MULTI-CARRIER SPREAD-SPECTRUM & RELATED TOPICS
Multi-Carrier Spread-Spectrum & Related Topics

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*Invited paper*
EDITORIAL INTRODUCTION

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We are currently observing that frequency spectrum is a limited and valuable resource for wireless mobile communications. A good example can be observed among European network operators for the prices to pay for frequency bands for UMTS/IMT2000. Keeping this in mind, the first goal when designing future wireless communication systems has to be the increase in spectral efficiency by allowing higher flexibility for the system design and deployment. The development in digital communications in the past years has enabled efficient modulation and coding techniques for robust and spectral efficient data, speech, audio and video transmission. Here, we should mention two interesting and successful techniques. These are the multi-carrier modulation (e.g. OFDM) and the spread spectrum technique (e.g. DS-CDMA).

During the last decade of this millennium the technique of multi-carrier transmission for wireless broadband multimedia applications has received wide interest. Its first great success was in 1990 as it was selected for the European Digital Audio Broadcasting (DAB) standard. Its further prominent success was in 1995 and 1998 as it was selected as modulation scheme for the European Digital Video Broadcasting (DVB-T) standard and in three broadband wireless indoor standards, namely European ETSI-HIPERLAN/2, American IEEE-802.11a and Japanese MMAC, respectively.

On the other side, we have observed the success of the spread-spectrum technique in mobile communications, whose first commercial widespread employment came with the CDMA based mobile radio standard IS-95 in the USA and nowadays with the use of CDMA for third generation mobile radio systems world wide, known as UMTS/IMT 2000.

The benefits and success of multi-carrier (MC) modulation on the one hand and the flexibility offered by the spread-spectrum (SS) technique on the other hand motivated many researchers to investigate the combination of both techniques, known as multi-carrier spread-spectrum (MC-SS). This combination benefits from
the main advantages of both systems and offers higher flexibility, higher spectral efficiency, simpler detection strategies, narrow-band interference rejection capability, etc.. The basic principle of this combination is straightforward: The spreading is performed as direct sequence spread-spectrum (DS-SS) but instead of transmitting the chips over a single carrier, several sub-carriers could be employed. After spreading with the assigned user specific code, the frequency mapping and multi-carrier modulation will be applied. At the receiver side, after multi-carrier demodulation and frequency de-mapping, the corresponding detection algorithm will be performed. The MC modulation and demodulation could be easily done in the digital domain by performing IFFT and FFT operations.

Since 1993 various combinations of multi-carrier (MC) modulation and the spread-spectrum (SS) technique have been introduced and the field of MC-SS communications has become an independent and important research topic with increasing activities.

Meanwhile, deep system analysis and comparison of MC-CDMA with DS-CDMA have been performed that show the superiority of MC-CDMA. In addition, new application fields have been proposed such as high rate cellular mobile, i.e. 4 G, high rate wireless indoor and fixed wireless access (FWA) that will be used for UMTS/GSM-infrastructure (Backhaul). In addition, a multitude of research activities has been addressed to develop appropriate strategies on detection and interference cancellation, channel coding and modulation, synchronization (especially uplink) and low cost implementation design.

**SCOPE OF THIS ISSUE**

The aim of this issue, consisting of six parts, is to edit the ensemble of contributions presented during three days of the third international workshop on *Multi-Carrier Spread-Spectrum (MC-SS) & Related Topics*, held from Sept. 26-28, 2001, in Oberpfaffenhofen, Germany.

The first part is devoted to the general issues of MC-SS and its related topics. First, Sari gives an overview of multiple-access techniques based on MC-SS approaches. He proposes a generalization of all these proposed concepts under the umbrella of MC-CDMA. He makes also some comparison with other alternative solutions. Nakagawa and Esmailzadeh analyze the strategy and rule of power control for the 3rd generation mobile radio system operated with FDD (Frequency Division Duplex) and TDD (Time Division Duplex) modes in wide-band CDMA. This paper illustrates the main features of a TDD-CDMA and TDD Multi-Carrier DS-CDMA systems. A new timing estimator is proposed for the uplink of a multi-user OFDM system by Morelli and Mengali, where the estimator is based on the maximum likelihood (ML) criterion and exploits knowledge of two pilot symbols. Finally, in
this part Hara, Hane and Hara study the impact of intelligent antennas in case of OFDM in a frequency selective fading channel.

The second part is dedicated to different applications of multi-carrier and multi-carrier spread-spectrum for cellular, broadcast and air-traffic mobile communications. First, Al-Susa and Cruickshank propose and analyze the performance of an adaptive orthogonal multiuser MC-CDMA technique for a broadband mobile communication system. Then, Dammann and Kaiser present the performance of low complex antenna diversity techniques for mobile receivers in an OFDM based DVB-T system for outdoor and indoor applications. Sinn, Götze and Haardt study a common architecture for TD-CDMA and OFDM based mobile radio systems without the necessity of guard-time for third generation and beyond systems. Haindl suggests an application of MC-CDMA for air traffic control air/ground communication. Finally, Haas and Schnell present the hardware development and implementation of an advanced airport data link based on MC-CDMA.

The third part of this issue is devoted to coding and modulation. A general overview on the potential and benefits of the spatial dimension (SDMA) in case of MC-CDMA is given by Lindner. He shows that by employing space-time coding in a MIMO channel a high system throughput can be achieved. Atarashi and Sawahashi analyze a variable spreading factor concept in MC-CDMA packet wireless access. The influence of code selection for uplink and downlink on the performance of MC-CDMA systems is analyzed by Nobilet, Helard and Mottier. The use of complex spreading WH-codes in a serial code concatenation in a MC-CDMA scheme is proposed by Dekorsy and Kammeyer that provides a higher gain compared to the conventional spreading codes. Fujii, Shimizu, Suzuki, Itami and Itoh study the downlink capacity of a FD-MC/CDMA system in a frequency selective fading channel. The application of DMT and FMT for MC-CDMA systems is studied by Tomba. Finally, the performance of a delayed-multiplexing MC-CDMA system is analyzed by Sato and Kamio.

The fourth part assembles all issues related to detection, multiplexing and interference cancellation techniques. Here, first Le Gouable and Helard make a comparison of MC-CDMA and coded OFDM/TDMA techniques taking into account the system load for wireless indoor communications. A decorrelative MUD for the uplink of a MC-CDMA system is proposed by Bader, Zazo and Borrallo. For a downlink SS-OFDM-F/TA packet data transmission system a method of multi-user diversity is proposed by Novak and Krzymien. A multi-user joint detection with multi-antennas for OFDM systems is suggested by Skalvos, Weber, Costa, Haas and Schulz. Ibars and Bar-Ness present a rate-adaptive coded multi-user OFDM for downlink wireless systems. Attallah, Zoubir and Abed-Meraim propose an adaptive subspace multi-user detection for MC-DS-CDMA. Costa, Haas and Schulz introduce an optimization of the capacity assignment in MC-CDMA transmission systems. Maeda and Kohno present an optimum coefficient matrix of multi dimensional lattice filters for OFDM transmission. Gameiro presents a capacity enhancement of a DS-CDMA downlink transmission through the employment of a multi-carrier scheme with frequency overlapping. Combating near-far effects in
case of linear MMSE multi-user detection in coded MC-CDMA is analyzed by Feuersängger and Kühn. A downlink performance enhancement method is proposed by Bai and Ping by employing randomized OFDMA. McCormick, Grant, Thompson, Arslan and Erdogan present an implementation of an successive interference cancellation for a MC-CDMA base-station receiver. Some investigations on the use of channel state information of MC-CDMA for Pre-Rake diversity combining in TDD/CDMA systems is done by Jarot and Nakagawa. Finally, Li and Latva-aho present a parallel interference cancellation strategy for MC-CDMA systems in fading channels.

The synchronization and channel estimation aspects for MC and MC-SS transmission systems are discussed in the fifth part of this issue. An overview on iterative blind channel estimation for OFDM receivers using the output information of channel decoding is given by Kammeyer, Petermann and Vogeler. Panayirci and Cirpan present a non-data aided EM-based channel estimation for OFDM systems in time-varying fading channels. A joint channel characteristics and directions of arrival (DOA) estimation using circular array antennas for MC-CDMA is presented by Suzuki, Fuji, Itami and Itoh. Channel estimation for time-hopping impulse radio using no carrier is presented by Lottici, D’Andrea and Mengali. Finally, a comparison of different channel estimation techniques for a single carrier system using frequency domain equalization is done for HIPERLAN/2 systems by Witschnig, Koppler, Huemer and Weigel.

The last part of this book is devoted to the realization and implementation aspects. First, Okada, Takayanagi and Yamamoto present the implementation of an array antenna assisted Doppler spread compensator for OFDM systems. Then, Depailie, Minami, Come, Eberle and Donnay analyze the impact of the bit error rate performance of front-end filters in WLAN-OFDM transceivers. Kobayashi, Tanaka, Mori and Nagaosa propose for ISM-band high speed W-LAN systems to employ a SS-OFDM technique in order to increase the data rate. A joint technique of partial transmit sequences and adaptive clipping level control with filtering for OFDM peak power reduction is analyzed by Fujii and Nakagawa. Finally, Hofmann presents a radio link availability enhancement method and implementation architecture for a stand-by redundant system using spread-spectrum techniques.

In conclusions, we wish to thank all the authors who have contributed to this issue and all those in general who responded enthusiastically to the call. We also hope that this book may serve to promote further research in this new area.
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