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MULTICHANNEL M-ARY BI-ORTHOGONAL KEYING

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The new method of Multichannel M-ary Bi-Orthogonal Keying, its operating principle and performance studying are introduced in this paper. Utilized spectral efficiency and BER performance of this method are also studied in comparison with DS-CDMA. Overall efficiency as spectral-to-power efficiencies rate comparison of these multichannel CDMA techniques is presented. All theoretical issues are accompanied with simulation results in MATLAB software package.

Introduction

The direct sequence spread spectrum (DSSS) technologies hold a strong position in state of art multichannel wireless communication systems that are based on code division multiple access (CDMA), such as cdma2000, WCDMA, UMTS [1] and still developing by means of new orthogonal sequence sets (OSS) implementation [2]. Consequently, according to the DSSS nature, one channel data rate of such systems is decreased by value that is equal to spreading factor (SF) [1]. But interference immunity is increased on such value if only one DSSS channel is active. In another case, the interference immunity gain is decreased by value that equal to the number of active DSSS channels [3]. Such rates are achieved because one information symbol is represented by one sequence from OSS, so that DSSS is occurred. And several sequences from one OSS can be transmitted for multichannel communication establishing.

On the other hand, M-ary orthogonal keying (MOK) and its extension – M-ary bi-orthogonal keying (MBOK) [4-6] and complementary code keying (CCK) are existed [5, 6] and well-studied [7-10]. These techniques do not use DSSS, but express/encode information as index and polarity of some transmitted sequence from OSS. Data rate of MOK/MBOK is higher than of DSSS at equal SF, but this is not a multichannel technology, because only one orthogonal sequence (OS) can be transmitted during the one information symbol for its correct order determination and OS indexes differentiation.

The problem of one subscriber channel low data rate for DSSS technique was solved by allocation of several logical DSSS channels which are constructed by different OS spreading or by using of OVSF technique [1]. The first solution needs high level of computational performance [11], and the second has vulnerability that is revealed as decreasing of multipath signal propagation immunity while SF is reduced [1] and as necessity of equalizer and RAKE receiver resetting if SF is changed [12].

More stable and effective solution in the sense of one user channel data rate or utilized spectral efficiency (SE) at low number (< 20%) of active channels might be using of multichannel MBOK (MMBOK) for CDMA communication organization. Argumentation of the solution idea comparatively to DSSS or DS-CDMA is the basis of what given paper is dedicated for. DS-CDMA and MBOK are chosen for comparison, because their prototypes use Fast Walsh Transform (FWT) for channel coding/decoding [13, 14], and Harris Corp. in 1998 [15] presents these technologies as competitive cases for Wi-Fi 802.11b PHY layer of 11MBps data rate transmission. CCK as more advanced and complicated than MBOK is not considered here for a start of studying in multichannel MOK area.

In this paper utilized SE and BER performance of MMBOK study results are also presented comparatively to DS-CDMA. Case of quadrature MMBOK (MQMBOK) is also studied as much as DS-CDMA systems use QPSK.

MBOK & DS-CDMA Framework

For the first time MOK/MBOK as a class of channel coding are mentioned in [7]. MBOK developing and researching processes disclosed in [8-10], which are ended as appearance of complete patented technique [4-6]. MBOK was the first technique which is proposed for 802.11b PHY layer, but further it was replaced by CCK [6] as much better for combat with multipath interference. MBOK and CCK operation principles and modulator/demodulator (encoder/decoder) block schemes are disclosed at [6, 15]. Additional research has shown that complementary codes described in [6] cannot be used for multichannel CCK signaling due to their quasi orthogonality.

Shortly, MOK is technique, which assigns a set of n bits to the one sequence from OSS that consists of 2^n OS. In another, a set of some n bits is equal to respective OS index binary representation in OSS.

MBOK is type of MOK where polarity of OS that is transmitted is used as additional data bit that is equal to extending of current OSS by adding its inverse set.

If MBOK is implemented at both of in-phase and quadrature-phase (I/Q) channels then this coding type become quadrature MBOK (QMBOK) or M-ary Quadrature Orthogonal Keying – MQOK.

Block diagram of the QMBOK/MQOK encoder is shown in Fig.1. At this case OSS of 8 Walsh sequences and they inverse set are used to transmit 8 bits via QPSK modulator. 8 bits is obtained as doubling of $\log_2 8 = 3$ index plus 1 polarity bits of OS that are transmitted.

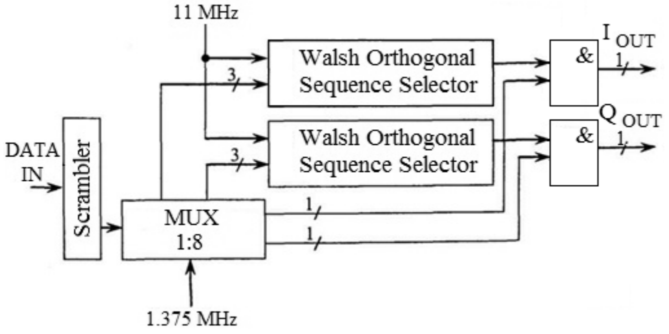


Fig. 1. Block diagram of QMBOK encoder

DSSS technique is much older than MBOK and well-studied. Quite good DS-CDMS framework description can be found in [1]. Shortly, in DSSS one data bit transmits as polarity of some dedicated OS, and this is easier to implement than MBOK. In current DS-CDMA systems FWT is used as main processing algorithm, thus implementation of MBOK and DSSS become the same.

Walsh-Hadamard OSS [1] is used in traditional DSSS and MBOK techniques, but super complementary code set as OSS with better correlation properties [2] for next generation CDMA systems is used in these study simulations without its "complementary" advantages implementation for better combating with channel impairments and SE increasing.

The FWT is the core signal processing scheme for DS-CDMA and MBOK channel encoders/decoders, but in DS-CDMA information symbol is represented as bit value in respective position of FWT response vector (Fig.2), and in MBOK information symbol (bit set) is represented as polarity and binary index of available sequence position of FWT response vector (Fig.3). Fig.2(b) and Fig.3 display FWT vector response for DS-CDMA and MBOK with equal SE.

Channel SE of DS-CDMA can be calculated using such equation:

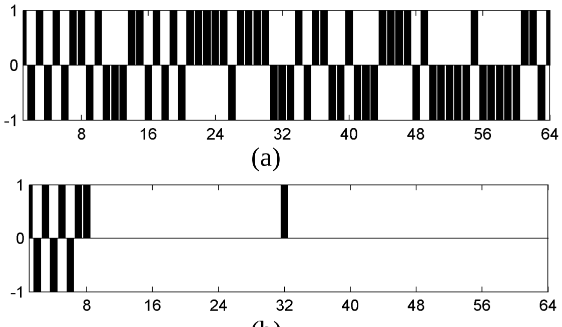
$$SE_{\text{DS-CDMA}} = 1/SF, \tag{1}$$

and of MBOK:

$$SE_{\text{MBOK}} = (1+\log_2(SF))/SF. \tag{2}$$

Taking into account the channel coding framework mentioned above, the modulation of one DS-CDMA channel is BPSK/QPSK and of MBOK is APSK-3/APSK-9. Modulation constellations for different MBOK types are shown in Fig.4.

Initially and really MBOK uses BPSK/QPSK for signal transmission [4], but APSK-3/APSK-9 are considered, because zero point in modulation constellation also indicates information that wrong OS or respective bit set not being transmitted. This fact is well shown when MBOK signal is received in low signal-to-noise rate (SNR) condition. This is equitable for DS-CDMA when full channel set is not used and zero constellation point indicates that inactive channels are really not transmitting the data.



(a)

(b)

Fig. 2. Random FWT response vector of DS-CDMA at (a) full channels load, (b) 12.5% channels load

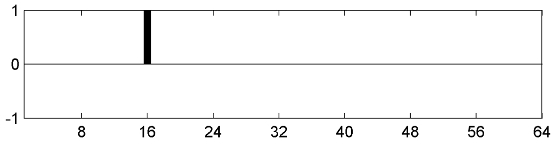


Fig. 3. Random FWT response vector of MBOK

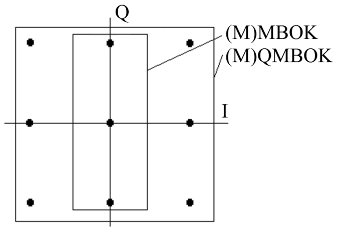


Fig. 4. Modulation constellations for different MBOK types

Multichannel MBOK

Organization of MMBOK needs to define order of simultaneously transmitted OS or indexes of different data transmission channels. Several bits from transmitted bit set needs to be assigned for this purpose.

In MMBOK the high-order bits of OS index binary representation contain the information about the number of CDMA channel or about information symbols transmission order in different channels while one user utilizes several MBOK channels, and the low-order bits directly contain transmitted data by the channel with the corresponding number. In MQMBOK case the operating principle of MMBOK from in-phase channel is translated to quadrature-phase channel [4]. High-order bits were chosen for MMBOK channel indexes representation, because in this case all OSS is divided to several subsets and only one OS from each subset can be transmitted. Thus additional wrong bit set receiving protection principle is introduced for low SNR condition case of signal transmission. The quantity of subsets is equal to the number of MMBOK channels.

For example, if MMBOK uses complete 1024 symbols OSS and 16 channels are transmitting the data, then the first 4 ($2^4 = 16$) bits are allocated for the channel number, the next 7 bits (1 polarity + 6 index) are allocated directly for data transmission of the 11 existing bits that are encoded (10 ($2^{10} = 1024$) bit on the index sequence + 1 polarity bit). So, 1024 sequences from the available OSS are divided into 16 uniform blocks of 64 sequences that follow one another. Data transfer in *k*-th channel is provided by the transmission of the one of 64 sequences from *k*-th subset. Random FWT response vector of MMBOK for this case is shown in Fig.5.

Thus bit allocation of transmitted OS indexes for different MOK types and relative SE in case of complete 64 symbols OSS usage are shown in Table I.

Table 1. Bit allocation and spectral efficiency of MOK

Type	**Bit allocation**	**Spectral efficiency, bit/s/Hz**
MOK	– – – – – – OS index	6/64
MBOK	– – – – – – – polarity + OS index	7/64
MMBOK	– – – – – – – polarity + ch. number + OS index	32/64
MQMBOK	2x – – – – – – – polarity + ch. number + OS index	64/64

Multichannel or utilized SE of system that is based on DS-CDMA or MMBOK can be calculated as multiplication of the resulting values from (1) and (2) by the number of active channels.

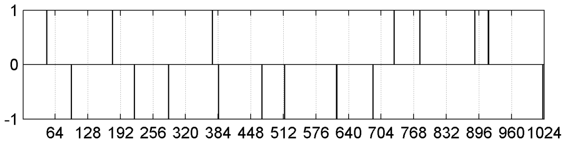


Fig. 5. Random FWT response vector of MMBOK

MMBOK signal is formed as in multichannel DS-CDMA case. After constructing of symbol sequences for each channel by respective channel encoder they are sent to APSK modulation mapper and then to channel combiner (accumulator). Resulted combined multichannel signal is translated from digital-to-analog converter to RF circuit. MMBOK signal receiving or decomposition is done in back order.

Block diagram of the quadrature MMBOK encoder shown in Fig.6.

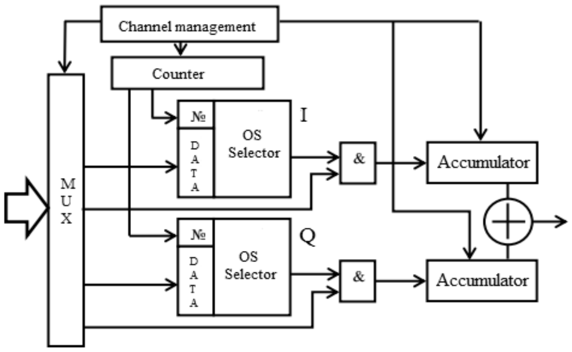


Fig. 6. Quadrature MMBOK encoder

MMBOK performance

MMBOK performance was studied comparatively to DS-CDMA by using of MATLAB model that was created taking into account all issues mentioned in previous sections.

First of all, let’s define basic performance values for CDMA systems as spread spectrum gain and actual or utilized SE. MMBOK/DS-CDMA channel encoders which use complete OSS of 1024 sequences and are appropriate only for APSK-3/BPSK are applied for this purpose. Performance values for these encoders are listed in Table II.

Performance values that are listed in Table II are brought to relative number of CDMA channels with maximum of 1024 that can be expressed in percent values. So if encoder uses OSS of 64 sequences, then these values for one channel are allocated in row that contains 16/1024 relative number of channels.

Table 2. DS-CDMA and MMBOK performance values

Relative number of channels	**Spread spectrum gain, dB**	**DS-CDMA utilized spectral efficiency, bit/s/Hz**	**MMBOK utilized spectral efficiency, bit/s/Hz**
1/1024	30,103	0,000977	0,0107422
2/1024	27,0927	0,001953	0,0195313
4/1024	24,0824	0,003906	0,0351563
8/1024	21,0721	0,007813	0,0625
16/1024	18,0618	0,015625	0,109375
32/1024	15,0515	0,03125	0,1875
64/1024	12,0412	0,0625	0,3125
128/1024	9,0309	0,125	0,5
256/1024	6,0206	0,25	0,75
512/1024	3,0103	0,5	1
1024/1024	0	1	1

Utilized SE efficiency is doubled and spread spectrum gain is reduced by half for MQMBOK/DS-CDMA encoders which are appropriate for APSK-9/QPSK comparatively to MMBOK/DS-CDMA. Because APSK-9/QPSK needs that the transmitted energy is doubled for twice more data transmission comparatively to APSK-3/BPSK.

MMBOK and DS-CDMA utilized SE dependence on the number of channels is shown in Fig.7 for more clearly visual perception of their difference. As shown in Fig.7 MMBOK has better than DS-CDMA utilized SE values at all channel quantities in constant SF = 1024 condition.

Then, let's study CDMA system based on MMBOK BER performance comparatively to DS-CDMA by using of MATLAB model simulation results. MATLAB model describes CDMA systems that utilize complete super complementary code set of 1024 sequences, data is transmitted by 16 channels with AWGN, and that are based on MMBOK/MQMBOK and DS-CDMA channel encoders/decoders. This simulation results are shown in Fig.8.

As shown in Fig.8 MMBOK has twice lower BER performance than DS-CDMA in case of 16 channels transmission. This result can be explained by assumption that BPSK is really used for data transmission in DS-CDMA and APSK-3 is used in MMBOK case, because APSK-3 need higher SNR than BPSK for 3 dB in achieving of equal BER, due to minimum distance between constellation points of APSK that is half of this equal for BPSK. Thereby MQMBOK has half of MMBOK BER performance as it needs twice more energy for double rate data transmission.

On the other hand SE of MMBOK is 7 times more than of DS-CDMA in case of 16 channels transmission. Therefore, initially, overall efficiency as spectrum-to-power efficiencies rate of MMBOK is 7/2 = 3.5 times more than of DS-CDMA in this simulation case.

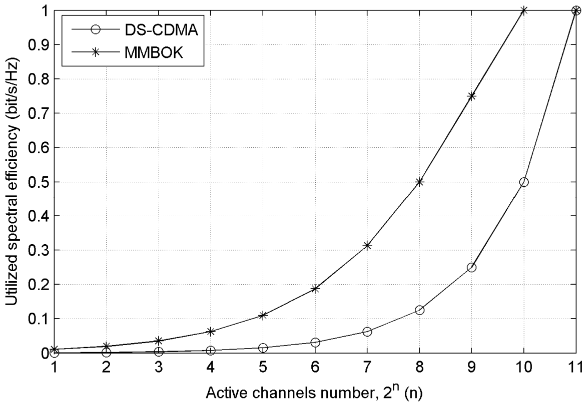


Fig. 7. Utilized spectral efficiency

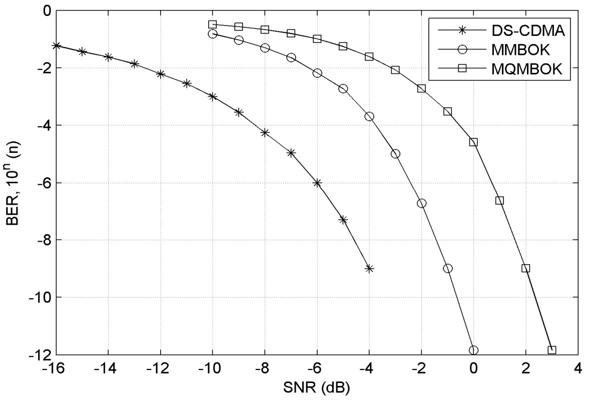


Fig. 8. MMBOK/MQMBOK and DS-CDMA BER performance of 16 channels with AWGN

For more accuracy, consider another overall efficiency comparison method, due to different MMBOK and DS-CDMA encoding nature. Firstly, find the cases where their BER performance or power efficiency is equal, and then compare SE for them. According to issues mentioned above, 16 channel DS-CDMA and 8 channel MMBOK transmission cases have equal BER performance. But MMBOK has 4 times more SE, so it is more effective than DS-CDMA.

Thus, for equal BER performance cases Fig.7 can be redrawn and is shown as Fig.9. From Fig.9 overall efficiency advantage of MMBOK over DS-CDMA can be calculated. Results of these calculations are shown in Fig.10. As shown in Fig.10, MMBOK is more effective multichannel CDMA technique than DS-CDMA in all different channels quantity cases. Maximum advantage of MMBOK is occurred when data being transmitted by only one channel and advantage is decreased while number of channels is increased.

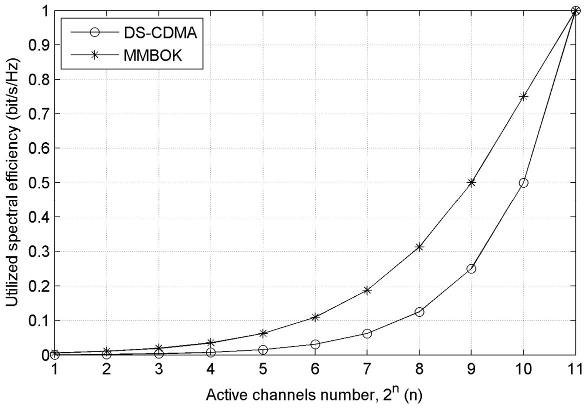


Fig. 9. Utilized spectral efficiency in equal BER cases

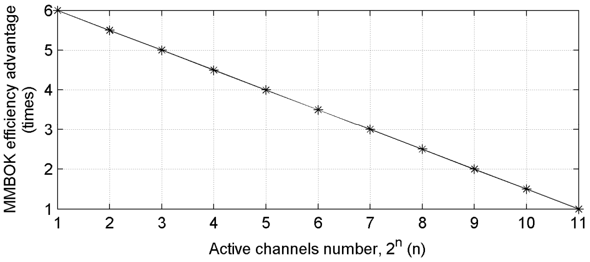


Fig. 10. Overall performance advantage of MMBOK over DS-CDMA

Conclusions

The new method of MMBOK for CDMA, its operating principle and performance studying comparatively to DS-CDMA are presented in this paper.

Initially, MBOK as the core scheme of the technique which is proposed is more spectrally efficient than DS-CDMA, because in DS-CDMA one informational bit is transmitted as OS of shorter symbols and in MBOK one OS represents an informational bit set that is the binary representation of some OS index from OSS. Thus utilized SE and channel data rate of MBOK is higher than of DS-CDMA, but power efficiency is lower, because APSK-3/9 is used with MBOK and BPSK/ QPSK with DS-CDMA. MMBOK inherits these features.

The main feature of MMBOK organization is implementation of channel number and data bit separation of OSS index binary representation of MBOK. Thus, several bits from OSS index representation are assigned for channel number or bit set transmission order. High-order bits were chosen for this purpose, because in this case all OSS is divided to several subsets and only one OS from each subset can be transmitted. Thus additional wrong bit set receiving protection principle is introduced. The quantity of subsets is equal to the number of MMBOK channels that is favorable to be 2^n, n is quantity of assigned bits. In MQMBOK case the operating principle of MMBOK from in-phase channel is translated to quadrature-phase channel.

BER performance studying shows that such values of MMBOK is lower than that of DS-CDMA in equal transmitted channel cases, due to lower power efficiency of APSK that is used for MMBOK than BPSK for DS-CDMA. But spectral efficiency of MMBOK is higher than that of DS-CDMA in all cases of active channels loading. Thus overall efficiency as spectral-to-power efficiencies rate of MMBOK is always higher than that of DS-CDMA. MMBOK becomes DS-CDMA when the number of its channels becomes equal to a number of OS symbols.

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