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Cognitive Radio 시스템의 OFDM을 위한 효율적 DCT/DFT 계산에 관한 연구

(Efficient DFT/DCT Computation for OFDM in Cognitive Radio System)

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요 약

본 논문에서는 Cognitive Radio 시스템에서의 DFT와 DCT에 근거한 OFDM을 제시한다. 적응 OFDM은 허가된 사용자의 주파수 간섭을 피하기위해서 개별적인 반송파를 무효화시키는 capacity를 갖는다. 그러므로 OFDM 송신기에서 IDFT/DFT, IDCT/DCT의 입력과 출력이 상당수의 0값을 갖는다. 따라서 DFT와 DCT의 표준 방법은 0에서 필요치 않은 연산 때문에 더 이상 효율적이지 않을 수 있다. 이러한 고찰에 근거하여, 본 논문은 IDFT/DFT, IDCT/DCT를 위한 2차원적(2-D) 단축된 정렬 변환 분해 방법을 보이고, 이 알고리즘이 Cognitive Radion 시스템 환경의 OFDM의 계산을 효율적으로 수행 할 수 있는 방법을 제시한다.

Abstract

In this paper, we address the OFDM based on DFT or DCT in Cognitive Radio system. An adaptive OFDM based on DFT or DCT in Cognitive Radio system has the capacity to nullify individual carriers to avoid interference to the licensed users. Therefore, there could be a considerably large number of zero-valued inputs/outputs for the IDFT/DFT or IDCT/DCT on the OFDM transceiver. Hence, the standard methods of DFT and DCT are no longer efficient due to the wasted operations on zero. Based on this observation, we present a transform decomposition on two dimensional (2-D) systolic array for IDFT/DFT and IDCT/DCT, this algorithm can achieve an efficient computation for OFDM in Cognitive Radio system

Keywords : DCT, DFT, OFDM, Cognitive Radio

Ⅰ. Introduction

Orthogonal frequency division multiplexing (OFDM) has recently received considerable attention for its efficient usage of available frequency bandwidth and robustness to frequency selective fading environments. OFDM systems normally use the discrete Fourier transform (DFT) for multicarrier modulation of the data to be transmitted. However, under certain channel conditions, throughput is enhanced when using the discrete cosine transform (DCT) rather than the DFT[1].

The basic idea of Cognitive Radio (CR) is to provide a system with the ability to sense available spectrum slots not occupied by existing users and detect whether any primary user is demanding the bands that the CR system currently uses. Since CR only used non-contiguous band in the spectrum, OFDM is considered a suitable transmission technique[2~3].

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In spectrum pooling, OFDM is proposed as the baseband transmission scheme. Those subcarries which cause the interference to the licensed user should be nullified. Therefore, there are zero-valued inputs for the IDFT or IDCT of the transmitter and zero-valued outputs for the DFT or DCT of the receiver. When zero valued inputs/outputs outnumber non-zero inputs/outputs, the standard IDFT/DFT or IDCT/DCT used for OFDM is no longer efficient. If there is a large number of zero inputs/outputs, we propose to use computationally efficient IDFT/DFT and IDCT/DCT based on the transform decomposition [4~6].

The rest paper is organized as follows. In Section II, the OFDM-Cognitive Radio framework will be introduced. In Section III, we will present the efficient computation for DFT and DCT in OFDM-Cognitive Radio system. Simulation results are discussed in Section IV. Finally, Section V concluded this paper.

II. OFDM-Cognitive Radio Framework

An important aspect of the cognitive radio platform is its ability to opportunistically use portions of the spectrum that are not being used, which requires the ability to efficiently scan spectrum usage. Furthermore, it is very important to detect and identify types of interference that the platform is facing. This becomes increasingly difficult for arbitrary radio systems. Thus we can focus on an OFDM radio platform because it allows a simple characterization of interference in terms of the OFDM subcarriers.

A general schematic of an OFDM-Cognitive Radio (OFDM-CR) transceiver is shown in Fig. 1. Without loss of generality, a high speed data stream, $x(n)$ is modulated. Then, the modulated data stream is split into N slower data streams using a serial-to-parallel (S/P) converter. Note that the subcarriers in the OFDM-CR transceiver do not need to be all active as in conventional OFDM.

Moreover, active subcarriers are located in the unoccupied spectrum bands, which are determined by dynamic spectrum sensing and channel estimation techniques.

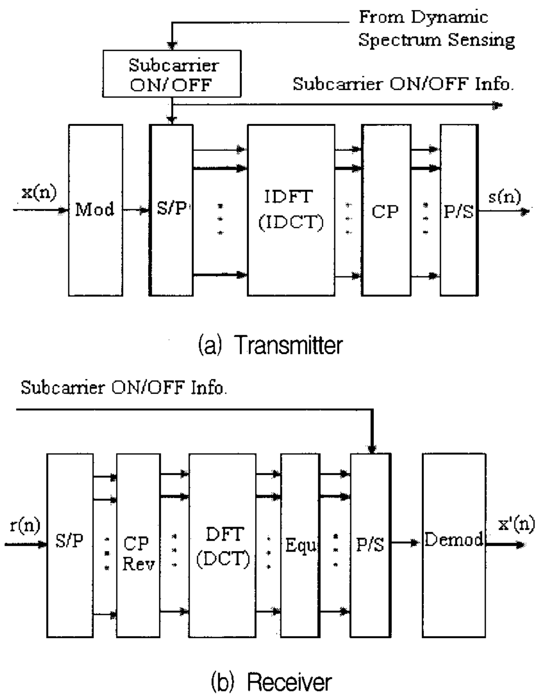

그림 1. OFDM 전송기의 구조
Fig. 1. Schematic of an OFDM transceiver.

The IDFT or IDCT is then applied to these modulated subcarrier signals. Prior to transmission, a guard interval with a length greater than the channel delay spread is added to each OFDM-CR symbol using the cyclic prefix (CP) block in order to mitigate the effects of intersymbol interference. Following the parallel-to-serial (P/S) conversion, the baseband OFDM-CR signal, $s(n)$ is then passed through the transmitter radio frequency(RF) chain, which amplifies the signal and up converts it to the desired center frequency. The receiver performs the reverse operation of the transmitter, mixing the RF signal to baseband for processing, yielding the signal $r(n)$. Then, the signal is converted into parallel streams using S/P converter, the CP is discarded, and DFT or DCT is then applied. After compensating distortion introduced by the channel using per-tone equalization, the data in the active subcarriers is multiplexed using a P/S converter, and demodulated into a reconstructed version of the original high-speed input, $x'(n)$.

From this system overview, we observe that the

IDFT (IDCT) and DFT (DCT) blocks are critical components of the transceiver. In the next section, we will describe how it is possible to implement efficient versions of these blocks. We confine all the following discussions on DFT and DCT due to the same computation structure of DFT and IDFT as well as DCT and IDCT.

Ⅲ. Efficient Computation for DFT and DCT in OFDM-CR System

In this section we will introduce the algorithms on 2-D systolic array for DFT and DCT, which can result in a faster execution time in OFDM-CR system.

가. Transform decomposition on 2-D systolic array for DFT

From the definition of DFT,

$$X(k)=\sum_{n=0}^{N-1} x(n)W_N^{nk}, \quad 0 \le k \le N-1 \tag{1}$$

where $W=e^{-j\frac{2\pi}{N}}$ $,j=\sqrt{-1}$, we assume that only L outputs are nonzero and that there exists a P such that P divides N and define $Q=N/P$, using the variable substitution

$$n=Qn_1+n_2 \tag{2}$$

where

$n_1=0,1,\cdots,P-1$, $n_2=0,1,\cdots,Q-1$. we can rewrite the DFT as follows:

$$X(k)=\sum_{n_2=0}^{Q-1}\sum_{n_1=0}^{P-1} x(n_1Q+n_2)W_N^{(n_1Q+n_2)k}$$

$$=\sum_{n_2=0}^{Q-1}\left[\sum_{n_1=0}^{P-1} x(n_1Q+n_2)W^{n_1\langle k\rangle_p}\right]W_N^{n_2k} \tag{3}$$

where $\langle\ \rangle_p$ denotes reduction modulo P, and k takes on any L values between 0 and N-1. Breaking this up into two equations

$$X(k)=\sum_{n_2=0}^{Q-1} X_{n2}(\langle k\rangle_p)W_N^{n_2k} \tag{4}$$

where

$$X_{n2}(j)=\sum_{n_1=0}^{P-1} x(n_1Q+n_2)W_P^{n_1j} \tag{5}$$

$$=\sum_{n_1=0}^{P-1} x_{n2}(n_1)W_P^{n_1j} \tag{6}$$

for $j=0,1,\cdots,P-1$, and

$$x_{n2}(n_1)=x(n_1Q+n_2) \tag{7}$$

Inspecting (6), it can be seen that sequence over which the DFT has to be computed is two dimensional and hence depends on n_2. Thus a DFT has to be computed for each different value of n_2, and there are Q such length P DFT's. We consider the case where L outputs are nonzero. Because the index K only consists of L nonzero values, only L twiddle factors are multiplied with each $X_{n2}(\langle k\rangle_p)$ for $n_2=0,1,\cdots,Q-1$. This multiplication part results in a reduction of the computation. The mathematical derivation for the transform decomposition algorithm with zero inputs is rather similar, details can be found in [4].

나. Transform decomposition on 2-D systolic array for DCT

Reposing on a close study of the DCT[7], we can also achieve the transform decomposition for 2-D DCT. The DCT of a date sequence $f(n)$, where $n=0,1,\cdots,N-1$ is defined by

$$F(k)=\sqrt{2/N}B_k\sum_{n=0}^{N-1} f(n)\cos\frac{(2n+1)k\pi}{2N} \tag{8}$$

and

$$B_k=\begin{cases}\sqrt{1/2}, & k=0\\ 1, & k=1,2,\ldots,N-1\end{cases}$$

Supposing N is even, we define a new N point sequence $x(n)$ by:

$$x(n) = f(2n),\ x(N-1-n) = f(2n+1),\ n = 0,1,\cdots,N/2-1. \tag{9}$$

substituting (9) into (8), it can be rewrite as

$$F(k) = \sqrt{2/N}C(k)\sum_{n=0}^{N-1} x(n)\cos\frac{(4n+1)k\pi}{2N} \tag{10}$$

thus the DCT $F(k)$ can be evaluated as

$$F(k) = \sqrt{2/N}C(k)\,\mathrm{Re}\left[\exp(\frac{jk\pi}{2N})Z(k)\right] \tag{11}$$

where the date sequence $x'(n)$ IDFT is

$$Z(k) = \sum_{n=0}^{N-1} x(n)W_N^{-nk} \tag{12}$$

Using symbol A to denote $\sqrt{2/N}C(k)\exp(\frac{jk\pi}{2N})$ we can obtain a concise equation

$$F(k) = \mathrm{Re}\left[A\bullet Z(k)\right] \tag{13}$$

Fig.2 shows the process for calculating DCT based on IDFT.

From the analysis of transform decomposition for 2-D DFT previously, we can easily obtain the transform decomposition for 2-D $Z(k)$ as follows:

$$Z(k) = \sum_{n_2=0}^{Q-1} Z_{n2}(\langle k\rangle_p)W_N^{-n_2 k} \tag{14}$$

where

$$Z_{n2}(j) = \sum_{n_1=0}^{P-1} x(n_1 Q + n_2)W_P^{-n_1 j} = \sum_{n_1=0}^{P-1} x_{n2}(n_1)W_P^{-n_1 j} \tag{15}$$

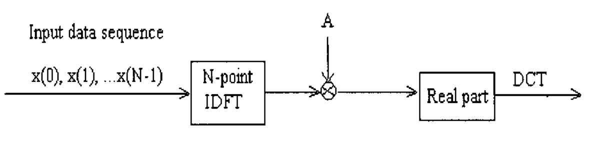

그림 2. DCT 계산을 위한 블록 다이어그램
Fig. 2. Block diagram for DCT computation.

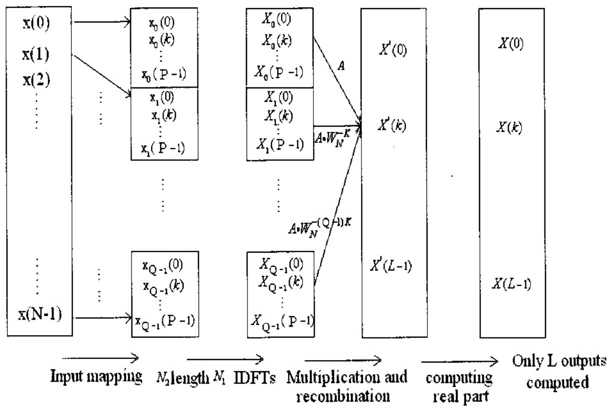

그림 3. DCT를 위한 변환 분해의 블록 다이어그램
Fig. 3. Block diagram over transform decomposition for DCT.

for $j = 0,1,\cdots,P-1$ and $N = PQ$, $n = Qn_1 + n_2$, $n_1 = 0,1,\cdots,P-1, n_2 = 0,1,\cdots,Q-1$.

Substituting (14) into (13), we obtain:

$$F(k) = \mathrm{Re}\left[A\bullet\sum_{n_2=0}^{Q-1} Z_{n_2}(\langle k\rangle_p)W_N^{-n_2 k}\right] \tag{16}$$

Obviously, we can also implement the efficient computation for DCT.

We show the computational structure for DCT in Fig.3. Basically the computation can be divided into two stages: IDFT and multiplications with recombination.

Ⅳ. Simulation Results

The number of multiplications for N-point radix -2 FFT is

$$M_{DFT} = (N/2)\log_2 N \tag{17}$$

Under the definition of DCT-II, the precise count of real multiplications is shown in the below[8],

$$M_{DCT} = 2N\log_2 N - N + 2 \tag{18}$$

Based on the transform decomposition for 2-D DFT and DCT, we make quantitative analysis on the computational complexity by counting the number of complex multiplications. In this case, the number of multiplications for DFT and DCT are presented as following:

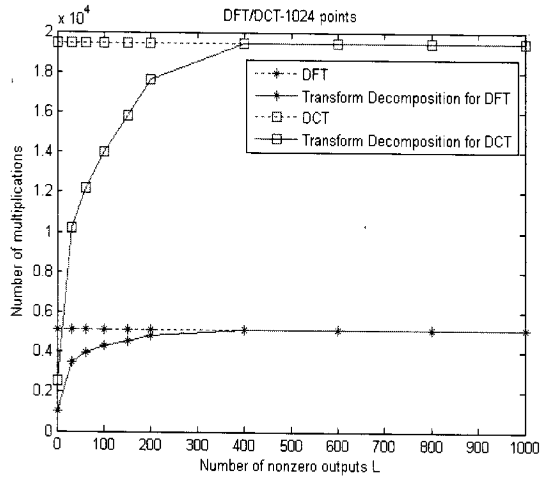

그림 4. 2-D DFT/DCT를 위한 변환 분해와 기존 방법의 계산 비교

Fig. 4. Comparison of computation between the traditional way and the transform decomposition for 2-D DFT/DCT.

$$M_{TD-DFT} = \frac{N}{2}\log_2 P + (Q-1)\cdot L \qquad (19)$$

$$M_{TD-DCT} = 2N\log_2 P - N + 2Q + (Q-1)\cdot L \qquad (20)$$

In Fig.4 we compare the computation complexity between the conventional method and the transform decomposition for 2-D DFT and DCT. During the simulation, we assume the total number of subcarriers for OFDM is 1024, when the number of nonzero outputs L is relatively few, we can get significantly reduced computational complexity for both DFT and DCT based on the transform decomposition. For example, when only 64 out of 1024 subcarriers are available for CR, transform decomposition offers 22% and 37% saving of computations for the OFDM-DFT system and the OFDM-DCT system respectively. Because the IDFT/DFT or IDCT/DCT are the most computational intensive parts in an OFDM transceiver, the savings can significantly reduce the computational complexity of the overall system. Therefore, transform decomposition for 2-D DFT or 2-D DCT can be an efficient option for an OFDM in Cognitive Radio system when only a small number of subcarriers are available for Cognitive Radio.

V. Conclusion

In terms of the decomposition for 2-D DFT and DCT, we proposed an efficient computation for DFT and DCT which can result in a faster execution time in the case that a large number of subcarriers are nullified in the OFDM-CR system.

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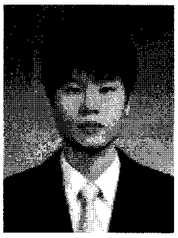

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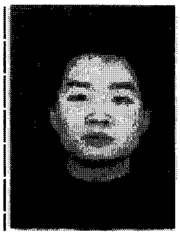

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