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Ke Chen
University of Wollongong

Xiaojing Huang
University of Wollongong, huang@uow.edu.au

Jiangtao Xi
University of Wollongong, jiangtao@uow.edu.au

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Abstract

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A Novel Approach for Interference Suppression in Multi-Subband Convolutional Coded OFDM System

Ke Chen*, Xiaojing Huang† and Jiangtao Xi*
*School of Electrical, Computer & Telecommunications
University of Wollongong, Australia
E-mail: {kc245, jiangtao_xi}@uow.edu.au
† ICT Centre
Commonwealth Scientific and Industrial Research Organization, Australia
E-mail: Xiaojing.Huang@csiro.au

Abstract— **This paper proposes a novel approach of suppressing narrowband interference from a multi-subband convolutional coded orthogonal frequency division multiplexing (OFDM) system. In this system, the convolutional coded data symbols using different coding generators are transmitted in different subbands. By identifying and discarding the interfered subband(s), the interference level can be greatly reduced and the system performance of the OFDM system can be improved. The interference thresholds for discarding the interfered subband(s) are determined through simulations over additive white Gaussian noise (AWGN) channel for demonstration purpose. The principle can also be applied to multipath fading channel.**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a form of multicarrier modulation, where a single data stream is transmitted over a set of orthogonal subcarriers [1]. It was proposed for communication devices to achieve better performance over dispersive fading channels by Chang in 1966 [8]. During the early years of OFDM, it was recognized that OFDM was difficult to realize due to the digital signal processing limitation of the devices. This situation remained unchanged until the Fast Fourier Transform (FFT) and its inverse operation were put in the implementation of OFDM in 1971 [9]. In recent years, OFDM is widely applied in wireless communications, such as in the wireless local area network (WLAN), digital audio broadcast (DAB), and digital video broadcast (DVB) systems [2][3].

With the development of wireless industry, electromagnetic spectrum becomes more and more crowded. In order to employ frequency spectrum efficiently, it is very common that different wireless devices using OFDM share the same spectrum. These devices are often placed close to each other, which consequently interfere with each other and degrade the performance. Therefore, interference reduction is an important issue.

To avoid interference between OFDM devices, many techniques have been proposed, such as interleaving [4], channel coding, and spectrum spreading [5]. Each of them introduces processing gain and/or coding gain to enhance system performance over channel noise and mutual interference.

Convolutional coding is considered as a major category of channel coding comparing to block coding, another category of channel coding. It brings more robustness to systems over fading, noise and interference. Thus, it has been broadly applied in OFDM-based wireless standards, e.g., IEEE 802.11a/g [3].

Recently, with the development of channel state information detection techniques, not only interference power level but also spectrum location can be sensed. Cognitive Radio (CR) [6] technique is an example of these techniques. In [6], the interfered subband can be treated specifically. Thereby, the interference level in the operating spectrum can be reduced by implementing additional process on the interfered subbands.

In this paper, we propose a multi-subband convolutional coded OFDM system with subband selection technique for suppressing interference. Assuming both the power level and spectrum location of interference are identified by the receiver, the system performance can be improved by discarding the interfered subband adaptively.

The rest of this paper is organized as follows. In Section II the system model is introduced. In Section III, the bit error ratio (BER) performance of this system under different interference to noise power ratios (INRs) over Gaussian channel is simulated and the INR threshold for removing interfered subband(s) is determined. Finally, conclusions are drawn in Section IV.

II. SYSTEM MODEL

A. Multi-subband convolutional coding

As shown in Fig. 1, the system is a multi-subband convolutional coded OFDM system consisting convolutional coding, OFDM modulation and subband selection.

In order to understand how this system works, we start with the transmitter. As shown in Fig.1, the input data are expressed as a binary sequence $\mathbf{m} = (m_1, m_2, m_3, \dots, m_L)$ with length L and firstly sent to a group of convolutional coding generators $\mathbf{G} = (\mathbf{g}_1^{\mathrm{T}}, \mathbf{g}_2^{\mathrm{T}}, \ldots, \mathbf{g}_N^{\mathrm{T}})^{\mathrm{T}}$, where N is the number of generators. A single coding generator is denoted as $\mathbf{g}_{\mathrm{i}} = (g_{\mathrm{i}1}, g_{\mathrm{i}2}, \ldots, g_{\mathrm{i}K})$ where $g_{\mathrm{ij}} = 0$ or $g_{\mathrm{ij}} = 1$, $\mathrm{i} = 1, \ldots, N$, $\mathrm{j} = 1, \ldots, K$, K indicates the constraint length of encoder. The codewords **U** can be expressed as

$$\mathbf{U} = \begin{pmatrix} u_{11} & u_{12} & \cdots & u_{1(L+K-1)} \\ u_{21} & u_{22} & \cdots & u_{2(L+K-1)} \\ \cdots & & & \\ u_{N1} & u_{N2} & \cdots & u_{N(L+K-1)} \end{pmatrix}. \tag{1}$$

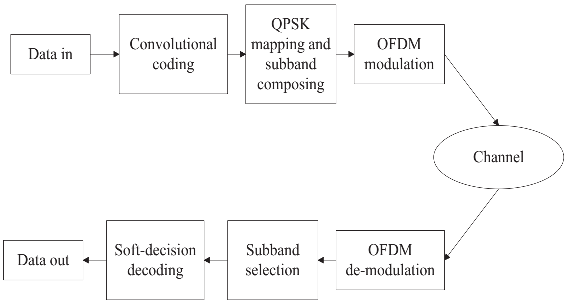


Fig. 1 Multi-subband convolutional coded OFDM with subband selection techniques.

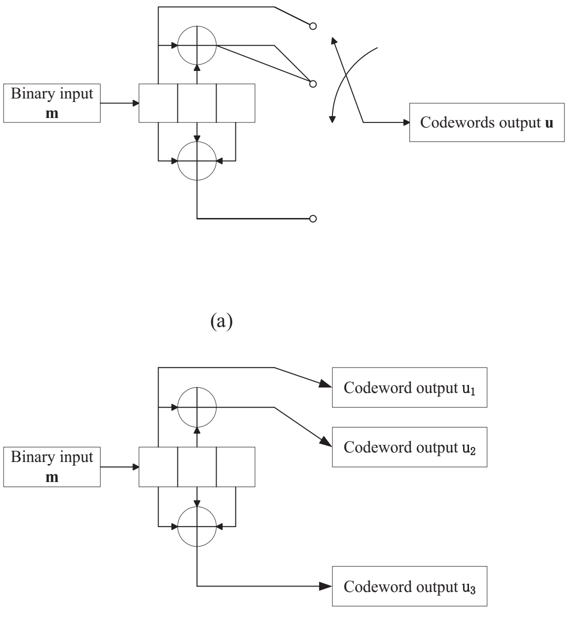
The conventional convolutional coding is shown by Fig. 2(a), where the codewords from different coding generators are multiplexed into difference time slots and output in time-division manner. If such a scheme is employed by the system in Fig. 1, every codeword will be transmitted in all OFDM subbands, and consequently a narrow band interference occurring in a single subband will result in errors in all the codewords. Discarding an interfered subband will also affect all the codewords, which is obviously not desirable.

In order to solve this problem, we propose a novel approach in Fig.2 (b). Instead of multiplexing the codewords in a time division manner, we put the codewords into different sequences in parallel, and each of them is modulated and fed into a section of adjacent frequency bins for OFDM modulation. In other words, an individual codeword stream will only occupy a particular section of OFDM subcarriers. This will bring us a significant advantage which is, when one or more subband components are detected as interfered and discarded by the receiver, transmitted data message can still be recovered from other OFDM subband components. We will demonstrate the effectiveness of this approach in the following sections.

B. QPSK mapping and OFDM modulation

Suppose that QPSK mapping is used for simplicity, by which every two bits in the codewords are mapped to a corresponding complex symbol. Thus, codewords **U** are mapped to groups of complex symbols **B** by QPSK mapping. **B** can be expressed as

$$\mathbf{B} = \begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1(\frac{L+K-1}{2})} \\ b_{21} & b_{22} & \cdots & b_{2(\frac{L+K-1}{2})} \\ \cdots & & & \\ b_{N1} & b_{N2} & \cdots & b_{N(\frac{L+K-1}{2})} \end{pmatrix}, \quad 1 \le i \le N. \tag{2}$$



(a)

(b)

Fig. 2 (a) K=3, N=3, coding rate=1/3 conventional convolutional encoding and (b) K=3, N=3, coding rate=1/3 multi-subband convolutional encoding.

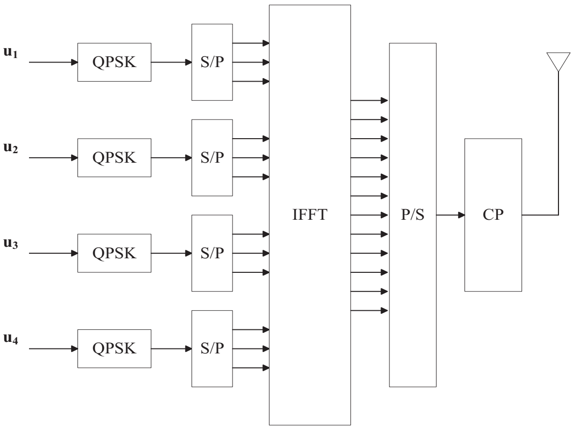


Fig. 3 A four-subband OFDM modulation (N=4).

After QPSK mapping, Inverse Fast Fourier Transform (IFFT) is used to modulate input data onto multiple subcarriers, and convert them into a serial output OFDM signal. Note that cyclic prefix (CP) is also added to the output OFDM signal.

The difference between the proposed multi-subband OFDM and conventional OFDM in modulation is that multi-subband OFDM has multiple-inputs, each of which is generated by a convolutional coding generator and modulates subcarriers in a corresponding subband.

A conventional OFDM signal [6] [7] can be expressed as

$$\begin{aligned} x(n) &= \sum_{k=0}^{M-1} b_k e^{j2\pi f_k n} \\ &= \sum_{k=0}^{M-1} b_k e^{j2\pi \frac{k}{M} n} \end{aligned} \tag{3}$$

where b_k denotes the k^{th} input QPSK symbol, M denotes the number of OFDM subcarriers, and n denotes the n^{th} time instant.

The difference between the proposed multi-subband OFDM and conventional OFDM is that the former has N codeword streams, each from a different codeword generator. The whole frequency band is divided into N subbands. Every codeword stream is modulated (e.g., using QPSK) and placed into a particular subband before OFDM modulation by means of IFFT.

Based on (3), a multi-subband OFDM signal can be expressed as

$$x_{MS}(n) = \sum_{i=1}^{N} \sum_{k=0}^{M/N} b_{ik} e^{j2\pi \frac{[(i-1)\frac{M}{N}+k]}{M} n} \tag{4}$$

where b_{ik} denotes the k^{th} input QPSK symbol in the i^{th} subband. From (4), it can be seen that in a multi-subband convolutional coded OFDM system with subband selection technique, the number of convolutional coding generators is equal to the number of subbands.

C. Subbands selection

At the receiver, the interfered subbands will be identified by comparing their interference level to an interference threshold. In order to realize this step, the received OFDM signal is converted to soft bit outputs through subcarrier de-mapping as shown in Fig. 4.

The soft bits output can be written as

$$\mathbf{R} = \begin{pmatrix} \mathbf{r}_1 \\ \cdots \\ \mathbf{r}_i \\ \cdots \\ \mathbf{r}_N \end{pmatrix} = \begin{pmatrix} \mathbf{u}_1 + \mathbf{j}_1 + \mathbf{n}_1 \\ \cdots \\ \mathbf{u}_i + \mathbf{j}_i + \mathbf{n}_i \\ \cdots \\ \mathbf{u}_N + \mathbf{j}_N + \mathbf{n}_N \end{pmatrix}, \quad 1 \le i \le N . \tag{5}$$

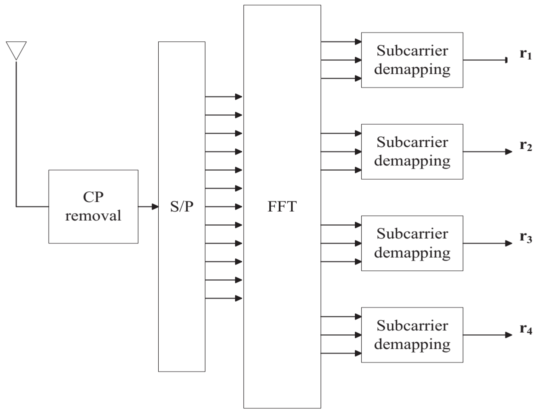


Fig. 4 A four-band OFDM demodulation (N=4).

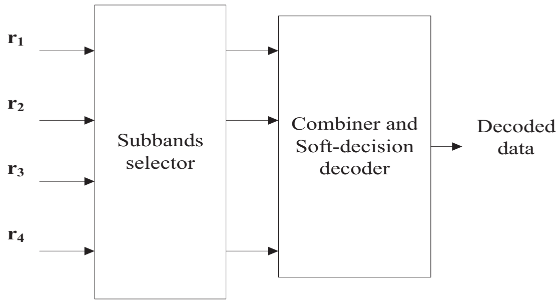


Fig. 5 Subband selection and decoding.

In (5), $\mathbf{j}_i$ denotes the interference in respective subbands, and $\mathbf{n}_i$ indicates the noise in each subband introduced by the channel. The interference levels in different subbands can be indicated by $INR_{(i)}$ which is expressed as

$$INR_{(i)} = \frac{||\mathbf{j}_i||^2}{||\mathbf{n}_i||^2}, \qquad 1 \le i \le N , \tag{6}$$

where $\|\cdot\|$ denotes the Frobenius norm.

The threshold of interference level υ is an INR value. The determination of the threshold υ will be discussed in the following section. If $INR_{(i)} > \upsilon$, the soft bits in the corresponding subband are severely interfered and should be removed to improve the overall system performance. Otherwise, the interference can be tolerated.

Fig.5 shows an example of subband selection. The soft bits in the third subband $\mathbf{r}_3$ are severely interfered, so they will be discarded by the subband selector and not be combined for decoding.

The corresponding convolutional coding generators of the remaining subbands are used in the soft-decision decoder to convert soft bits into binary sequence. Thus, the data vector $\mathbf{m}$ is recovered.

III. DETERMINATION OF INTERFERENCE LEVEL THRESHOLD

The BER performance of a coded OFDM system is different at different coding rate. Let $P_{e,(1/r)}(SNR)$ denotes the BER, at a signal to noise ratio (SNR) value *SNR* of a convolutional coded OFDM system, where *1/r* is the coding rate. Therefore, the BER difference P_{BER} at the same SNR value between two different coding rate coded OFDM systems can be written as

$$P_{BER}(r_1,r_2)=P_{e,(1/r_2)}(SNR)-P_{e,(1/r_1)}(SNR),\quad r_1>r_2\ . \tag{7}$$

Although the proposed approach is able to reduce the interference and noise level, it also results in a loss of coding gain. Therefore both of the two factors should be considered when determining the interference level threshold.

When interference is presented, (7) can be re-written as

$$P_{BER}(N,N-I)=P_{e,(1/(N-I))}\left(\frac{SNR}{1+INR_2}\right)-P_{e,(1/N)}\left(\frac{SNR}{1+INR_1}\right)$$
$$1\le I\le N\ ,INR_1>INR_2 \tag{8}$$

where I is the number of interfered subbands. INR_1 denotes the INR value when interfered subbands are kept, and INR_2 denotes the INR value after interfered subbands are discarded. The INR threshold υ can be determined by letting

$$P_{BER}(N,N-I)=P_{e,(1/(N-I))}\left(\frac{SNR}{1+INR_2}\right)-P_{e,(1/N)}\left(\frac{SNR}{1+\upsilon}\right)$$
$$=0 \tag{9}$$

for $1\le I\le N$.

An analytical solution for the INR threshold is difficult to obtain due to the convolutional coding. However, the threshold can be determined through simulations. Fig. 6 to Fig. 8 show the simulation results at *SNR* = 7 dB and various INR values for a 4-subband OFDM system in AWGN channel when the number of interfered subbands is 1, 2, and 3 respectively. We see that, for a given number of interfered subbands, once the INR is above a threshold the BER performance after discarding the interfered subband(s) will be better than that if the interfered subband(s) is (are) kept. Table I summarizes the threshold υ of an *N* subband OFDM for *N* = 2 and 4.

The interference thresholds υ at different BERs and various numbers of interfered subbands can be also found. In convolutional coded multi-subband OFDM system with subband selection, the receiver firstly assumes that there is only one subband has been interfered (I=1), and then compares the INR value of each subband with the threshold υ.

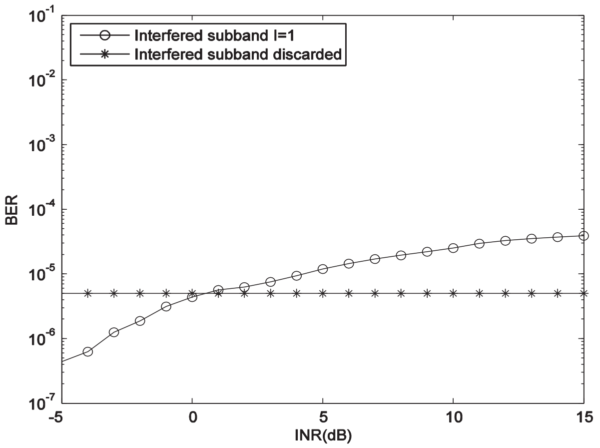


Fig. 6 INR threshold over AWGN channel of a convolutional coded 4-subband OFDM system I =1 (*SNR*=7dB).

If more than one subbands have higher INR value than υ, then the receiver will consider there are two subbands interfered (I=2). If more than two subbands have higher interference levels than υ, then the receiver will consider there are three subbands interfered (I=3). This process will continue

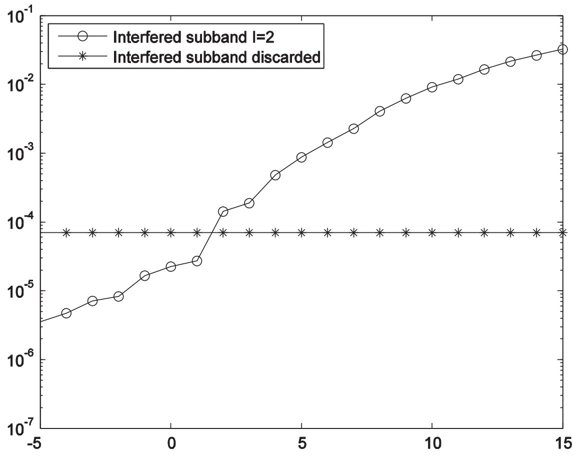


Fig. 7 INR threshold over AWGN channel of a convolutional coded 4-subband OFDM system for I =2 (*SNR*=7dB).

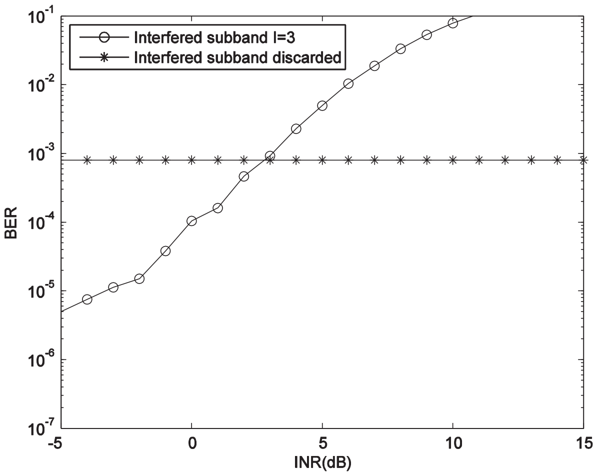


Fig. 8. INR threshold over AWGN channel of a convolutional coded 4-subband OFDM system I =3 (SNR=7).

TABLE I
THRESHOLD υ FOR MULTI-SUBBAND OFDM

Interfered subbands	***Threshold υ (dB) N=2***	***Threshold υ (dB) N=4***
I=1	2.0	0.5
I=2	-	1.8
I=3	-	2.9

unless all the subbands are checked. By this process, interfered subbands can be identified and discarded.

A comparison of BER performance of convolutional coded multi-subband OFDM system before and after interfered subband(s) being removed is shown in Fig. 9 when there is a constant interference at INR = 7 dB. We see that after removing the interfered subband(s), the system performance is significantly improved.

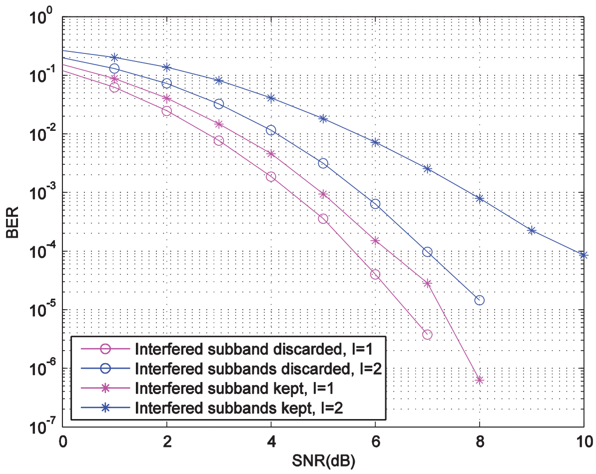


Fig. 9 BER performance of a convolutional coded 4-subband OFDM before and after interfered subband(s) removed at INR=7dB.

IV. CONCLUSIONS

In this paper we have investigated a subband selection method to suppress interference in multi-subband convolutional coded OFDM systems. The interference thresholds over Gaussian channel at different BERs and different numbers of interfered subbands have been determined through simulation. This method can be applied to any convolutional coded multi-subband OFDM system with narrowband interferences at any channel condition, either AWGN or multipath fading, to improve the system coexistence performance. It can be also applied to future generation cognitive communication systems.

REFERENCES

[1] H. Liu, G. Li, OFDM-based broadband wireless networks: design & optimization, Wiley-Interscience, 2005.

[2] L. Hanzo, M.Munster, B.J. Choi, T. Keller, *OFDM and MC-CDMA*, John Wiley & Sons, 2003.

[3] P. Tu, X. Huang, E. Dutkiewicz, "Diversity performance of interleaved spread spectrum OFDM signals over frequency selective multipath fading channels," in *Procedings of 2007 International Symposium on Communications and Information Technologies*, Sydney, Australia. pp. 184-189, 17-19 Oct. 2007.

[4] Z. Wu, C.R. Nassar, "Narrowband interference rejection in OFDM via carrier interferometry spreading codes," *IEEE Transaction on wireless communication*, 4 (4), pp.1491-1505, July 2005.

[5] G. Kaleh, "Frequency-diversity spread-spectrum communication system to counter bandlimited Gaussian interference," *IEEE Transactions on Communications*, vol.44, issue 7, pp.886-893, July 1996.

[6] D. Cabric and R. W. Brodersen, "Physical layer design issues unique to cognitive radio systems," in *Proceedings of IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications*, vol. 2, pp. 759-763, Nov. 2005.

[7] P. Tu, X. Huang, E. Dutkiewicz, "Adaptive subband selection in OFDM-based cognitive radios for better system coexistence," in *Proceedings of the 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications*, pp. 1-6, May, 2008.

[8] S.B. Weinstein and P.M. Ebert, "Data transmission by frequency division multiplexing using the discrete fourier transform," *IEEE Transactions on Communication Technology*, vol. COM-19, pp.628-634, October 1971.