MULTI-CARRIER SPREAD-SPECTRUM

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Edited by

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*Invited

EDITORIAL INTRODUCTION

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To operate future generation multimedia communications systems high data rate transmission needs to be guaranteed with a high quality of service. For instance, the third generation cellular mobile systems should offer a high data rate up to 2 Mbit/s for video, audio, speech and data transmission [1]. In addition, the important challenge for these cellular systems will be the choice of an appropriate multiple access scheme. These trends motivated many researchers to look for multiple access systems that offer high spectral efficiency.

The technique of spread spectrum originating from the military applications may allow partly to fulfill the above requirements. Advantages of spread spectrum technique are broadly known: High immunity against multipath distortion, no need for frequency planning, high flexibility, easier variable rate transmission etc. [1-2]. A multiple access scheme based on direct sequence spread spectrum, known as direct sequence code division multiple access (DS-CDMA) relies on spreading the data stream using an assigned spreading code for each user in the time domain. The capability of minimising multiple access interference (MAI) is given by the cross-correlation properties of spreading codes. In the case of multipath propagation the capability of distinguishing one component from others in the composite received signal is offered by the auto-correlation properties of the spreading codes [2]. Therefore, the receiver, i.e. the RAKE may contain multiple correlators, each matched to a different resolvable path in the received composite signal [1]. The performance of a DS-CDMA system will depend strongly on the number of active users, the channel characteristics, and on the number of arms employed in the RAKE. The system capacity is limited by self- and multiple access interference (MAI), which results from the imperfect auto- and cross-correlation properties of spreading codes. Therefore, it will be very difficult for a DS-CDMA receiver to make full use of the received signal energy scattered in the time domain and hence, to handle a full load [2].

On the other hand, the technique of multi-carrier transmission has recently been receiving wide interest for high data rate applications. The advantages of multi-carrier transmission are known such as the robustness in the case of frequency selective fading channels, in particular the reduced signal processing complexity by equalization in the frequency domain, and in the capability of narrow-band interference rejection. The technique of multi-carrier modulation (MCM) is based on transmitting data by dividing the high rate stream into several low rate streams, and by using these sub-streams to modulate different sub-carriers. By using a large number of sub-carriers, a high immunity against multipath dispersion can be provided. The symbol duration T_s of each sub-stream will be much higher than the channel time dispersion, hence the effects of inter-symbol interference (ISI) will be minimized. Since the amount of filters and oscillators is considerable for large number of sub-carriers, an efficient digital implementation of the special form of MCM called orthogonal frequency division multiplexing (OFDM) was proposed in [3] that can be easily realised by using the discrete Fourier transform (DFT). OFDM, having densely spaced sub-carriers with overlapping spectra of modulating signal, abandons the use of steep band-pass filters to detect each sub-carrier as it is used in the frequency division multiple access schemes. Therefore, it offers a high spectral efficiency. Today, the progress in semiconductor technology enables the realization of a DFT also for higher numbers of sub-carriers (up to several thousands), which has been helping for OFDM to gain much on importance. Residual ISI in MC communications can be completely suppressed if a guard interval larger than the channel time delay is inserted to each OFDM symbol [4]. The breakthrough for MC communications happened in the 1990s as OFDM was the modulation underlying Amati´s proposal which was chosen for ADSL in the US [5], and it was chosen for the European digital audio broadcasting (DAB) standard [4]-[6]. Further prominent applications include its selection in 1995 as the modulation for the European digital terrestrial television broadcasting (DTTB) system [7-8].

The advantages and success of multi-carrier (MC) modulation and the spread spectrum (SS) technique motivated many researchers to investigate the suitability of the combination of MCM with SS, known as multi-carrier spread-spectrum (MC-SS) for cellular systems. This combination, introduced in 1993 as a multiple access scheme will allow one to benefit from the advantages of both schemes: Higher flexibility, higher spectral efficiency, simpler detection techniques, narrow band interference rejection capability, etc..

Different multiple access concepts based on the combination of MC modulation with DS-CDMA for mobile and wireless indoor communications have been introduced late 1993 [9-15]. The main differences between them are in the spreading, frequency mapping and the detection strategy.

Recently, the topic of MC-SS has received widespread interest by researchers. Judging from the response to our Call for Papers and from the number of papers at international conferences, it illustrates the necessity of organizing this first international workshop covering the general issues of MC-SS, its applications, the coding & detection algorithms, the interference rejection methods, the synchronisation & channel estimation techniques, etc..

MULTI-CARRIER SPREAD-SPECTRUM MULTIPLE-ACCESS SYSTEMS

In the following we will have a brief look at three different concepts introduced in 1993. A detailed description covering these and further concepts is given in [16], which is summarised below.

The first concept, known as MC-CDMA, is based on a serial concatenation of DS spreading with MC modulation [9-12]. The high rate DS spread data stream is MC modulated in that way that the chips of a spread data symbol are transmitted in parallel on each sub-carrier. As for DS-CDMA, a user may occupy the total bandwidth for the transmission of a single data symbol. The separation of the user´s signals is performed in the code domain. The data symbols are first multiplied with the chips of the spreading code assigned to the specific user and then serial parallel converted. This reflects that the MC-CDMA system performs the spreading in the frequency domain. Hence, this approach compared to the DS-CDMA system has an additional degree of freedom which is the mapping onto the frequency domain that allows for simple methods for signal detection in the frequency domain. This concept was proposed with OFDM for optimum use of the available bandwidth. The realisation of this concept implies a guard time between adjacent OFDM symbols to prevent ISI [10-12] or to assume that the symbol duration is significantly larger than the time dispersion of the channel [9]. Thus the number of sub-carriers N_c has to be chosen sufficiently large to guarantee frequency non selective fading on each sub-carrier. The application of orthogonal codes, such as Walsh-Hadamard codes for a synchronous system, e.g. the down-link of a cellular system guarantees the absence of multiple access interference (MAI) in an ideal channel and a minimum MAI in a real channel [10-11]. As detection technique one may use equal-gain combining, zero forcing equalisation, maximum ratio combining, minimum mean square error equalisation, iterative detection, maximum likelihood detection etc..

The second and the third concepts of the combination of MCM with SS are based on first converting the data stream onto parallel low rate sub-streams before applying the DS spreading on each sub-stream in the time domain and modulating onto each sub-carrier [13-15].

Concept II, known as MC-DS-CDMA, modulates the sub-streams on sub-carriers with a carrier spacing proportional to the inverse of the chip rate. This will guarantee the orthogonality between the spectrums of the sub-streams [13-14]. If the spreading code length is smaller or equal to the number of sub-carriers N_c, a single data symbol is not spread in the frequency, instead it is spread in time domain. Spread spectrum is obtained by modulating N_c time spread data symbols on parallel sub-carriers. This concept by using high number of sub-carriers benefits from the time diversity. However, due to the frequency non-selective fading per sub-channel, frequency diversity could only be exploited if channel coding with interleaving or sub-carrier hopping is employed or if the same information is transmitted parallel on several sub-carriers. Indeed, copying the resulting spread sequence on each sub-stream may efficiently exploit the frequency diversity of the MC system. However, this approach is equivalent to a repetition coding that reduces the data rate by a factor N_c. Furthermore, here the sub-carrier spacing might be chosen larger than the chip rate that may give a higher frequency diversity for the system [14]. This concept was investigated for an asynchronous up-link scenario. For data detection, N_c coherent (non RAKE) receivers might be used.

Concept III, known as multi-tone-CDMA (MT-CDMA) applies the same data mapping and spreading as concept II. However, its sub-carrier spacing is by a factor N_c smaller than the inverse of the chip rate [15]. Thus, the N_c parallel converted data symbols before DS-spreading fulfill the orthogonality requirements. However, after the DS spreading per sub-carrier the orthogonality condition is not kept up, hence it results in inter-carrier-interference (ICI). On the other hand, the tight sub-carrier spacing enables the use of spreading codes which are by a factor of approximately N_c longer than the spreading code of a DS-CDMA. Therefore, at the expense of higher ICI, under certain conditions the system can supply more users than the DS-CDMA system [15]. Since each sub-channel might be affected by frequency selective fading, a RAKE or more complex multi-user detectors can be needed [15]. This concept was also investigated for the asynchronous up-link case.

Since 1993, the above three schemes have been deeply studied and new alternative solutions have been proposed. An overview of the research activity in this new field shows that a multitude of activities was addressed to develop these three concepts and to derive appropriate detection strategies [16-17]. A performance comparison between these concepts through software simulations is given in [17].

However, there is still a lot room for answering open questions and deriving novel solutions in this new research topic. In particular, investigations on the implementation of MC-SS systems for cellular mobile communications or other real applications have not been yet carried out sufficiently. These open questions cover the problem of the design of a suitable MC-SS scheme for both up- and down-link, simple coding and joint detection strategies, design of a powerful channel estimation and synchronisation technique (especially for the up-link), the cellular concept i.e. design of hierarchical cells such as macro, micro, pico cells, problems of non-linearities, low cost receiver design, etc.. This book will give us the opportunity to address some of these open problems more deeply.

SCOPE OF THIS ISSUE

The aim of this issue is to edit the ensemble of articles presented during the two days of the first international workshop on MC-SS that was held April 24-25 at DLR Oberpfaffenhofen.

This issue consists of five parts, where the first part is devoted to the general aspects of MC-SS. In this part first Linder gives an overview on MC-SS by considering its relation to the general multi-user and multi-sub-channel transmission methods. First, models for general multi-user and multi-sub-channel transmission are derived by taking into account the effects of the physical channel: All individual transmission channels belonging to individual users, the individual modulation, sub-channel division and multiple access schemes for all users. Then, depending on the application the advantages and the drawbacks of the MC-CDMA systems with optimum and sub-optimum multi-user detection algorithms are analysed. Vandendorpe gives an overview on the results of the MT-CDMA detection strategies. The performance of the system with diversity reception will be analysed and the design of improved detectors for single and multi-user detection will be investigated. Rohling, Gruenheid and Brueninghaus make a comparison of the different multiple access schemes, including OFDM-FDMA, OFDM-TDMA and OFDM-CDMA for the down-link of a cellular communication system. Finally, Castro *et al.* present the results of a link and system level performance of a MC-CDMA system which has been developed within the ACTS-FRAME project for the third generation mobile communications system.

In the second part of this book results on applying MC-SS for wireless indoor, mobile, and for the return channel of a cable-TV (CATV) system are presented. Harada and Prasad analyze a new multi-code and multi-carrier hybrid transmission system for future broadband mobile communications system. The problems related to multi-carrier and multi-code transmissions are discussed and solutions are proposed. Kaiser and Fazel present a new multiple access scheme based on multi-carrier spread-spectrum. This scheme with coherent detection can be used for the up- as well for the down-link of a cellular mobile communications system. Sari suggests the use of OFDMA as a multiple access scheme with frequency hopping and diversity for the return channel of a CATV-distribution. Different types of frequency hopping and error correction schemes in this multiple access technique are discussed. An M-ary orthogonal Walsh modulation scheme for a MC-CDMA system for wireless indoor communications is proposed by Dekorsy and Kammeyer. The uplink aspects are analyzed through software simulation. The comparison of a MC-SS system with the American standard IEEE-802 for WLAN is made by Banelli *et al.* by showing that the MC-SS system outperforms the IEEE-802 scheme.

The third part of this issue is devoted to coding and detection strategies for MC-SS. Maxey and Ormondroyed analyse the performance of a convolutionally coded MC-CDMA system and interference cancellation methods in fading channels. The behaviour of different equalisation schemes with coding techniques are compared in slow and fast fading channels. An approach for a MC-SS system with RAKE receiver is given by Nahler and Fettweis. By comparing two systems, namely MC-SS and DS-SS, an analysis in the time domain is carried. It is shown that by using a RAKE for both systems a similar performance can be expected. A novel MC modulated orthogonal CDMA (MCM-OCDMA) system proposal is given by Magill. The problems related to fixed and mobile subscribers in a cellular system are discussed. It is shown that the MCM-OCDMA is a particularly well suited scheme for PCS applications with fixed subscribers. Sorger, De Broeck and Schnell present a new multiple access scheme based on MC modulation for cellular mobile radio communications. In this scheme continuous transmission is used and compared to a CDMA system no spreading code is necessary to distinguish the different user signals. Hence, there will be no MAI. However, the cost to avoid MAI is to allow for ISI that requires an equalization on the receiver side. Some aspects on wide-band MC communications for military applications are detailed by Nilsson. The behaviour of the system with no guard-time and high spreading factor (low data rate) in very noisy multipath channel is investigated. The equalisation and coding for an extended MC-CDMA system over a frequency selective fading channel is detailed by Egle, Reinhard and Lindner. The performance of an iterative detection algorithm, called Soft Block Decision Feedback Equaliser is analysed. Finally Teich, Egle, Reinhard and Lindner present in the case of multipath channel the performance of a new detection method based on reccurent neural network (RNN) structure for a MC-CDMA scheme. Contrary to other neural network approaches, the RNN has the advantage that the network size and its coefficients can be obtained from parameters which characterise the communications system.

The aspects of synchronization and channel estimation for MC transmission are treated in the fourth part of this issue. Steendam and Moeneclaey analyse the sensitivity of a MC-CDMA system in the presence of carrier phase jitter. They have shown that the phase jitter gives rise to the multi-user interference. A channel estimation algorithm in time domain is proposed by Steiner for the up-link of a MC-CDMA system for mobile radio applications. The channel estimation is based on the transmission of known pilot tones. A subspace-based joint time-delay and frequency-shift estimation algorithm for a MT-CDMA system is proposed by Eric, Obradovic and Simic. This algorithm is robust especially in addressing the near-far problem. Hoeher, Kaiser and Robertson compare the performance of a two-dimensional filter with two one-dimensional filters in the case of a pilot symbol aided channel estimation in time and frequency. A family of extended Gaussian functions with a nearly optimal localisation property for OFDM scheme is given by Roche and Siohan. Unlike classical OFDM by using these functions, the presence of guard-time and rectangular window-shaping can be abandoned. Some aspects of the duality between the MC-SS and single carrier transmission system are given by Brueninghaus and Rohling. Finally, Simic, Zejak, Dukic and Eric analyse the detection of a MC complementary SS signal in Radar and Sonor systems.

The importance of the aspects of the up-link of a cellular mobile radio system based on MC-SS implies a separate part. The last part of this issue is devoted to these aspects. A combination of MC-CDMA with slow frequency hopping for the uplink is presented by Tomba and Krzymien. Both antenna space diversity with block coding are considered. The spectral efficiency of MC joint detection CDMA for the up-link is analysed by Berens, Jung and Plechinger. Here, a macro-cellular environment is considered. Results are presented in the case of slow power control schemes. Welch and Ziemer present the simulation results of a MC-DS-CDMA system in the presence of Doppler shift. A DPSK modulation with a channel gain averaging scheme for maximum ratio combiner is considered. Similar analysis is done by Ochiai and Imai for an asynchronous MC-CDMA system. Here, the utilisation of complementary sequences as the orthogonal sequences is discussed. Finally, the performance comparison of OC-FD/DS-CDMA and MC-CDMA over Rayleigh fading channel is given by Lee, Tafazolli and Evans.

REFERENCES

[1] A. Baier, U.-C. Fiebig, W. Granzow, W. Koch, P. Teder, and J. Thielecke, “Design study for a CDMA-based third generation mobile radio system,“ IEEE JSAC, Vol. 12, pp. 733-734, May 1994.

[2] R. Prasad, “CDMA for Wireless Personal Communications,“ Artech House, Boston , London, 1996

[3] S. B. Weinstein and P. M. Ebert, “Data transmission by frequency division multiplexing using the discrete Fourier transform,“ IEEE-Trans. On Com. Tech. Vol. COM-19, pp. 628-634, Oct. 1971.

[4] M. Alard and Lassalle,“Principles of modulation and channel coding for digital broadcasting for mobile receivers“, EBU Review, Technical No. 224, pp. 47-69. Aug. 1987.

[5] J. S. Chow, J.-C. Tu and J. M. Cioffi, “A Discrete Multitone Transceiver System for HDSL Applications“, IEEE JSAC, Vol. 9, pp. 895-908, 1991

[6] ETSI, ETS 300 401, "Radio Broadcast Systems: Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers"

[7] K. Fazel, S. Kaiser, P. Robertson, and M. Ruf, "A Concept of Digital Terrestrial Television Broadcasting", Wireless Personal Communications, Vol. 2, No 1&2 pp. 9-27, 1995.

[8] ETSI, pr ETS 300 744, "Radio broadcast system for television, sound and data services; Framing structure, channel coding and modulation for digital terrestrial television"

[9] N. Yee, J.-P. Linnartz and G. Fettweis, "Multi-carrier CDMA for indoor wireless radio networks," Proc. IEEE-PIMRC'93, Yokohama, Japan, pp. 103-113, Sept. 1993.

[10] K. Fazel, L. Papke, "On the performance of convolutionally coded CDMA/OFDM for mobile communications system", Proc. IEEE-PIMRC'93, Yokohama, Japan, pp. 468-472. Sept. 1993.

[11] K. Fazel, "Performance of CDMA/OFDM for mobile communications system", Proc. IEEE-ICUPC'93, Ottawa, Canada, pp. 975-979, Oct. 1993.

[12] A. Chouly, A. Brajal, S. Jourdan, "Orthogonal multi-carrier techniques applied to direct sequence spread spectrum CDMA system", Proc. IEEE Globecom'93, Houston, USA, pp. 1723-1728, Nov./Dec. 1993.

[13] V. DaSilva and E.S. Sousa, "Performance of orthogonal CDMA codes for quasi-synchronous communications systems," IEEE-ICUPC'93, Ottawa, Canada, pp. 995-999, Oct. 1993.

[14] S. Kondo and L.B. Mistein, "On the use of multicarrier direct sequence spread spectrum systems", IEEE-MILCOM'93, Boston, USA, pp. 52-56, Oct. 1993.

[15] L. Vandendorpe, "Multitone direct sequence CDMA system in an indoor wireless environment," Proc. IEEE-First Symposium of Communications and Vehicular Technology, Delft, The Netherlands, pp. 4.1.1-4.1.8, Oct. 1993.

[16] S. Kaiser, "Multi-Carrier CDMA Mobile Radio Systems ", Manuscript (PhD Thesis), to appear end 1997.

[17] R. Prasad and S. Hara, "An Overview of Multi-Carrier CDMA", Proc. IEEE ISSSTA'96, Mainz, Germany, pp. 107-114, Sept. 1996.

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