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A Wideband Spectrum Data Compression Algorithm base on Energy Detection

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Abstract: In cognitive radio systems, interactive perception spectrum data between cognitive users can effectively improve the overall performance of the user's perception of communication. However, a large number of spectrum data accumulation will increasing the consumption of resources during interaction, lack of effective spectrum data compression algorithm cognition become a bottleneck restricting the collaboration. This paper presents a wideband spectrum data compression algorithm based on the energy detection and sliding window, removing redundant information of noise, compressing the detail of signal with different weights, reserving useful information, improving the compression ratio and reducing compression loss. In addition, the algorithm retains the spectrum details of the signal by the DCT transform in the case of a high compression ratio, and those details are propitious to spectrum analysis. Especially under low occupancy ratio circumstances, experimental results show that the compression performance of this algorithm increase several times compare to JPEG and JPEG2000.

Keywords: Cognitive Radio, Wideband spectrum compression, DCT transform

1 Introduction

In traditional management mechanism of spectrum, the most parts of the frequency band are been exclusively by parts of authorized user, this mechanism waste of spectrum resources also limits the development of wireless applications. The spectrum efficiency of authorized users is very low [1]. Accordingly, researchers have proposed a cognitive radio (CR) to improve the spectrum utilization efficiency [2]. In cognitive radio, cognitive users (*non-authorized users*) to use the idle frequency band of authorized user. The cognitive users need to continuously monitoring spectrum to ensure the timely exit when an authorized user appears. However, various factors influence individual cognitive user is difficult to ensure detection performance [3]. The researchers propose a method that cognitive user collaboration spectrum sensing can effectively improving the reliability of spectrum sensing, reducing the perception of time, reducing perception accuracy of node needs, improving overall system performance, and so on [4,5,6]. But because there is a large number of spectrum data interaction between cognitive users that resulting in more energy Consumption, but also the radio resources occupied when data interaction [7].

To reduce the resource consumption when spectrum data interaction, data compression is an effective method and has been widely used in the field of image processing. According to lossless data compression algorithm and lossy compression algorithms for the image are proposed by redundancy characteristic of data and images. Spectrum data has its own unique properties, simply use the existing compression algorithms is difficult to meet the demand of compression performance and complexity of the algorithm.

Similarly, as a one-dimensional data, numbers of research results emergence in the electrocardiogram (ECG) signal date and power monitoring of data compression [8,9,10], some of the image compression algorithms is improved to adapt to the specific one-dimensional data compression.

Currently, the compression algorithm suitable for spectrum data rarely attracts researchers's attention. Only in the literature [11], the researchers aiming at data sequence is presented a compression algorithm which base on Chebyshev, but higher complexity and difficult to achieve.

Firstly, this paper analyzes the redundant characteristics of wideband spectrum data in the case of

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multiple-communication systems coexist. Then this paper proposed a wideband spectrum compression algorithm which base on Discrete Cosine Transform (DCT) transform and improved energy detection which is applied in wideband scenario in absence of priori information. Finally, we simulate the proposed algorithm and compare performance with the existing JPEG and JPEG2000 these two advanced image compression algorithms.

The most commonly used compression method is JPEG which base on DCT transform [12]. JEPG2000 is a newer image compression technology, and it base on 2-D wavelet transform [13].

2 Spectrum data Characteristic analysisls

In conventional communication systems, spectrum efficiency is low and part of the spectrum in the form of white holes which allocated to the system. This means that a large part of the perceived spectrum data is noise data. As can be seen from the Fig 1, signal is only a small part of the band, as shown in Fig 1. In the conventional image compression algorithm, any data to transform domain compress with equal weight. And we can use different ways to compress the useful signal spectrum and the noise spectrum data. A signal spectrum have significantly larger effect in spectrum analysis so that less distortion compression method have been used, the available information of noise spectrum is small so that higher compression ratio can be employed by way of compression. This is the main starting point of the algorithm in this paper.

Spectrum data in the transform domain also has available redundancy characteristic. The main components of the conventional image of transform domain data are concentrated in the low frequency, but the energy component of transform domain in spectrum data with different characteristics. As can be seen from the Fig 3, after the DCT spectrum data changes can be seen the DCT components are descending order from low frequency to high frequency. By analyzing the characteristics of the above spectrum data, we can see if using the spectrum sensing detection results to separate noise and signal and process them by different methods respectively can effectively improve the spectrum efficiency of data compression.

Therefore, this paper proposes an efficient algorithm to compresses wideband spectrum data and applied in cognitive radio. Firstly, use the judgment result of spectrum sensing separation of signal and noise data, and compression processing. Then use the DCT transform process spectrum data and keep the main component.

3 Spectrum data segment compression algorithm

3.1 Specific steps of the algorithm

1. Spectrum sensing bandwidth is B, Spectrum sensing frequency resolution is f_r, Input the length N of spectrum data $x(i), i = 1, \ldots, N$ where the N coefficients are given by $N = B/f_r$, Input the same length N of the signal energy detection results is defined by $d(i), i = 1, \ldots, N$, when $d(i)$ is 0 represents the sample point is the noise data, when $d(i)$ is 1 represents the sample point is the signal. Use $d(i)$ extracted noise data x_N and signal data x_I, where $x_N = x(i)|d(i) = 0$ and $x_I = x(i)|d(i) = 1$. In this paper we choose an improved energy detection method [14] to obtain detection results

2. $d(i)$ is a binary-data sequence, we use block skipping method [15] conduct lossless compression and then get the compressed data of energy detection results D . Block skipping method is an efficient algorithm to compress binary-data and especially the data is composed of continuous 0 sequences and continuous 1 sequences [16].

3. Compress noise data, which noise carry redundant information, only the average noise power with information of spectrum analysis required, so that the noise data compression only retains the mean of noise power P_N.

4. According to the detection results, perceived signal identification of signal spectrum data, follow these steps:

1) For signal spectrum data x_I doing DCT transform then get DCT coefficients S_d.

2) According to the energy threshold T retain the coefficients S_d of low frequency, making the total energy of low frequency is below or equal to $sum(S_d^2) * T$, then we obtain the retained coefficients sequence S_{LP}.

5. For the quantification of S_{LP}, the following steps:

Quantization step is $step_q = \frac{max(S_{LP})-min(S_{LP})}{N_{ql}}$. Where N_{ql} is quantization progression, get quantized coefficients sequence S.

6. Finally we have to encode two types of data:

1) The retained DCT coefficients vector S.

2) The compressed detection results vector D.

We have chosen to encode all these types of data with the arithmetic encoder. Then we obtain arithmetic code data C_a.

7. arithmetic code data C_a, The lengths of retained coefficients and detection results as well as mean of noise consisting of a compressed frame header.

3.2 Algorithm analysis

Our algorithm is different from common image compression algorithms, it decompose the spectrum data into noise part and signal part. We retaining only mean of noise power and compress the signal spectrum data with the method of segment compression which base on DCT transform, the energy detection results are lossless compressed by the block skipping method. Since those processing methods reduce the noise data quantity which describes noise details and be not of much use in spectrum analysis, the compression ratio of our algorithm is higher than traditional compression algorithms. The energy detection results are additional overhead in

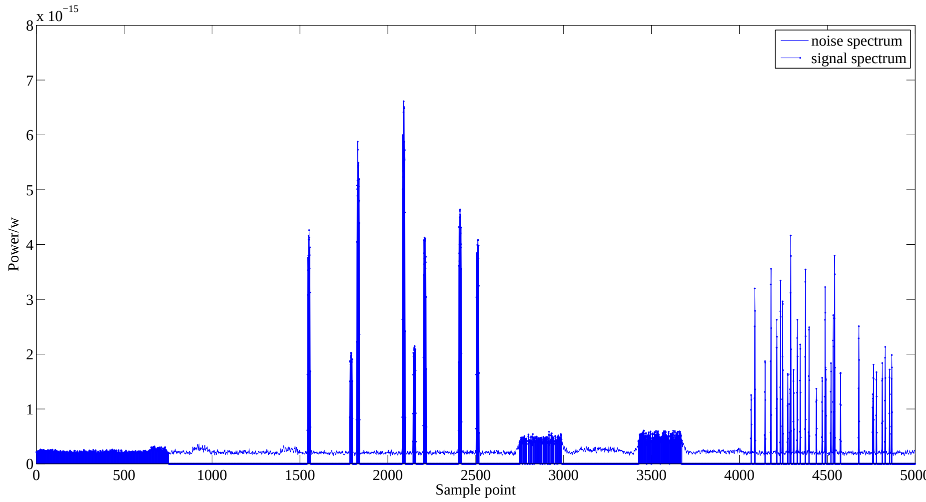

Fig. 1: L-band broadband spectrum

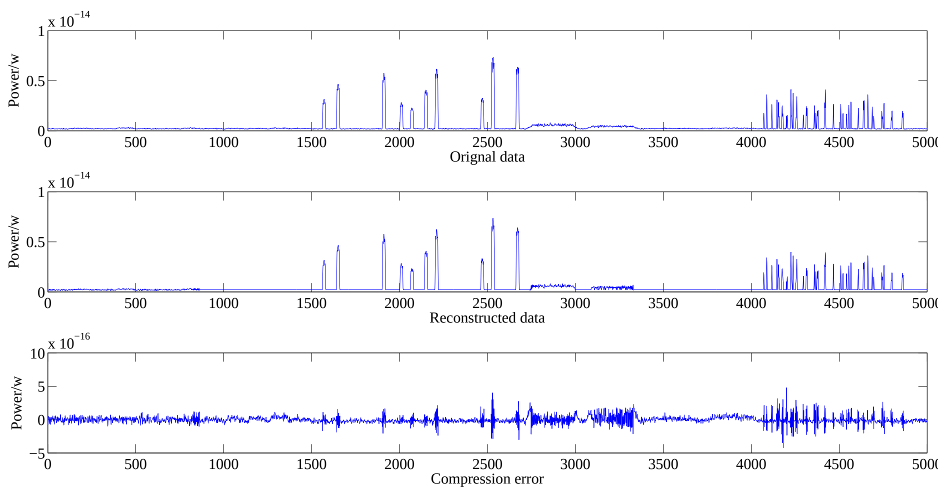

Fig. 2: Decomposition of signal spectrum

compressed data, but they are composed of 01 sequence which could represent by boolean data and amount of overhead is small. In addition, we know the fact that there are much continuous 0 sequences and continuous 1 sequences, and the energy detection results are suitable for lossless compression with. The reason of lossless compression is that detection results are spectrum position information and it is important to compressed data reconstruction.

After that, we encode retained DCT coefficients and compressed detection results vector with the arithmetic encoder.

The main operations of our algorithm concentrated on DCT transform and entropy coding, and the other operations are much smaller. As we know, the main steps of JPEG are DCT transform, quantization and entropy coding. So the complexity of the algorithm proposed by this paper is similar to that of JPEG.

4 Simulation Analysis

4.1 Performance metrics

Two performance metrics were used for evaluating the performance of the compression algorithms. The

Table 1: Compression performance comparison

occupancy ratio	This algorithm			JPEG			JPEG2000		
	CR	PRD	PRD	CR	PRD	PRD	CR	PRD	PRD
%		%	(only signal)		%	(only signal)		%	(only signal)
0-10	47.62	6.76	4.09	10.34	9.97	4.48	19.42	8.16	4.45
10-20	24.10	7.94	4.50	9.71	8.00	5.24	15.92	7.51	5.13
20-30	17.33	6.92	4.68	8.76	8.55	5.09	15.67	7.95	5.37
30-40	14.64	6.91	4.88	8.73	7.39	5.13	14.12	7.11	5.25
40-50	13.02	6.49	4.72	7.89	6.43	5.39	10.96	5.70	5.01
50-60	12.10	6.61	4.96	7.96	6.20	5.29	10.93	5.72	4.98

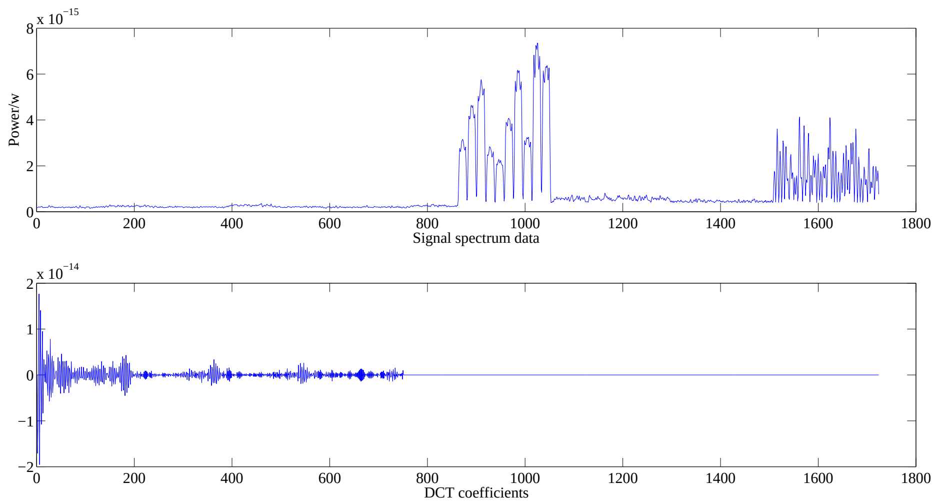

Fig. 3: The coefficients of DCT transform

compression performance indicator is Compression Ratio (CR).

$$CR = \frac{b_{orig}}{b_{comp}} \quad (1)$$

Where b_{orig} is the total number of original data bits, and b_{comp} is the total number of compressed data bits. The error performance indicator is Percent of Root-mean-square Difference in Percentage (PRD).

$$PRD = \sqrt{\frac{sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{sum_{i=1}^{N} x_i^2}} \quad (2)$$

x is the original spectrum data, and $\hat{x}$ is the reconstructed data.

4.2 Simulation results and analysis

Experimental data is L-band satellite communication spectrum sensing data, and The resolution of each sample is 16 bits/sample. The spectrum sensing bandwidth $B = 50MHz$,the frequency resolution of spectrum sensing $f_r = 10kHz$,and data length $N = 5000$. This paper implements our algorithm, JPEG and JPEG2000 by matrix laboratory (Matlab2012) in experiments. Our algorithm parameter settings as shown in the following table.

Table 2: Algorithm parameter setting

Parameter	Value	describe
L_{block}	10	Block length of block skipping
T_{cyc}	3	Segmented cycle
T	0.99	Ratio of DCT coefficient energy retained
N_{ql}	256	Quantization step

The parameters of JPEG and JPEG2000 are the default values. Because of the ratio of noise in spectrum depend on the spectral environment, for test compression performance in different spectral environment more effectively, this paper choose different spectrum data to experiment and their spectrum occupancy ratios are from 0% to 60%. The spectrum occupancy ratio is the ratio of the total signal bandwidth and the total sensing bandwidth.

Fig 2 is the compression effect, reconstructed data retains the main details of the signal and the error is very small. In this paper, our algorithm will be compared with JPEG and JPEG2000. We divide test data into 6 classes by their occupancy ratio and the test value is the mean value of performance metrics in same class. The number of each class is 20. The Table 1 shows comparative results.

As can be seen from Table 1, performance metrics of this compression algorithm are almost all superior to those of JPEG and JPEG2000 in all different spectrum occupancy ratio, especially in case of low occupancy ratio. And under normal circumstances, the spectrum utilization is low. Occasionally, the PRD performance of compression is slightly worse than JPEG2000 and JPEG. This is because the main error of segmented compression concentrates on noise part. But in spectrum cognition, the details of noise spectrum are unimportant compare to signal details. If we only calculate PRD of signal spectrum, this algorithm is advanced. So our compression made high gain in CR performance than the traditional image compression algorithms in the case of similar error performance. The performance of JPEG2000 is also good in the case of higher occupancy ratio, but the complexity of JPEG2000 is very high.

5 Summary and conclusions

For take full advantage of spectrum redundant features to improve compression performance, this paper analysis the shortcomings of traditional image compression algorithms in wideband spectrum data compression and presents a wideband spectrum data compression scheme based on the frequency detection and DCT. The performances of the compression algorithm are test in experiment and the results show that the CR performance of this compression algorithm is much better than JPEG and JPEG2000 in case of different spectrum occupancy ratio. Especially in case of low occupancy ratio, the compression ratio performance increase several times compare to JPEG and JPEG2000. The same time our algorithm ensures the accuracy of reconstructed data. And the complexity of our algorithm is closer to JPEG, much smaller than JPEG2000. Technologies related DCT are very mature, easy to implement and be able to meet the real-time requirements of cognitive radio system. So the compression algorithm proposed by this paper can resolve the data exchange bottleneck in cooperative cognitive radio system, and can be applied to sensor networks, spectrum monitoring etc.

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