The selective transmission with majority even/odd subcarriers for increasing the data transmission throughput in OFDM based Cognitive Radio systems

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Abstract: - The novel method for increasing the data transmission throughput in OFDM based Cognitive Radio system was proposed. If only even or odd subcarriers are assigned to input, the symmetrical IFFT output is generated. By using the property of symmetry, only half part of OFDM symbol with even or odd data is transmitted during first half of OFDM symbol duration, another even or odd different data can be transmitted during second half of OFDM symbol duration. And the receiver can recover the data using only the received half OFDM signal. Therefore it is possible to increase the data transmission throughput. And the comparative description how the data transmission throughput can be increased is given in the view point of statistical analysis.

Key-Words: - Data throughput; OFDM; Cognitive Radio; FFT; Pruning; Computational complexity

1 Introduction

In OFDM based Cognitive Radio system, some of individual subcarriers are nullified and those corresponding inputs/outputs for the IFFT/FFT should be zeros. If there are considerably a large number of zero-valued inputs/outputs in the IFFT/FFT, the standard FFT is no longer efficient. Therefore there have been some researches for making a design of the efficient FFT algorithm which can reduce computational complexity due to multiplication in the butterfly structure with twiddle factors in the OFDM based Cognitive Radio, where zero valued inputs/outputs outnumber nonzero input/output.

Markel proposed the Decimation-In-Frequency (DIF) FFT pruning algorithm [1] and later the pruning algorithm was extended to the Decimation-In-Time (DIT) FFT by Skinner [2]. However, in case of the practical OFDM based cognitive radio system which has zero inputs/outputs with arbitrary distributions, the effort to design the control circuit for the selection of the butterflies corresponding to nonzero inputs/outputs makes the HW implementation of FFT pruning to be complex. In order to escape complex HW implementation of FFT pruning due to zero inputs/outputs with arbitrary distributions, Sorensen and Burrus proposed Transform Decomposition (TD) [3] with regular design structure, even though it doesn't reduce computational complexity than pruning based method. And recently Split-Radix FFT (SRFFT) pruning with more reduced computational complexity was proposed [4]. In this method, the pruning matrix generator with regular design structure, which is the essential circuit for selecting multiplication part with twiddle factors at every stage of IFFT, was devised. The reduction of computational complexity makes it possible power consumption lower. And it is expected that the computational speed gets faster thanks to the reduction of computational complexity. Because the Cognitive Radio system was introduced for increasing the efficiency of spectrum utilization in the limited frequency resources, it might be more important to increase the data transmission throughput during the available time when those vacant subcarriers were sensed. Now it is meaningful to review the relation between data transmission throughput and the effect of the shortened computational time thanks to the reduction of computational complexity.

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Even though the computation time for generating IFFT output signal of OFDM was shortened, the OFDM symbol period is constant. During one OFDM symbol time, only the number of data which is same as the number corresponding to the vacant subcarriers is transmitted. In this paper, the novel idea for increasing the number of data which can be transmitted during one OFDM symbol time was proposed.

In this novel transmission method, even or odd subcarriers among those vacant subcarriers will be used repeatedly two times for transmitting input data during one OFDM symbol time.

Using the symmetric form in the output signal of IFFT with even (odd) inputs whose number is more than odd (even), only half part of the whole output signal is transmitted instead of transmitting the whole signal part which consists of the first half signal part and another same half signal part. During the half OFDM symbol time corresponding to the latter half signal part, the next new data can be transmitted, which can increase the data transmission throughput.

In the following section II, the output signal processed in the transmitter with only even (or odd) subcarriers and in the receiver which can recover the data using the received half OFDM signal is described in the view point of signal processing. And also the comparative description how the data transmission throughput can be increased is given in the view point of statistical analysis.

2 System description of the selective transmission with majority even/odd subcarriers

2.1 Transmitter part

Those vacant subcarriers acquired through spectrum sensing have even and odd index numbers. Instead of using the total vacant subcarriers with even and odd (E+O)subcarriers, if the data is assigned only to one of those subcarriers with even index in the IFFT as in Fig. 1, the waveform of IFFT output signal from 0 to NT/2 is repeated again from NT/2 to NT as in Fig. 2. However, if the data is assigned only to those subcarriers with odd index in the IFFT, same waveform with negative sign is repeated.

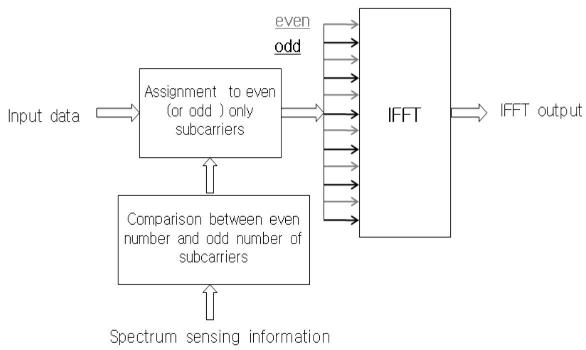

Fig.1 Structure of the selective transmission with majority even/odd subcarriers

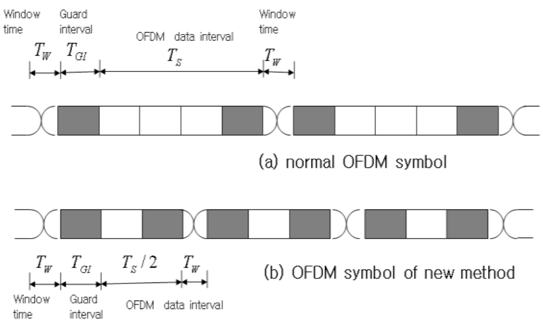

Fig.2 OFDM symbol structure of the selective transmission with majority even/odd subcarriers

Fig. 3 shows the repeated waveform in one OFDM symbol duration in case of 8 point IFFT as a simple example.

The output signal from IFFT with only even or odd index inputs is described as in eq. (2) and eq. (4).

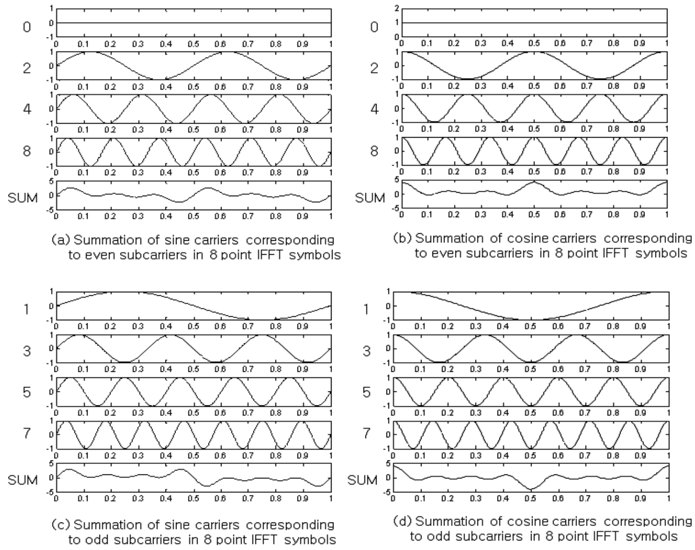

Fig.3 Symmetrical waveform of sine or cosine carriers corresponding to even or odd subcarriers in OFDM IFFT symbol

• In case of input with even index : $X_{2m+1} = 0$

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j2\pi\frac{nk}{N}} = \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m} e^{j2\pi\frac{nm}{N/2}} a \qquad (1)$$

$$\begin{aligned} x_{n+N/2} &= \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m} e^{j2\pi\frac{(n+N/2)2m}{N}} \\ &= \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m} e^{j2\pi\frac{nm}{N/2}} e^{j2\pi m} = x_n \end{aligned} \qquad (2)$$

• In case of input with even index : $X_{2m} = 0$

$$x_n = \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} e^{j2\pi\frac{n(2m+1)}{N}} \qquad (3)$$

$$\begin{aligned} x_{n+N/2} &= \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} e^{j2\pi\frac{(n+N/2)(2m+1)}{N}} \\ &= \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} e^{j2\pi\frac{n(2m+1)}{N}} e^{j2\pi m} e^{j\pi} = -x_n \end{aligned} \qquad (4)$$

Therefore it is not necessary to transmit the whole OFDM waveform whose first half part is repeated once again symmetrically in the one OFDM symbol duration.

Instead of the normal transmission in OFDM with even or odd indexed IFFT, only half of OFDM symbol is transmitted and second half OFDM transmission time can be assigned to another new data, which makes data throughput increased more than normal Cognitive Radio transmission.

2.2 Receiver part

Those transmitted half OFDM symbol is processed using N/2 point FFT as shown in the following eq. (6) and eq. (8).

- In case of input with even index : $X_{2m+1} = 0$

$$X = [X_0, 0, X_0, \cdots\cdots X_{N-2}, 0\ ]$$
$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j2\pi\frac{nk}{N}} = \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m} e^{j2\pi\frac{nm}{N/2}} \tag{5}$$

$$\begin{aligned}
X_k &= \sum_{n=0}^{N/2-1} x_n e^{-j2\pi\frac{nk}{N/2}} \\
&= \sum_{n=0}^{N/2-1}\left(\frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m} e^{j2\pi\frac{nm}{N/2}}\right)e^{-j2\pi\frac{nk}{N/2}} \\
&= \frac{1}{N}\sum_{n=0}^{N/2-1}\sum_{m=0}^{N/2-1} X_{2m} e^{j2\pi\frac{nm}{N/2}} e^{-j2\pi\frac{nk}{N/2}} \\
&= \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m} \sum_{n=0}^{N/2-1} e^{j2\pi\frac{n(m-k)}{N/2}}
\end{aligned} \tag{6}$$
$$\text{where} \sum_{n=0}^{N/2-1} e^{j2\pi\frac{n(m-k)}{N/2}} = \begin{cases} 0, & m \neq k \\ N/2, & m = k \end{cases}$$
$$\therefore \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m} \sum_{n=0}^{N/2-1} e^{j2\pi\frac{n(m-k)}{N/2}}$$
$$= \frac{1}{N} X_{2k} \frac{N}{2} = \frac{X_{2k}}{2} = \frac{X_{2m}}{2}$$

- In case of input with even index : $X_{2m} = 0$

Differently from even index case, the phase rotation with e^(-j2π n⁄N)should be introduced to the received signal.

$$X = [0, X_1, 0, \cdots\cdots X_{N-1}\ ]$$
$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_n e^{j2\pi\frac{nk}{N}} = \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} e^{j2\pi\frac{n(2m+1)}{N}} \tag{7}$$
$$= \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} e^{j2\pi\frac{nm}{N/2}} e^{j2\pi\frac{n}{N}}$$

$$\begin{aligned}
X_k &= \sum_{n=0}^{N/2-1} x_n e^{-j2\pi\frac{n}{N}} e^{-j2\pi\frac{nk}{N/2}} \\
&= \sum_{n=0}^{N/2-1}\left(\frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} e^{j2\pi\frac{nm}{N/2}} e^{j2\pi\frac{n}{N}} e^{-j2\pi\frac{n}{N}}\right)e^{-j2\pi\frac{nk}{N/2}} \\
&= \frac{1}{N}\sum_{n=0}^{N/2-1}\sum_{m=0}^{N/2-1} X_{2m+1} e^{j2\pi\frac{nm}{N/2}} e^{-j2\pi\frac{n(m-k)}{N/2}} \\
&= \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} \sum_{n=0}^{N/2-1} e^{j2\pi\frac{n(m-k)}{N/2}} e^{j2\pi\frac{n}{N}}
\end{aligned} \tag{8}$$
$$\text{where} \sum_{n=0}^{N/2-1} e^{j2\pi\frac{n(m-k)}{N/2}} = \begin{cases} 0, & m \neq k \\ N/2, & m = k \end{cases}$$
$$\therefore \frac{1}{N}\sum_{m=0}^{N/2-1} X_{2m+1} \sum_{n=0}^{N/2-1} e^{j2\pi\frac{n(m-k)}{N/2}} e^{j2\pi\frac{n}{N}}$$
$$= \frac{1}{N} X_{2k+1} \frac{N}{2} = \frac{X_{2k+1}}{2} = \frac{X_{2m+1}}{2}$$

As shown in the above equations, the output result's amplitude was scaled downed as half of the original data. Therefore it is necessary to scale up the result's magnitude with 2.

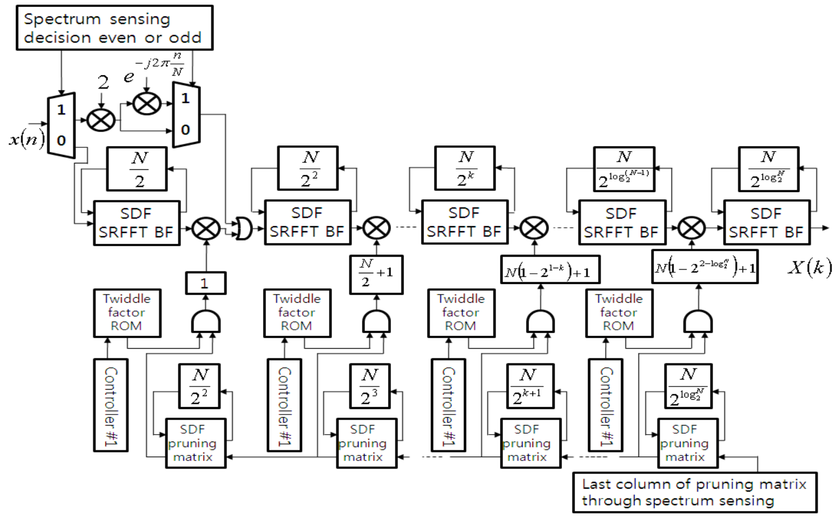

Fig.4 Structure of the receiver

As in Fig. 4, the normal CR signal is processed in N point split radix FFT and the signal transmitted from the selective transmission with even or odd majority subcarriers is processed in N/2 point FFT. The lower part of Fig. 4 is pruning generator which eliminates the unnecessary multiplication operation about zero inputs in OFDM based CR system.

3 Analysis of data throughput increase

When the number of vacant subcarriers is m in some instance, the number of even or odd vacant subcarriers will have an uniform distribution from 0 as a minimum number to m as maximum number.

However, if only even or odd subcarriers with majority number are selected for transmission, the PDF will be an uniform distribution from m/2 to m with 3m/4 as mean.

Assuming the length of OFDM data and the cyclic prefix as N and N/4 respectively, the throughput efficiency of normal CR system is m/(N+N/4)=4m/5N as in Fig. 5 and Fig. 6. In case of the selective transmission with majority even or odd subcarriers, the averaged throughput efficiency is 2x(3m/4)/(N+N/2)=m/N, considering that even or odd subcarriers with majority number is used two times in one OFDM symbol duration and the additional cyclic prefix is required for second half symbol.

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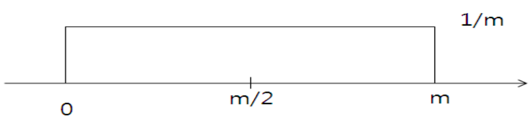

Fig.5 PDF of even/odd subcarriers in m subcarriers

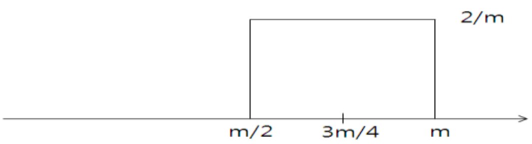

Fig.6 PDF of the selective transmission with majority even/odd subcarriers

4 Conclusion

Using the symmetrical feature of IFFT output with even or odd index only inputs, the novel structure was proposed for the selective transmission with majority even or odd subcarriers which can increase the data transmission throughput. The feasibility for the proposed method was proved in the view point of signal processing and the data throughput is shown to be increased higher than the normal Cognitive Radio transmission.

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