TJES

ISSN: 1813-162X
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

Design and Implementation of Sequency-Ordered Fast Walsh-Hadamard Transform (FWHT) in WCDMA

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ABSTRACT

This paper presents the implementation of the Fast Walsh Hadamard Transform (FWHT) in sequence ordered method, in order to minimize the interference due to two users trying to transmit at the same time, and an attempt has made to simulate them. The simulations designed satisfy most of the requirements of the parameters mentioned in the 3GPP specifications. The main objectives of this paper are to construct a model using MATLAB 7.4.0(R2007a) to illustrate the simulation.

In image processing and pattern recognition the motivation for using transforms other than Fourier is either to reduce computation time for a given resolution, or to increase resolution without increasing the length of the computation time and to minimize the hardware resources. Fast Walsh-Hadamard Transform has been used effectively to satisfy these requirements.

KEYWORDS:WCDMA, Fast Walsh-Hadamard Transform (FWHT), Hadamard matrix, Sequency ordering.

تصميم وتنفيذ تسلسل الامر لتحويل والش- هادمرد السريع (FWHT) لنظام WCDMA

الخلاصة

يعرض هذا البحث تنفيذ تحويل ولش- هادامارد (FWHT) السريع في أسلوب تسلسل الأمر، وذلك للتقليل من التداخلات الحاصلة بين مستخدمين اثنين في محاولتهما للارسال في نفس الوقت، ومحاولة تنفيذ نظام للمحاكاة. في تصميم المحاكاة يتم تلبية معظم الاحتياجات من العوامل في مواصفات نظام GPP3. ان الأهداف الرئيسية لهذا البحث هي لبناء نموذج محاكاة باستخدام برنامج(MATLAB 7.4.0 (R2007a وذلك لتوضيح نموذج المحاكاة.

في معالجة الصور والتعرف على نمط الدافع يتم استخدام تحويلات فوريير هي إما لتقليل الوقت اللازم لحساب الدقة ، أو في زيادة الدقة دون زيادة زمن الحساب وكذلك تقليل موارد الأجهزة. وقد استخدم تحويل والش-هادامارد السريع بفاعلية لتلبية هذه المتطلبات.

الكلمات الدالة: WCDMA، تحويل والش-هادامارد (FWHT) السريع ، مصفوفة هادامارد ، تسلسل الامر.

INTRODUCTION

WCDMA is a wideband Direct Sequence Code Division Multiple Access (DS-CDMA) system, which means that the user information bits (symbols) are spread over a wide frequency bandwidth by multiplying the user data bits with a spreading code sequence of "chips"[1]. WCDMA is quite resistant against interference and frequency selective fading. In a normal wireless data transmission system the used bandwidth more or less equals the user data rate, in wireless data transmission systems based on Spread Spectrum, the used bandwidth is much higher than the data rate. Walsh Code is a group of spreading codes having good autocorrelation properties and poor cross correlation properties. Walsh codes are the backbone of CDMA systems and are used to develop the individual channels in CDMA.

The main purpose of Walsh codes in CDMA is to provide orthogonality among all the users in a cell. Each user traffic channel is assigned a different Walsh code by the base station. Orthogonal means that cross correlation between Walsh codes is zero when aligned.[1]

However, the auto-correlation of Walsh-Hadamard code words does not have well. The partial sequence cross correlation can also be non-zero and un-synchronized users can interfere with each other particularly as the multipath environment will differentially delay the sequences. Hence the FWHT proves to be very useful in high speed digital systems. Applications have been found in many areas such as radar processing, data compression, holography, seismology, optical devices, multiplexing, chemical analysis, voice processing and image processing, This is why Walsh-Hadamard codes are only used in synchronous CDMA and only by the base station which can maintain orthogonality between signals for its users.[2]

The Walsh-Hadamard Transform

The Walsh-Hadamard transform of a signal x, of size $N = 2^n$, is the matrix-vector product WHTN_x, where [5][6]:

$$WHT_N = \bigotimes_{i=1}^{n} DFT_2 = \overbrace{DFT \otimes \;.\otimes\; DFT_2}^{n} \quad \text{... (1)}$$

The matrix:

$$DFT_2 = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \quad \text{............ (2)}$$

is the 2-point DFT matrix, and denotes the tensor or Kronecker product. The tensor product of two matrices is obtained by replacing each entry of the first matrix by that element multiplied by the second matrix. Thus, for example,

$$WHT_4 = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{pmatrix} \quad \text{............(3)}$$

Walsh codes are created out of Hadamard matrices and Transform. Hadamard is the matrix type from which Walsh created these codes. Walsh codes have just one outstanding quality. In a family of Walsh codes, all codes are orthogonal to each other and are used to create channelization within the 1.25 MHz band. Here are first four Hadamard matrices. The code length is the size of the matrix. Each row is one Walsh code of size N. The first matrix gives us two codes; 00, 01. The second matrix gives: 1111, 1-11-1, 11-1-1, 1-1-11 and so on.

In general each higher level of Hadamard matrix is generated from the previous by the Hadamard transform and can be defined recursively as:

$$H_{N=} \begin{bmatrix} H_N & H_N \\ H_N & -H_N \end{bmatrix} \quad \text{........................ (4)}$$

Where H_N is a matrix of size NxN, where $N=2^n$ and $-H_N$ is the inverse of H_N , this case is not complicated because It is possible to be seen with facility that all the columns and the rows are mutually orthogonal. The following properties can be derived if is defined the Walsh sequence Hi like the row or column i^{th} of Hadamard matrices:

- The sequences of Walsh are binary sequences with values of +1 and -1.
- The length of the sequences of Walsh is always power of 2.
- The sequences of Walsh are mutually orthogonal if they are synchronous.
- All the sequences of Walsh begin by +1.

FAST WALSH-HADAMARD TRANSFORM

A Fast Walsh-Hadamard Transformer (FWHT) can be used to provide such a low hardware complexity decoding circuitry [1]. The FWHT is used for detecting and correcting errors during the transmission of Walsh-Hadamard code words. The FWHT is an orthogonal transform and requires only addition and subtraction operations. A FWHT is based on square waves, unlike the Fast Fourier Transform (FFT) which is based on sine waves. This feature allows the FWHT to be implemented in hardware simply with additions and subtractions, rather than multiplications as in the FFT [1][4],this leads to savings in hardware resources as no multiplier is used [3][4]. When data is transmitted over CDMA link, this data are cyclic redundancy checking for bit error correction. In addition, data are block interleaved to avoid burst error[9]. In this paper a FWHT is designed for WCDMA systems to be used in achieving synchronization with the base station. Previous FWHT implementations consume a lot of hardware resources in terms of memory requirements.

The FWHT is an efficient algorithm to compute the Walsh-Hadamard transform (WHT). A naïve implementation of the WHT would have a computational complexity of O(N2). The FWHT requires only $N \log N$ additions or subtractions [4].

The FWHT is a divide and conquer algorithm that recursively breaks down a WHT of size $N/2$. This implementation follows the recursive definition of the 2N x 2N Hadamard matrix H_N fig.(1).

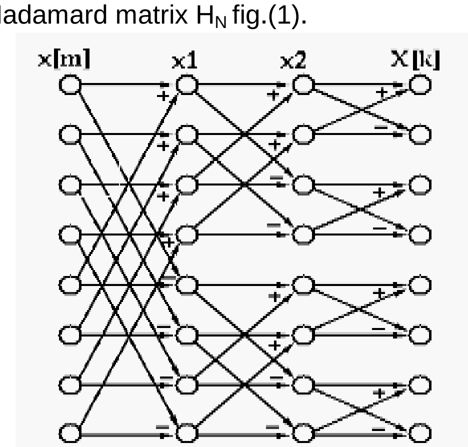

Fig.1:Butterflies of Hadamard-ordered FWHT

$H_N = 1/\sqrt{2}$ normalization factors for each stage may be grouped together or even omitted. **Fast Walsh-Hadamard Transform (Sequency-Ordered) Matrix.**

The sequency ordered Walsh-Hadamard transform (WHT_w, also called Walsh ordered WHT) can be obtained by first carrying out the fast WHT_h and then reordering the components of X as shown

$$\sum_{m=0}^{N-1} x[m] \prod_{i=0}^{n-1} (-1)^{(k_i+k_{i+1})m_{n-1-i}}$$

above. Alternatively, it can use the following fast WHT_w directly with better efficiency. A FWHT is based on square waves, unlike the Fast Fourier Transform (FFT) which is based on sine waves. This feature allows the FWHT to be implemented in hardware simply with additions and subtractions, rather than multiplications as in the FFT. The substitute of the FFT is a binary

$$\mathrm{W} = \frac{1}{\sqrt{8}} \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \end{bmatrix} \begin{matrix} 0 & 0 \\ 1 & 4 \\ 2 & 6 \\ 3 & 2 \\ 4 & 3 \\ 5 & 7 \\ 6 & 5 \\ 7 & 1 \end{matrix}$$

transform, such as Walsh, that should reduce the operations 3 times because it uses only real additions. Surprisingly, the used algorithm does not require using the transform more than once. This made the method more efficient. The sequency ordered WHT of X[m] can also be defined as [6]

$$X[k] = \sum_{m=0}^{N-1} w[k,m]x[m] = \quad \ldots\ldots\ldots\ldots\ldots..(5)$$

$\triangle$

where $N=2^n$, $K_n= 0$, and the exponent of -1 represents the conversion from sequency ordering to Hadamard ordering (binary-to-Gray code conversion and bit-reversal conversion).Assume n=3, $N = 2^3 = 8$, and represent $\underline{m}$ and $\underline{k}$ in binary form as, respectively,$(m_2m_1m_0)_2$ and $(k_2k_1k_0)_2$.

$$x_2[4k_2 + 2k_1 + l_0] \stackrel{\triangle}{=} x_1[4k_2 + l_0] +$$

$$(-1)^{k_1+k_2} x_1[4k_2 + 2 + l_0]$$

$$= \sum_{l_0=0}^{1} (-1)^{(k_i+k_{i+1})l_0} x_2[4k_2+2k_1+m_0] \quad ....(6)$$

where x_2 s defined as

$$X[k] = \sum_{l_0=0}^{1} (-1)^{(k_i+k_{i+1})l_0} [x_1[4k_2+l_0] + \quad ....(7)$$

$$(-1)^{k_1+k_2} x_1[4k_2+2+l_0]]$$

Finally, expanding the 1st summation into two terms, we have

$$X[k] = x_2[4k_2+2k_1] +$$

$$(-1)^{k_0+k_1} x_2[4k_2+2k_1+1] \quad .... (8)$$

Summarizing the above steps, we get the fast WHT_w algorithm composed of the three equations (6), (7), and (8), as illustrated in figure(2) were the output coefficients X(i) are in sequency order, the solid line indicates addition operation and the dotted line are subtraction operation.

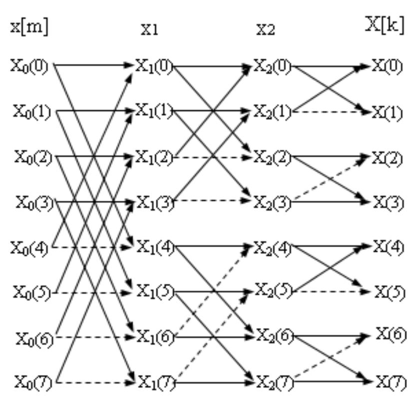

Fig.2 Signal flow graph for the sequency-ordered FWHT

Finally the matrix can be write as shown below, were w is walsh-hadamard ordered . (9) We see that this matrix is still symmetric as shown in fig.(3): Were w[k , m] = w[m , k]

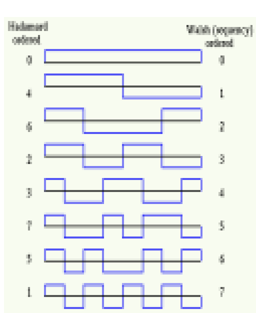

Fig.3 The Sequency-Ordered of FWHT

SIMULATION and RESULTS

In this paper, the simulation efficient design and implementation of Fast Walsh-Hadamard Transform in Sequency-Ordered (FWHT) in WCDMA system were presented because it is simple and important. In this paper a FWHT is designed for WCDMA systems to be used in achieving synchronization with the base station. FWHT is similar to the Fast Fourier Transform (FFT) and its variants, the only difference between them is that there are no twiddle factors and bit-reversal is not necessary [1]. The design as shown in fig.(4) was done by using Matlab 7.4.0(R2007a) as the complete tool.

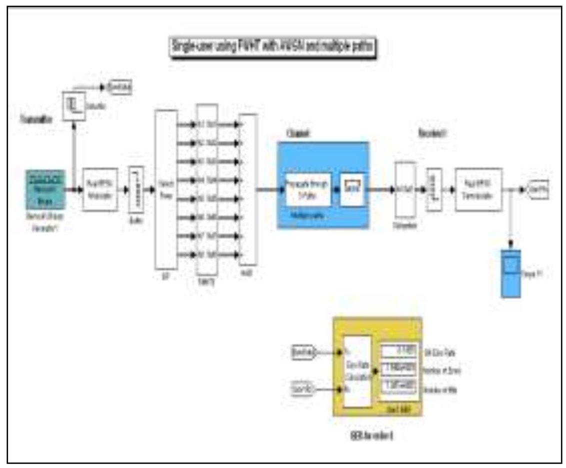

Fig.4 The Simulation of Sequency-Ordered FWHT

The simulation used sequency-ordered codes (Walsh code and Hadamard code) fig(3), when these codes are transmitted over the air channel, they are affected by interference, distortion and noise which may be additive white Gaussian noise (AWGN), Rayleigh fading or multipath channel fading. A Fast Hadamard Transformer (FWHT) can be used to provide such a low hardware complexity circuit. The FWHT is used for detecting and correcting errors during the transmission of Walsh-Hadamard code words. The FWHT is an orthogonal transform and requires only addition and subtraction operations. The proposed designs in this study lead to considerable savings in hardware resources in terms of memory requirements.

The simulation design of FWHT was based on butterfly structure as shown in fig(2) and measured the bit error rate(BER) under AWGN and multipath fading as shown in fig(5). The implementation consist of FWHT of order 2, 4, 8 and 16 butterflies, and fig(6) shows that the BER reduced in order 8 and 16 respectively. When used two users transmits at the same time, the result as shown in fig(7),it can see that the BER is reduced and minimize the interference when the users increased comparing with traditional Walsh-Hadamard codes.

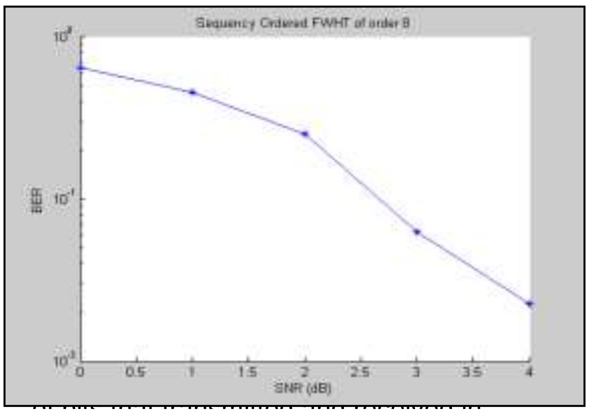

Fig.5 FWHT of Order 8 Under AWGN+Multipath Fading

Table 1. Number of bits transferred and received

FWHT Ordered	Simulation Time(T)				
	0.2	0.4	0.6	0.8	1.0
2	1.536 e+004	3.072 e+004	4.608 e+004	6.144 e+004	7.68 e+004
4	6.144 e+004	1.229 e+005	1.843 e+005	2.458 e+005	3.072 e+005
8	2.458 e+005	4.915e +005	7.373 e+005	9.83 e+005	1.229 e+006
16	4.915e+ 005	9.83 e+005	1.475 e+006	1.966 e+006	2.458 e+006

simulation model will be increased in order 2, 4, 8 and 16 respectively at the same simulation time, that leads to transform a lot of data or information in short time with low hardware resources. It is possible to use different bit ordering but the reduced length sequence will also reduce the detection time. Thus, the reduced length Walsh-Hadamard sequence helps in achieving faster decoding and reduced hardware circuitry. This is not the case if different size was chosen for the

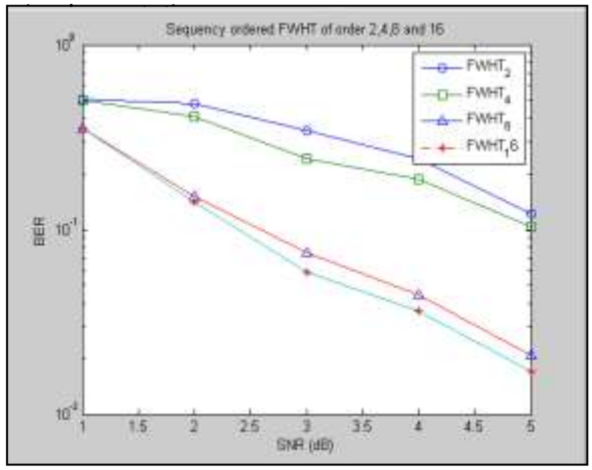

Fig.6 FWHT Under AWGN+Multipath Fading

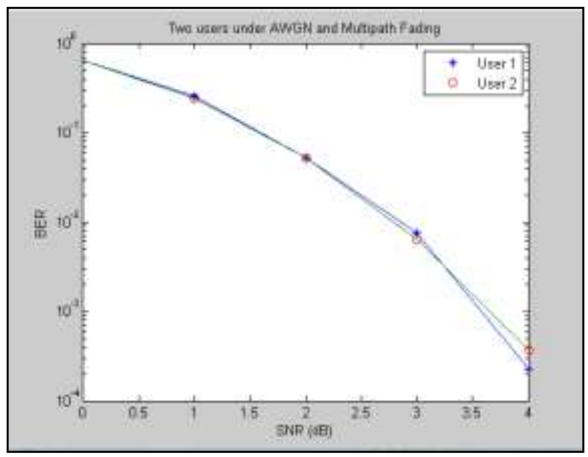

Fig.7 FWHT of Order 8 Under AWGN+Multipath Fading

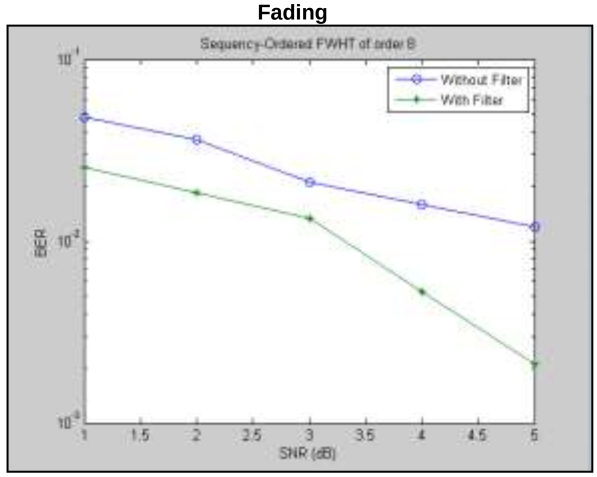

Fig.8 FWHT of Order 8

In the simulation model was used real BPSK filter, which used widely in radio communications applications today. This modulation is the most robust of all the PSKs since it takes the highest level of noise or distortion. It is, however, only able to modulate at 1 bit/symbol and so is unsuitable for high data-rate applications when bandwidth is limited. The simulation result of using BPSK filter shown in Fig.8 the BER is reduced and we can see the scope image for using this filter in Figs.10 and 11 respectively were the output signal is bounded from 0 to 1.

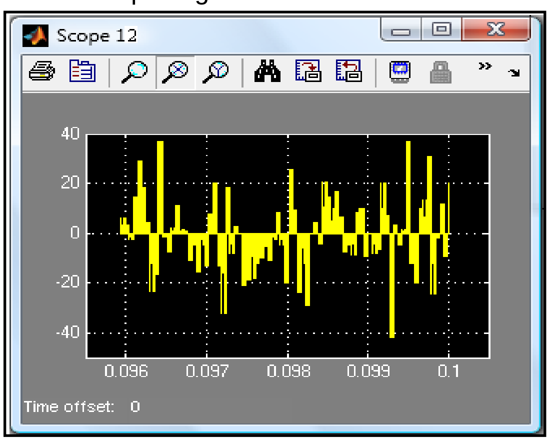

Fig.9 FWHT of Order 8 without BPSK Filter

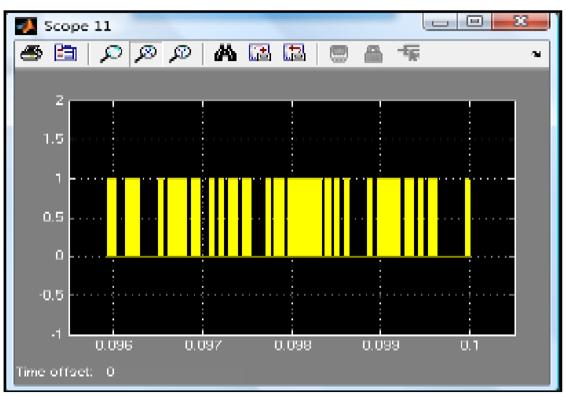

Fig.10 FWHT of Order 8 with BPSK Filter

popular digital transform since its kernel function is only consisted from 0 and 1 (black and white). FWHT is a unitary transform and being unitary it has to be a orthogonal transform and its transform's with good to very good energy compaction A Fast Hadamard Transformer (FHT) can be used to provide such a low hardware complexity decoding circuitry. The FHT is used for detecting and correcting errors during the transmission of Walsh-Hadamard code words. The FWHT has gained prominence in digital signal processing applications, since it can be computed using addition and subtractions only without multiplication. BER performances of the proposed model are simulated under additive white Gaussian noise (AWGN) conditions for 2-user case the SNR were decreased.

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