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New Orthogonal Codes for Direct Sequence CDMA Communications

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ABSTRACT

From a long period Walsh codes and Gold codes have been used as a spread spectrum codes in Code Division Multiple Access (CDMA) communications because of their ease of generation than the efficiency of these codes. Drawback of these codes is that they are limited in number and in their lengths. In this paper, we relaxed linear phase requirements of Walsh code and new sets of Walsh-like nonlinear phase binary orthogonal user codes (transforms) are obtained for asynchronous and synchronous spread spectrum multiuser communications. We designed simulink model and performed algorithm using MATLAB (R2011a version) to obtain this newly proposed Walsh-like code set for multiuser spread-spectrum communications. We compared their performance with existing codes like Gold code and Walsh code families. Our comparisons include their time domain properties like autocorrelation and cross correlation along with bit error rate(BER) performances in additive white Gaussian noise(AWGN) for the synchronous and asynchronous DS-CDMA communications. We proved that the proposed binary user code family outperforms the Walsh codes significantly and they match in performance with the popular, nearly orthogonal Gold codes closely for asynchronous multiuser communications in additive white Gaussian noise (AWGN) channels. We present in this paper that there are a good number of such desirable code sets available in the binary sample space with different transform sizes. These new binary sets with good performance and flexible code lengths might help us to improve the spread spectrum multiplexing capabilities of future wire line and wireless CDMA communications systems.

Index Terms: Additive white Gaussian noise (AWGN) channel, code division multiple access (CDMA), Gold sequences, orthogonal binary codes, Walsh sequences.

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I. INTRODUCTION

The binary Walsh codes have been well studied in the literature over the last few decades and found their many popular applications including multiuser wireless communications. Walsh codes are perfectly orthogonal binary block codes that found their use in many popular applications including synchronous multiuser communications. But they perform poorly for the case of asynchronous multiuser communications due to poor cross correlation value between codes. Therefore, the near-orthogonal and nonlinear phase - Gold codes are the preferred user codes in asynchronous direct sequence code division multiple access (DS-CDMA) communications standards[3].

The simplicity of their generation and fixed power feature along with orthogonality property make them good choice for synchronous multiuser communications. On the other hand the near orthogonal Gold codes and their extensions are shown to perform superior to the Walsh codes for asynchronous multiuser communications due to their good auto correlation and cross correlation properties[5]..

All of these binary sequences proposed in the literature belong to binary sample space. Our main focus in this paper is on binary valued orthogonal carrier sequences that are spread in the time and frequency domains. Therefore they are called spread spectrum user codes in DS-CDMA communication system.

A. WALSH- HADAMARD TRANSFORM

The Walsh–Hadamard transform (WHT), is defined with its built-in scalability as follows:

$$H_1 = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \qquad (1)$$

$$H_{2N} = \frac{1}{\sqrt{2}}\begin{pmatrix} H_N & H_N \\ H_N & -H_N \end{pmatrix} = H_N \otimes H_N \qquad (2)$$

The higher length of Walsh code sets are iteratively generated from lower length of Walsh code sets using Kronecker product[1].These sequences are utilized in the current wireless communications standards such as IS-95, CDMA2000, WCDMA as binary user codes or multicarrier units[9].WHT codes are employed for downlink (cell tower to mobile units)and Gold codes are used for uplink (from mobile units to cell tower)communications as binary carrier .

B. PROPERTIES OF WALSH HADAMARD TRANFORM

Property1: WHT has a constant (DC) sequence in the function set. This feature is a requirement from any practical transform being employed in source coding applications where DC component of a signal is significant in many signal types.

Property 2: WHT basis functions are linear phase sequences.

Property 3: Walsh set has a unique number of zero-crossings in the time domain. In a typical $N \times N$ size WHT matrix, row indices(i=0,1,2,…,N-1) also indicates numbers of zero crossing of the corresponding row sequence.

Property 4: Except the DC sequence, the remaining sequences in a Walsh set have zero-mean values.

Block transforms have been used for source coding applications where orthogonality, having DC basis function, and linear phase features are important requirements for a good performance.

II. WALSH-LIKE TRANSFOM

Linear phase response is an inherent feature of orthogonal Walsh sequences, but spread spectrum CDMA communication does not have such requirement. In addition Walsh sets have restricted not to include more than one sequence with the same number of time domain zero crossings.

In this paper, we propose a new, Walsh-like binary orthogonal transform with nonlinear phase basis sequences. For that we relaxed linear phase property to enlarge the search region within binary sample space having orthogonal codes with better correlation properties than the Walsh family. We also relaxed the strict condition of having basis sequences with unique number of time-domain zero-crossings in the set. In addition, any of these new sets does not have to have DC basis sequence. We performed brute force searches in the binary sample space in order to obtain some of these new orthogonal sets. The binary sample space for n-length orthogonal code sets generated through brute force search consists of $(2^n - 1)$ integer numbers.

A. BRUTE FORCE SEARCH METHOD FOR NEW WALSH-LIKE TRANSFORM BASES

First basis function in the orthogonal code set is selected by representing an integer number in the sample space as *n* -length binary code with elements [0,1] . Furthermore, [0, 1] elements of this binary code are mapped into [-1, 1], respectively, to generate n -length spreading code.

Select the next basis function by checking the orthogonality with the first basis function.

Repeat the process *n* —1 times to obtain a complete *N* **x** *N* orthogonal code set.With this search process, a number of orthogonal code sets are formed with the first basis sequence as the common basis sequence for different orthogonal code sets.

By choosing a different integer as the first basis sequence of the set, a number of unique orthogonal sets can be formed.Finally, select orthogonal code sets that have minimum cross-correlation values among all pairs of codes as a performance metric for further analysis [6]. A number of non-linear phase (Walsh-like) orthogonal code sets are obtained for lengths that are multiples of 4 (8, 12, 16, 20 ...).

Table I: Decim Al Values Of 8, 16, 32 Bits Non Linear Phase Walsh -Like And Walsh Codes .

Sr No	NLP Walsh like (8 bit)	Walsh (8 bit)	NLP Walsh like (16 bit)	Walsh(16bit)	NLP Walsh like (32 bit)	Walsh (32 bit)
1	7	255	112	65535	61183585	4294967295
2	8	170	779	43690	150228466	2863311530
3	52	204	3223	52428	352724423	3435973836
4	59	153	4076	39321	509083300	2576980377
5	82	240	12428	61680	632502326	4042322160
6	93	165	13303	42405	786621269	2779096485
7	97	195	15467	50115	856722320	3284386755
8	110	150	16144	38550	943804419	2526451350
9			21797	65280	1155073796	4278255360
10			21978	43605	1334368679	2857740885
11			23102	52275	1383772514	3425946675
12			23233	39270	1496018737	2573637990
13			26182	61455	1657777299	4027576335
14			26297	42330	1771991744	2774181210
15			26973	49980	1953241845	3275539260
16			27042	38505	2134754390	2523502185
17					2249029968	4294901760
18					2371658291	2863289685
19					2427374086	3435934515
20					2617184661	2576467270
21					2686179319	4042264335
22					2873756772	2779077210
23					3065537697	3284352060
24					3186212802	2526439785
25					3245467845	4278190335
26					3391108758	2857719210
27					3620888147	3425907660
28					3699605744	2573624985
29					3882304418	4027518960
30					3963002113	2774162085
31					4056216884	3275504835
32					4204079975	2533490717

Table I displays the decimal values of binary basis sequences of the proposed Walsh-like transforms for the sizes of 8, 16,and 32 bits along with WTs where -1 value of binary sequence samples are replaced by 0 valued bits for this representation.

In Section III, we present performance of the proposed Walsh-like binary, nonlinear phase orthogonal codes. We compared their performance with the popular codes such as Gold and Walsh families.

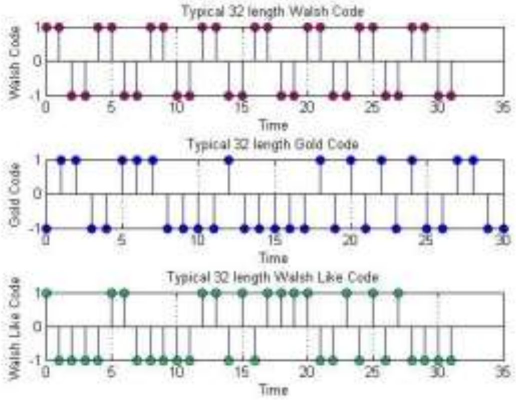


Fig. 1. Typical 32-length Walsh code, a typical 32-length proposed Walsh-like (NPOT) code along with a typical 31-length Gold code

Our comparisons include their time-domain properties like auto- (intracode) and cross- (intercode) correlations, and bit error rate (BER) performances for the asynchronous multicarrier communications scenarios in additive white Gaussian noise (AWGN). It is shown that the proposed Walsh-like nonlinear phase binary orthogonal transform significantly outperforms Walsh codes, and provides a performance comparable to the Gold codes in AWGN channels for all performance metrics and communications scenarios considered in this paper.

It is shown that all the code families tested tend to perform comparable for all channel types when the number of users in the channel is increased.

III. PERFORMANCE COMPARISONS

A. Time-Frequency and Correlation Properties

A typical 32-bit orthogonal Walsh code, a typical 32-length proposed Walsh-like code, and a 31-length Gold code are displayed in Fig. 1. Magnitude and phase functions of these codes are also shown in Fig. 2(a) and (b), respectively. Note that the sample sequence of the proposed orthogonal codes has more evenly spread frequency spectrum compared to the sample Walsh code of the same length. Additionally, proposed Walsh-like and Gold sequences have nonlinear phase functions while Walsh sequences are linear phase functions.

For direct sequence spread spectrum applications we require unique coding of different user signals that occupy same transmission bandwidth in multi access system and synchronization for WCDMA system where there is no global timing. [9].

To achieve these objectives the coding sequences require special correlation properties referred to cross correlation and autocorrelation. crosscorrelation and autocorrelation sequences for typical codes of three families are displayed in Fig. 3(a) and 3(b)resp, The cross-correlation sequences between an arbitrary pair of codes [for two-user case with codes $x_i(n)$ and $x_j(n)$ defined as $R_{xx}(m) = \sum_n x_i(n)\, x_j(n+ m)$] . It is observed from the figure that the Gold and the proposed nonlinear phase Walsh-like orthogonal codes have similar autocorrelation (intracode correlation) and cross-correlation (intercode correlation) sequences while sample Walsh pair has worse correlation properties than the others[2-6].

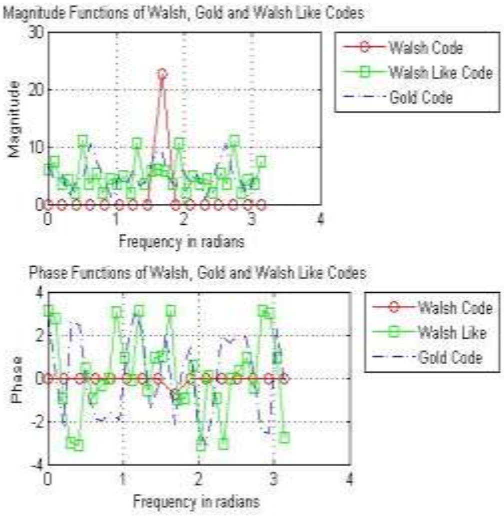
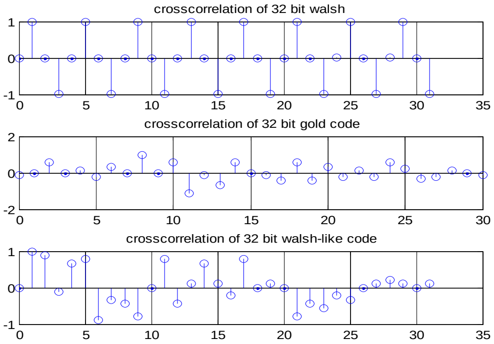
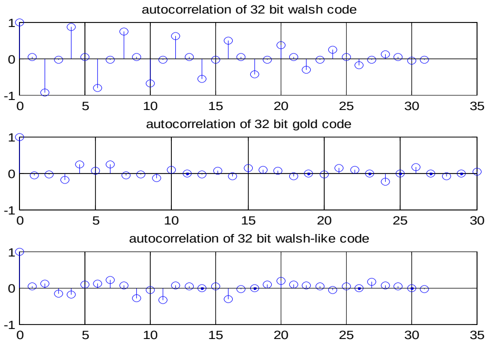


Fig2. Magnitude functions and phase functions of Walsh,Gold,and proposed Walsh-like binary codes plotted in Fig.1



(a)



(b)

Fig. 3. (a) cross correlation and (b) auto correlation sequences for typical Gold, Walsh, and Walsh-like codes.

B. AWGN Channel Performance

Bit error rate (BER) of a communication system is defined as the ratio of number of error bits and total number of bits transmitted during a specific period.. There are many ways of reducing BER. Here, we focus on spreading code & modulation techniques.

In our case, we have considered the most commonly used channel, the Additive White Gaussian Noise (AWGN) channel where the noise gets spread over the whole spectrum of fequencies. BER has been measured by comparing the transmitted signal with the received signal and computing the error count over the total number of bits. For any given modulation, the BER is normally expressed in terms of signal to noise ratio (SNR).

Our goal here is to investigate the BER performance of the communications system with AWGN noise assumption for different user code families considered. This helps us to better understand the variations of the intra and intercode correlations at the receiver whenever the channel noise is present since it dominates the performance of the binary detector especially for low SNR cases. The communications performance of a multiuser communications system is computed by taking the average of BER measurements over all possible pairs of codes and all possible delays for any given code family.

Fig.4 displays BER performances of 8-bit,16-bit and 32-bit Walsh codes. Fig.5 displays BER performances of 8-bit,16-bit and 32-bit Walsh-like codes. Fig.6 displays BER performances of 7-bit,15-bit and 31-bit Gold codes. Fig.7 displays BER performances of 8-bit Walsh code,8bit Walsh-like and 7bit Gold code. Fig. 8 displays BER performances of 16-bit Walsh and proposed Walsh-like code families. It is clearly seen from this figure that the latter significantly outperforms the first one. Similarly, Fig. 9 displays the BER curves for 32-bit Walsh and Walsh-like and 31-bit Gold codes.

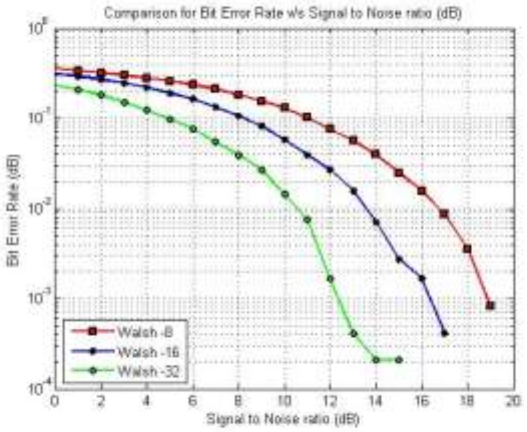


Fig. 4.

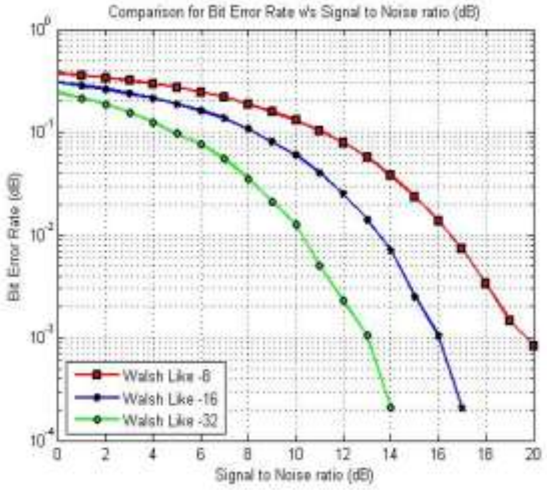


Fig.5.

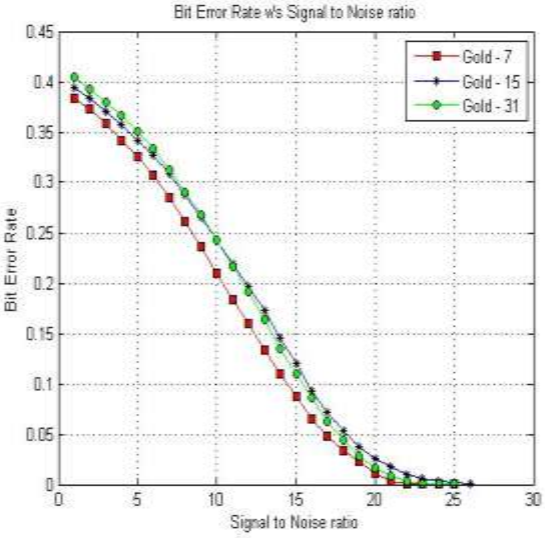


Fig.6.

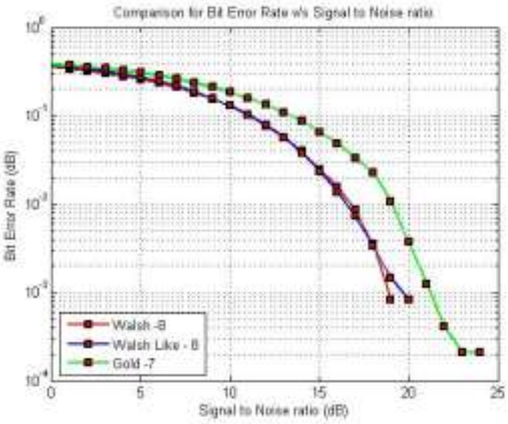


Fig. 7

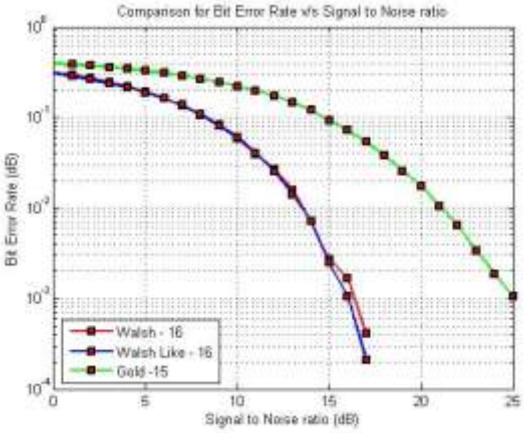


Fig. 8

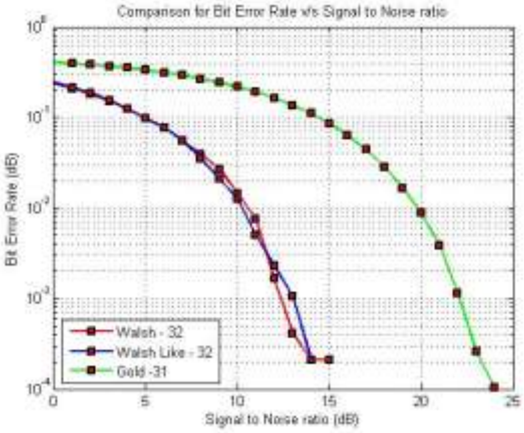


Fig. 9

Table Showing Bit error rate values for different codes for given Signal to Noise ratio values

Signal to Noise Ratio in db	**W-8**	**W-16**	**W-32**	**WL - 8**	**WL - 16**	**WL - 32**	**Gold -7**	**Gold -15**	**Gold -31**
0	0.355	0.312	0.231	0.370	0.304	0.243	0.384	0.394	0.404
1	0.338	0.290	0.207	0.356	0.284	0.215	0.373	0.388	0.393
2	0.319	0.269	0.180	0.337	0.260	0.186	0.358	0.370	0.379
3	0.301	0.245	0.151	0.318	0.236	0.154	0.341	0.357	0365
4	0.280	0.218	0.123	0.295	0.212	0.124	0.325	0.342	0.356
5	0.257	0.189	0.098	0.273	0.186	0.096	0.307	0.326	0.333
6	0.234	0.163	0.076	0.246	0.160	0.077	0.284	0.308	0.312
7	0.211	0.133	0.054	0.219	0.137	0.054	0.261	0.288	0.290
8	0.183	0.106	0.039	0.187	0.107	0.035	0.236	0.265	0.267
9	0.154	0.082	0.027	0.156	0.080	0.021	0.210	0.243	0.242
10	0.130	0.057	0.014	0.130	0.059	0.012	0.183	0.219	0.216
11	0.102	0.039	0.007	0.103	0.040	0.004	0.159	0.196	0.191
12	0.076	0.026	0.001	0.070	0.024	0.002	0.133	0.172	0.163
13	0.056	0.013	0	0.050	0.014	0.001	0.109	0.145	0.134
14	0.039	0.007	0	0.037	0.007	0	0.087	0.119	0.110
15	0.024	0.002	0	0.023	0.002	0	0.065	0.093	0.086
16	0.015	0.001	0	0.013	0.001	0	0.048	0.071	0.062
17	0.008	0	0	0.007	0	0	0.032	0.05	0.044
18	0.003	0	0	0.003	0	0	0.022	0.037	0.028
19	0	0	0	0	0	0	0.010	0.025	0.016
20	0	0	0	0	0	0	0.003	0.017	0.008

It is observed from these curves and table that the proposed nonlinear phase Walsh-like orthogonal code family outperforms Walsh codes significantly, and its performance closely matches with the Gold codes.

IV CONCLUSION

We presented in this paper that Walsh codes utilize only a small subset of the orthogonal binary sample space due to their intrinsic restrictions such as linear phase,zero mean and unique zero crossings.But this is not the requirement of spread spectrum CDMA communications. The growing demand for orthogonal, fixed power binary user codes requires us to design additional orthogonal codes to be employed in the emerging and future applications of multicarrier spread spectrum communications with flexible code sizes and power requirements than the traditional ones used in the current wireless technologies. We made an attempt to address that need. We proposed a design methodology, and searched and obtained a number of nonlinear phase Walsh-like orthogonal code sets that outperform Walsh codes, and closely match with the Gold codes for asynchronous and synchronous multicarrier CDMA applications. The communications capabilities of the existing spread spectrum systems using Walsh and Gold codes might be improved in their next generations by employing these new code sets and others. Additionally, having a rich library of binary code sets, with flexible lengths and good performance, will offer further efficiencies and additional information about security options in the user code level for the wireless communications and sensor networks applications in the future.

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