, additionally, the splitting of the users in Q independent user groups according to the $M&Q$-Modification is illustrated in Fig. 3.10. The total number of subcarriers used by the MC-CDMA system with $M&Q$-Modification is $N_c = QML, \quad (3.41)$ where each user only exploits a subset of $M L$ subcarriers for data transmission due to the FDMA component introduced by the Q-Modification. The maximum number of active users is given by (3.38). The total OFDM symbol duration including the guard interval results with the $M&Q$-Modification in $T'_s = T_g + QMLT_c. \quad (3.42)$ Kaiser-1998 at 44. R1-021246, which discloses: Based on the above discussion, we would like propose a baseline system with multiple configurations suitable for different channel conditions. Some benefit of having multiple configurations are: (1) To allow shorter symbol durations when the multipath is less severe, this would result in wider subcarrier spacing which would make the system more immune to frequency offset (2) To use shorter symbol duration which makes the system less susceptible to high Doppler and hence reduces the ICI (3) To use smaller size FFT which lowers the power consumption and the UE complexity. These multiple configurations have the same sampling frequency, which will simplify the receiver implementation while allowing UE to switch smoothly to different configurations supported by the Node Bs in different multipath environments.
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R1-021246 at 3-5.

Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a 1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system’s resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations.

R1-021246 at 5.

System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

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	R1-021246 at Table 4. We have suggested an OFDM system with multiple configurations that can be deployed in different environments. The system is designed to fit into the current UMTS time slot structure. If agreed upon, the system will be used as a baseline for future OFDM study. R1-021246 at 7. Böhnke-501, which discloses: Signals transmitted on the basis of a OFDM/TDMA-system by allocating a plurality of subcarriers, which are orthogonal to each other, to a variable number of channels, each channel containing a variable number of subcarriers depending on the information to be transmitted. Böhnke-501 at 2:44-48. The present invention is directed to a burst (time-domain) and frequency slot allocation of an OFDM/TDMA-system, which is as far as possible backward compatible to the existing GSM-burst and frequency structure. The parameters of the OFDM/TDMA-system are chosen to support flexible band with services in the mobile environment. Böhnke-501 at 10:33-38. Dolle-010, which discloses: As has been already been set forth above, the advantage of the transceiver 10 as shown in FIG. 1 is that the transmission frequency f_{C1} operates at the same time as the intermediate frequency 4 f_{C2} This allows the system to operate in two different frequency ranges with different propagation properties and thus fulfills a wide range of application requirements. In addition the structure allows interoperability between different systems (system 1 and system 2, for example), which are not only distinguished by its different transmission
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	frequencies but also by its different channel bandwidth. To achieve the interoperability, the air interface channel of the system 1 has to be mapped properly to the air interface channel structure of the system 2. Dolle-010 at 5:28-40.
[Claim 22] The apparatus of claim 17, wherein each of the plurality of different selectable subcarrier spacings produces a different number of symbols per frame.	While StarTAC has transmitter-control circuitry, StarTAC is not an OFDM product, and thus does not have an OFDM transmitter that can 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: For example, Galda-2002 discloses: 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

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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 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

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	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. To the extent that Galda-2002 does not disclose that each of the plurality of different selectable subcarrier spacings produces a different number of symbols per frame, each of the plurality of different selectable subcarrier spacings producing a different number of symbols per frame 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): Kaiser-1998, discloses: This section presents a novel multiple access scheme which is referred to as spread spectrum multi-carrier multiple access (SS-MC-MA). Similar to MC-CDMA, SS-MC-MA exploits the advantages given by the combination of the spread spectrum technique with MC modulation [KaF96, KaF97a]. An SS-MC-MA system is superior compared to an MC-CDMA system in the uplink of a mobile radio system due to a simple channel estimation and a low-complex data detection. Whereas, an MC-CDMA system outperforms an SS-MC-MA system in the downlink, as it will be shown at the end of this section. Before presenting the SS-MC-MA signal structure and its uplink performance, the basic similarities and differences between SS-MC-MA and MC-CDMA systems are pointed out. This can preferably be done by comparing the SS-MC-MA and the MC-CDMA transmitter for the downlink. Fig. B.1 shows the SS-MC-MA transmitter for the downlink. The counterpart is the MC-CDMA transmitter with M-Modification shown in Fig. 3.8. For convenience, the case with M equal to L and K_{max} equal to L is considered in this comparison. It can be observed that both transmitters are identical except for the mapping of the user data to the subsystems. In SS-MC-MA systems, one user maps L data symbols to one subsystem which this user exclusively uses for transmission. Consequently, different users use different subsystems in SS-MC-MA
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	systems. In MC-CDMA systems, M data symbols per user are mapped to M different subsystems where each subsystem is shared by different users. Kaiser-1998 at 130-131. Between SS-MC-MA and MC-CDMA systems exist the following similarities: • SS-MC-MA and MC-CDMA systems exploit frequency diversity by spreading each data symbol over L subcarriers. • Per subsystem, the same data detection techniques can be applied with both SS-MC-MA and MC-CDMA systems. • ISI and ICI can be avoided in SS-MC-MA and MC-CDMA systems, resulting in simple data detection techniques. Kaiser-1998 at 131. Between SS-MC-MA and MC-CDMA systems exist the following differences: • In SS-MC-MA systems, the code division is used for the simultaneous transmission of the data of one user on the same subcarriers, whereas in the case of MC-CDMA systems, the code division is used for the transmission of the data of different users on the same subcarriers. Therefore, SS-MC-MA is an FDMA scheme on subcarrier level, whereas MC-CDMA is a CDMA scheme. • MC-CDMA systems have to cope with MAI, which is not present in SS-MC-MA systems. Instead of MAI, the SS-MC-MA system has to cope with self interference caused by the superposition of signals from the same user. • In SS-MC-MA systems, each subcarrier is exclusively used by one user, enabling low complex channel estimation especially for the uplink. In MC-CDMA systems, the channel estimation in the uplink
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has to cope with the superposition of signals from different users which are faded independently on the same subcarriers, increasing significantly the complexity of the uplink channel estimation.

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

Kaiser-1998 at 131.

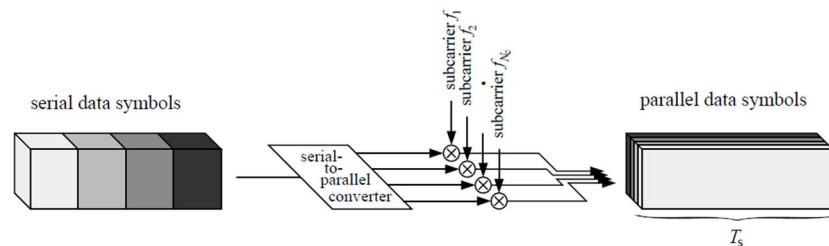


Figure 1.3: Principle of multi-carrier modulation; $T_s = T_d N_c$

Kaiser-1998 at Fig. 1.3.

The progress in wireless communications entails a demand for higher data rates and, thus, shorter symbol durations. However, if the duration of the transmitted symbol becomes smaller than the time dispersion of the multipath channel, the performance of the wireless communication system suffers from ISI. This is a crucial problem since the receiver complexity is related to the amount of ISI. An approach to prevent ISI is offered by parallel data transmission [Cha66, Sal67, WeE71], referred to as MC communications. The principle of MC modulation, depicted in Fig. 1.3, is to convert a high rate data stream into N_c low-rate substreams, where N_c is the number of subcarriers used for data transmission. Each substream is modulated on its assigned subcarrier $f_n, n = 1, \dots, N_c$. Thus, the available channel bandwidth is subdivided into N_c narrow subbands, which ideally appear frequency non-selective. The data

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symbol rate per subcarrier is reduced by a factor N_c and with that, the ISI is reduced. A common realization of MC communications is conventional frequency division multiplexing where the subbands are completely separated in the frequency domain. However, due to finite steepness of the filter roll-offs, the subchannel spacing has to be greater than the Nyquist bandwidth to avoid inter-subchannel interference (ICI). This inefficient use of the available spectrum can be overcome by permitting spectral overlap between adjacent subchannels [Cha66, Sal67]. ICI can be avoided by guaranteeing orthogonality between the signals on the subcarriers. With rectangular pulse shaping, orthogonality between the signals is obtained by choosing a subcarrier spacing equal to the reciprocal of the symbol duration per subcarrier T_s , known as orthogonal frequency division multiplexing (OFDM) [WeE71, Hir81, Cim85]. The N_c parallel modulated data symbols of duration T_s equal to $N_c \cdot T_d$ are referred to as an OFDM symbol with the assigned OFDM symbol rate $1 = T_s$. By increasing the number of subcarriers, the OFDM spectrum approaches an ideal rectangular shaping within the bandwidth B.

Kaiser-1998 at 5-6.

3.1.1 Orthogonal Frequency Division Multiplexing

The principle of MC modulation is to map a serial high rate source stream onto multiple parallel low rate substreams and to modulate each substream on another subcarrier. Since the symbol rate on each subcarrier is much less than the serial source symbol rate, the effects of delay spread significantly decrease, reducing the complexity of the equalizer. OFDM is a low-complex technique to bandwidth-efficiently modulate multiple subcarriers by using the digital signal processing as introduced in Section 1.2.1. In the sequel, MC modulation based on OFDM is described and forms the basis for the introduction of the MC-CDMA signal structure in Section 3.2. One of the main design goals for an MC transmission scheme based on OFDM in a mobile radio channel is that the channel can be considered as time-invariant during one OFDM symbol and that the fading per subcarrier can be considered as flat. Thus, the OFDM symbol duration should be smaller than the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), and the subcarrier spacing should be

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	smaller than the coherence bandwidth $(\Delta f)_c$ of the channel, cf. (2.9). By fulfilling these conditions, the realization of low-complex receivers is possible. A communication system with MC modulation transmits a sequence $\{S_n\}$ consisting of N_c complex-valued source symbols $S_n, n = 1, \dots, N_c$, in parallel on N_c subcarriers. Throughout the thesis, variables which can be interpreted as values in the frequency domain like the source symbols $S_n, n = 1, \dots, N_c$, each modulating another subcarrier frequency, are written with capital letters. The source symbols may, for instance, be obtained after source and channel coding, interleaving, and symbol mapping. For brevity, but without loss of generality, the transmission of a single but arbitrary sequence $\{S_n\}$ is considered in this chapter, so that no additional time index is required. The isolated consideration of $\{S_n\}$ is valid since ISI and ICI can be avoided with OFDM. The MC modulator maps a sequence $\{S_n\}$ of N_c serial source symbols of rate $1/T$ onto N_c parallel substreams, cf. Fig. 1.3. The source symbol rate per substream reduces to $\frac{1}{T_s} = \frac{1}{N_c T}. \quad (3.1)$ According to OFDM, the N_c substreams are modulated on subcarriers with a spacing of $F_s = \frac{1}{T_s}. \quad (3.2)$ to achieve orthogonality between the signals on the N_c subcarriers, presuming a rectangular pulse shaping. The N_c parallel modulated source symbols $S_n, n = 1, \dots, N_c$, are referred to as an OFDM symbol of duration T_s. The complex envelope of an OFDM symbol with rectangular pulse shaping has the form
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$$x(t) = \frac{1}{\sqrt{N_c}} \sum_{n=1}^{N_c} S_n \text{rect}\left(\frac{t}{T_s} - \frac{1}{2}\right) e^{j2\pi f_n t}. \quad (3.3).$$

Kaiser-1998 at 31-32.

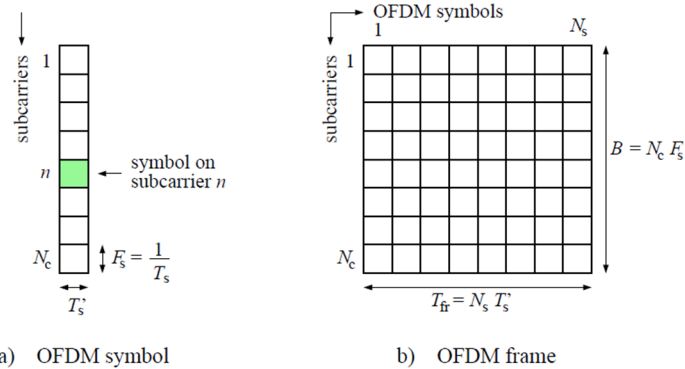


Figure 3.4: Time/frequency representation of an OFDM symbol and an OFDM frame

Kaiser-1998 at Fig. 3.4.

The time/frequency representation of an OFDM symbol used in this thesis is shown in Fig. 3.4 a). A block of subsequent OFDM symbols, where the information transmitted within this OFDM symbols belongs together, e.g., due to coding and/or spreading in time and frequency direction, is referred to as an OFDM frame. An OFDM frame consisting of N_s OFDM symbols with frame duration

$$T_{fr} = N_s T'_s \quad (3.15)$$

is illustrated in Fig. 3.4 b). The time/frequency representation in Fig. 3.4 is obtained from the three-dimensional time/frequency/power density representation introduced in Section 1.2 by omitting the dimension of the power density.

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Kaiser-1998 at 35.

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 symbol per user as far as possible, by omitting an otherwise necessary data symbol index. In the transmitter, the data symbol $\underline{d}^{(k)}$ is multiplied and, thus, marked with the user-specific spreading code

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

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

$$\frac{1}{T_c} = \frac{L}{T_d} \quad (3.27)$$

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	and is L times higher than the data symbol rate $1/T_d$. The complex-valued sequence obtained from the multiplication of a data symbol $\underline{d}^{(k)} \in V_d$, cf. (3.24), with the assigned spreading code $\underline{c}^{(k)}$ is given by the vector $\underline{s}^{(k)} = \underline{d}^{(k)} \underline{c}^{(k)} = \left(\underline{s}_1^{(k)}, \underline{s}_2^{(k)}, \dots, \underline{s}_L^{(k)} \right)^T. \quad (3.28)$ The rate of the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, before serial-to-parallel conversion is $1/T_c$. It should be noted that the transmission of $\underline{s}^{(k)}$ with single-carrier modulation conforms with the principle of DS spread spectrum according to Fig. 1.2. An MC-CDMA signal is obtained after modulating the components $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, in parallel onto L subcarriers according to (3.10) [FaP93, YLF93, CBJ93]. Thus, each data symbol $\underline{d}^{(k)}$ is spread over L subcarriers. The duration of an MC modulated component $\underline{s}_l^{(k)}$, $l = 1, \dots, L$, is equal to the OFDM symbol duration, which, including the guard interval, is $T'_s = T_g + N_c T_c. \quad (3.29)$ The transmission of one data symbol per user per OFDM symbol requires $N_c = L \quad (3.30)$ subcarriers. In this case, the OFDM symbol duration including the guard interval is $T'_s = T_g + T_d. \quad (3.31)$ Kaiser-1998 at 39-40. <i>M</i>-Modification: The intention of the <i>M</i>-Modification is to increase the number of subcarriers while maintaining constant the spreading code length and the maximum number of active users. Consequently, the OFDM symbol duration increases and the loss in bandwidth efficiency due to the guard interval decreases. Moreover, the tighter subcarrier spacing enables one to guarantee flat fading per subchannel in propagation scenarios with decreased coherence bandwidth. With the <i>M</i>-Modification, each user transmits
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	simultaneously M greater than 1 data symbols per OFDM symbol. The total number of subcarriers of the modified MC-CDMA system is $N_c = ML. \quad (3.34)$ Each user exploits the total of N_c subcarriers for data transmission. The OFDM symbol duration including the guard interval increases to $T'_s = T_g + MLT_c, \quad (3.35)$ where it can be observed that the loss in bandwidth efficiency due to the guard interval decreases with increasing M. The maximum number of active users is still defined according to (3.32). The assigned MC-CDMA transmitter is shown in Fig. 3.8. The data symbol index $m, m = 1, \dots, M$, is introduced in Fig. 3.8 to distinguish the M simultaneously transmitted data symbols $\underline{d}_m^{(k)}, m = 1, \dots, M$, of the kth user. The number M is upper limited by the coherence time $(\Delta t)_c$ of the channel, cf. (2.13), since the symbol duration T'_s, which increases with increasing M, has to be smaller than $(\Delta t)_c$ to guarantee that the channel is time-invariant during one OFDM symbol duration. To optimally exploit frequency diversity, the components of the sequences $\underline{s}_m, m = 1, \dots, M$, transmitted in the same OFDM symbol are interleaved over the frequency. Subcarriers used for the transmission of $\underline{s}_m$ should have a spacing greater than the coherence bandwidth of the channel. Thus, the components of one sequence $\underline{s}_m$ are affected independently, reducing the probability that $\underline{s}_m$ is completely located in a deep fade. The interleaving is carried out prior to OFDM. The frequency interleaver can be a block interleaver which guarantees the maximum frequency separation between the components of $\underline{s}_m$. However, due to a possible periodicity of the fading process in frequency, the block interleaver can fail if the periodicity is similar to the frequency separation between adjacent components. This effect can be reduced if a pseudo-random frequency interleaver is used. Kaiser-1998 at 41-42.
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	The OFDM symbol duration including the guard interval is $T'_s = T_g + QLT_c. \quad (3.40)$ Kaiser-1998 at 44. <i>M&Q</i>-Modification: The <i>M&Q</i>-Modification is a combination of the <i>M</i>- and the <i>Q</i>-Modification, resulting in an MC-CDMA system with adjustable number of subcarriers and receiver complexity, keeping constant the maximum number of active users. The transmission of <i>M</i> data symbols per user and, additionally, the splitting of the users in <i>Q</i> independent user groups according to the <i>M&Q</i>-Modification is illustrated in Fig. 3.10. The total number of subcarriers used by the MC-CDMA system with <i>M&Q</i>-Modification is $N_c = QML, \quad (3.41)$ where each user only exploits a subset of <i>M L</i> subcarriers for data transmission due to the FDMA component introduced by the <i>Q</i>-Modification. The maximum number of active users is given by (3.38). The total OFDM symbol duration including the guard interval results with the <i>M&Q</i>-Modification in $T'_s = T_g + QMLT_c. \quad (3.42)$ Kaiser-1998 at 44. R1-021246, which discloses: The sub-carrier spacing should be large enough to provide robustness against frequency offset and phase noise, but it also has to be small enough such that each sub-carrier experiences flat fading. Normally, the tone (or sub-carrier) spacing can be selected by first fixing a maximum delay spread from all possible channel conditions, calculating the coherence bandwidth and then using it as an upper bound for the sub-carrier spacing. From [3], the Pedestrian A, Pedestrian B, and Vehicular A channel model, have maximum delay spread at 410ns, 3.7usec and 2.5usec, respectively. We suggest that a maximum delay
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	spread of 10 usec be considered for the design of the OFDM system. The 10-usec suggestion takes into account only the cyclic prefix, some extra guard time should be added to allow some ramp-up and ramp-down period for the power amplifier. Time domain filtering maybe necessary to avoid the spurious effect due to the possible sudden transition between the consecutive OFDM symbols. In order to reduce the out of band emissions effectively, a raise cosine window with roll-off factor equal to one should be allowed. Note that it is observed that in a simulcast environment, the signal coming from the other cell is most likely the dominant multi-path which has longer delay than the non-simulcast signal. Therefore, larger delay spread should be considered if multicast and simulcast services are of interest. Table 2 shows some parameters for coherence bandwidth based on various definitions stated in [2]. R1-021246 at 2. FFT Size From Table 1., assuming the nominal UE speed is less than 120 km/hr, we can choose the OFDM symbol duration up to 805.5 usec as long as it does not violate the coherence bandwidth dictated by Table 2. To keep the time domain overhead, i.e. the cyclic prefix and guard time, small, it is desirable to limit the amount of time overhead to be less than 10% of the time domain symbol duration. Table 3. summarized the number of sub-carried allowed under 5, 10, and 15% time domain overhead (T_g) assumptions, and the number of FFT points required to implement it. Note that T_u is the useful/signal part of the symbol, and T_g is the guard time. The number sub-carriers can be supported in a 5MHz bandwidth is given by $\lfloor 5MHz/T_u \rfloor$, where the numbers are rounded to the nearest integers from below. R1-021246 at 2. Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one
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time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a 1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system’s resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations.

R1-021246 at 5.

System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

R1-021246 at Table 4.

Böhnke-501, which discloses:

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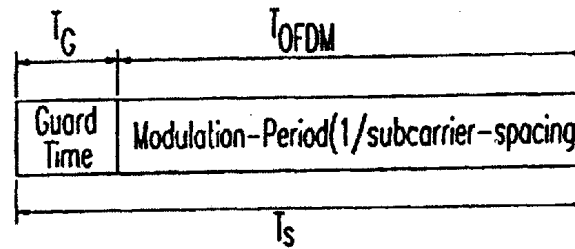


Fig. 7

Böhnke-501 at Fig. 7.

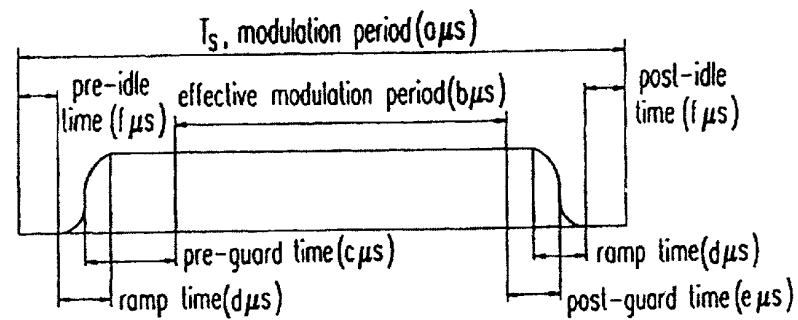


Fig. 8

Böhnke-501 at Fig. 8.

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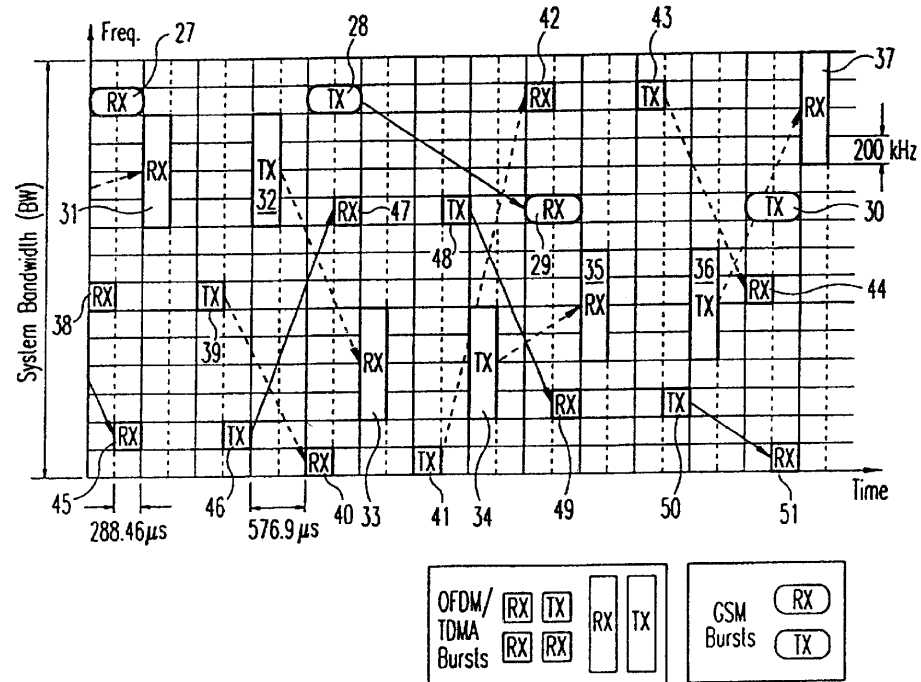


Fig. 12

Böhnke-501 at Fig. 12.

Böhnke-501, which discloses:

According to the present invention, a number of subcarriers of an OFDM/TDMA-system is allocated to each GSM-frequency channel so that a multiple of one resulting OFDM/TDMA-timeslot matches with one or a multiple of one GSM-timeslot. The spacing between two adjacent GSM-frequency channels is 200 kHz, and the length of a GSM-timeslot is 15/26 ms. According to the present invention, one GSM-frequency channel is divided into a number of subcarriers. The number of subcarriers is chosen, so that a multiple of one resulting OFDM/TDMA-timeslot fits well in one

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	or a multiple of one GSM-timeslot. The transformation of one subcarrier from the frequency domain into the time domain results in an OFDM/TDMA-time burst, which builds the largest part of the resulting OFDM/TDMA-timeslot. In FIG. 7, the basic structure of an OFDM/TDMA-timeslot is shown as containing an OFDM/TDMA-time burst, whereby the length of the OFDM/TDMA-timeburst T_{OFDM} corresponds to the effective Modulation Period and depends on the subcarrier-spacing (1/subcarrier-spacing). The subcarrier spacing depends on the number of subcarriers allocated to one GSM-frequency channel of 200 kHz. A guard time TG (or pre-guard time) is disposed in advance of the OFDM/TDMA-time burst T_{OFDM}. In FIG. 8, the detailed structure of an OFDM/TDMA-timeslot is shown. The length of the OFDM/TDMA-timeslot corresponds to the modulation period and has a length of a μs. After the transformation of the subcarriers into the time domain, whereby the OFDM/TDMA-timebursts are produced, a guard time consisting of the pre-guard time of length c μs and a post-guard time is of length e μs is added to the OFDM-TDMA-timebursts. The OFDM/TDMA-timebursts correspond to the effective modulation period and have a length b μs. Then, before transmitting, the ramp of the time domain signal is shaped according to a raised cosine function, as shown in FIG. 8, to reduce spurious emissions. As can be seen In FIG. 8, the ramp time in the front part and the back part of the OFDM/TDMA-timeslot, respectively, has a length d μs and overlaps partially with the pre-guard time and the post-guard time, respectively. The length of the post-guard time can be o μs. At the beginning of the OFDM/TDMA-timeslot there is located a pre-idle time in advance of the ramp time and at the end of the OFDM/TDMA-timeslot there is located a post-idle time behind the ramp time. The length of each of the pre-idle time and the post-idle time is f μs. Therefore, the resulting OFDM/TDMA-timeslot is composed of the OFDM/TDMA-timeburst (effective modulation period), the guard time consisting of the pre-guard time and the post-guard time, the ramp times and the pre-idle time and the post-idle time. The length b of the OFDM/TDMA-timeburst depends on the subcarrier spacing ($b=1/f_{SCS}$), where f_{SCS} is the subcarrier in Hz. According to the present invention, the
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	length a of one OFDM/TDMA-timeslot can for example correspond to 1, $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$ GSM-timeslot. Böhnke-501 at 4:14-67. Böhnke-501 at 4:14-67. In a 1st embodiment, the total number of subcarriers is 48, whereby one or more subcarriers on the borders can be left unmodulated to reduce interference to adjacent frequency slots. The resulting subcarrier spacing is $200 \text{ kHz}/48=4.166 \text{ Hz}$, which leads to an OFDM/TDMA-time burst T_{OFDM} of $48/200 \text{ kHz}=240 \text{ }\mu\text{s}$. The symbol duration ($240 \text{ }\mu\text{s}$) is therefore very long compared to the GSM-symbol duration (range of μs), which has the advantage of avoiding inter-symbol interference due to the radio channel delay profile. The guard time (pre-guard time and post-guard time) in the first embodiment is set to $30 \text{ }\mu\text{s}$, whereby it has to be noted that the guard time has to be set according to the expected channel delay profile (multipath environment). The ramp time is set to 10 to $20 \text{ }\mu\text{s}$, so that the total OFDM/TDMA-timeslot T_s has a length of 280 to $290 \text{ }\mu\text{s}$. This fits very well into $\frac{1}{2}$ of the basic GSM-timeslot of $576 \text{ } 923 \text{ }\mu\text{s}$. Therefore, in the 1st embodiment, two OFDM/TDMA-timeslots are mapped into one GSM-timeslot with an adaptation time guard, if necessary. The basic clock is $240 \text{ }\mu\text{s}/64=3.75 \text{ }\mu\text{s}$. The guard time (pre- and post guard time) can be set to $30 \text{ }\mu\text{s}$ (pre-guard: $22.5 \text{ }\mu\text{s}=6 \text{ samples}$, post-guard: $7.5 \text{ }\mu\text{s}=2 \text{ samples}$) and the ramp time can be set to $15.0 \text{ }\mu\text{s}$ ($=4 \text{ samples}$) which leads to a total symbol time of $(250 \text{ }\mu\text{s}/64)*(64+6+2+4)=285 \text{ }\mu\text{s}$. Böhnke-501 at 6:7-31. In the 2nd embodiment, the total number of subcarriers is chosen to be 32, wherein one or more subcarriers at the borders can be left unmodulated to reduce interference to adjacent frequency slots. The subcarrier spacing is $200 \text{ kHz}/32=6.25 \text{ kHz}$, which leads to an OFDM/TDMA-burst of $1/6.25 \text{ kHz}=160$
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	μs. The guard time (pre- and post guard time) can be set to 20 μs and the ramp time can be set to 10.0 μs, which leads to a total OFDM/TDMA-timeslot of 190 μs. 3 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. In other words, one OFDM/TDMA-timeslot T_s is mapped into $\frac{1}{3}$ of a GSM-timeslot. The basic clock is set to $160 \mu s / 32 = 5 \mu s$. To be more precise, the guard time (pre- and post guard time) can be set to 20 μs (pre-guard: $15.0 \mu s = 3$ samples, post-guard: $5 \mu s = 1$ sample) and the ramp time can be set to 10.0 μs (=2 samples) which leads to a total symbol time of $(160 \mu s / 32) * (32 + 3 + 1 + 2) = 190 \mu s$. Böhnke-501 at 6:48-65. In the 3rd embodiment, the total number of subcarriers is chosen to be 24, wherein one or more subcarriers at the borders can be left unmodulated to reduce interference to adjacent frequency slots. The subcarrier spacing is $200 \text{ kHz} / 24 = 8.33 \text{ kHz}$, which leads to an OFDM/TDMA-burst of $1 / 8.33 \text{ kHz} = 120 \mu s$. The guard time (pre- and post guard time) can be set to 15 μs and the ramp time can be set to 9 μs, which leads to a total OFDM/TDMA-timeslot of 144 μs. 4 OFDM/TDMA-timeslots T_s are mapped into one GSM-timeslot with an adaptation time guard. The scheme according to the 3rd embodiment is very advantageous for fast varying channel environments. In other words, one OFDM/TDMA-timeslot T_s is mapped into $\frac{1}{4}$ of one GSM-timeslot. The basic clock is set to $120 \mu s / 32 = 3.75 \mu s$. to be more precise, the guard time (pre- and post guard time) can be set to 15 μs (pre-guard: $11.25 \mu s = 3$ samples, post-guard: $3.75 \mu s = 1$ sample) and the ramp time can be set to 7.5 μs (=2 samples) which leads to a total symbol time of $(120 \mu s / 32) * (32 + 3 + 1 + 2) = 142.5 \mu s$. Böhnke-501 at 7:9-27. In the 4th embodiment, the total number of subcarriers is chosen to be 104, wherein one or more subcarriers at the borders can be left unmodulated to
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	reduce interference to adjacent frequency slots. The subcarrier spacing is 200 kHz/104=1.923 kHz, which leads to an OFDM/TDMA-burst of 1/1.923 kHz=520 μs. The guard time (pre- and post guard time) can be set to 25 μs and the ramp time can be set to 15 μs, which leads to a total OFDM/TDMA-timeslot of 560 μs. One OFDM/TDMA-timeslot is mapped into one GSM timeslot with an adaptation guard of 17 μs. The basic clock is set to 520 μs/128=4.0625 μs. To be more precise, the guard time (pre- and post guard time) can be set to 28.4375 μs (pre-guard: 20.3125 μs=5 samples, post-guard: 8.125 μs=2 sample) and the ramp time can be set to 12.1875 μs (=3 samples) which leads to a total symbol time of (520 μs/128)*(128+5+2+3)=560 625 μs. Böhnke-501 at 7:39-54. Dolle-010, which discloses: The subcarrier spacings of the OFDM system can be identical in the first transmission frequency band and the second transmission frequency band. The subcarrier spacings of the OFDM system in the first transmission frequency band and the second transmission frequency band alternatively can satisfy the following equation: $\Delta F_1 / \Delta F_2 = k * 2^i,$ wherein ΔF_1 and ΔF_2 are the subcarrier spacings used in the OFDM systems in the first transmission frequency band and the second transmission frequency band, respectively, and k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implementation of the baseband block to process the OFDM signals and/or symbols. Dolle-010 at 3:25-41.
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	According to the present invention, a channel mapping solution particularly for an OFDM system is provided. Thereby a solution is proposed for an OFDM system transmitting a dual frequency band and providing interoperability with a coexisting OFDM system. The following system parameters thereby are taken into account: total number of subcarriers: N_1, N_2 channel bandwidth: B_{C1}, B_{C2}, and subcarrier spacings: $\Delta F_1, \Delta F_2$ Between the above parameters the following relation exists: $\Delta F = \frac{B_C}{N}$ According to the present invention ΔF_1 can be equal to ΔF_2, which means the same subcarrier spacing in both frequency ranges and/or systems is used. Therefore $\frac{B_{C1}}{N_1} = \frac{B_{C2}}{N_2} \quad \text{or} \quad B_{C1} \times N_2 = B_{C2} \times N_1.$ The above equations can be rewritten $B_{C1} \times n = B_{C2} \times m \quad \text{and} \quad N_1 \times n = N_2 \times m,$ wherein the ratio n/m satisfies the following equation: $n/m = k \times 2^i,$ wherein k is a positive integer value and i is a negative or positive integer value including zero. The above selection of the ratios n/m is particularly advantageous for the effective implementation of the FFT algorithm generating the OFDM symbols. In FIG. 3 the two OFDM systems channel mapping is depicted. In the example shown in FIG. 3 $n = 8$ and $m = 1$, which means ideally 8 channels of the OFDM system (system 1) operating in the lower frequency
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	band can be mapped to one channel of the OFDM system (system 2) operating in the dual frequency bands. Depending on the required guard band ($F_{\text{guard } 2}$) between the channels in the upper frequency band the actual mapping of the system 1 channels could be limited to channel 2 through channel 7. The same subcarrier spacings are kept for both systems and/or frequency bands, thereby giving the highest efficiency of interoperability. In general the ratio of $\Delta F_1/\Delta F_2$ is selected to satisfy the following equation: $\frac{\Delta F_1}{\Delta F_2} = k \times 2^i,$ wherein k is a positive integer value and i is a negative or positive integer value including zero. This selection allows an effective implement of the base-band block to process the OFDM signals and/or symbols. Dolle-010 at 5:56-6:56.
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