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Performance Evaluation of GIG codes for DS CDMA Communication over Rayleigh Flat Fading Channel

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Abstract:

Using Spread Spectrum technique, CDMA system allows multiple users to communicate with each other by sharing common resources. In effect, each user is assigned a code which spreads its signal bandwidth in such a way that only the same code can recover it at the receiver end. Spreading codes are also called as user codes as they are used to discriminate multiple users of the system. In CDMA each user has its own spreading codes. The selection of code is important because of its good autocorrelation and cross correlation property and length of code sets bound on system capacity. Codes are of two types they are orthogonal codes and non orthogonal codes. Walsh codes are orthogonal codes and while maximal **s**equences, gold and kasami codes are non orthogonal sequences. In the recent years, researchers are concentrating on the design of multiple level spreading codes. This paper proposes new multi level orthogonal spreading codes constructed using ternary and quaternary Gray and Inverse Gray codes (GIG) for Direct Sequence Code Division Multiple Access systems. The methodology explained in this paper allows generating r-level user codes of length- 2n. It also allows generation of codes whose lengths are even multiples of the basic code sets. Multi level spreading codes which used in this paper are non-zero mean, varying power codes. Bit error rate performance of the proposed codes over Rayleigh flat fading channel and their comparison with those of Walsh and Gold codes is presented in this paper.

Keywords: Generalized Gray Codes, Multi level spreading codes, DS CDMA, Rayleigh fading channel

I. Introduction:

Code Division Multiple Access (CDMA) technique allows sharing of spectrum resources simultaneously by large number of system users. In comparison with the conventional multiple access techniques like Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), CDMA has the ability to incorporate more number of users which results in efficient band width utilization. The CDMA technique is widely used in the existing wireless communication systems such as W-CDMA and CDMA2000. In multiuser CDMA, spreading codes that are used to distinguish users and spread the signal. Binary valued Maximal, Walsh, Gold and Kasami codes are the popularly used spreading codes in wireless CDMA systems [1-3]. Spreading codes are broadly categorized into orthogonal and non orthogonal codes. Walsh codes are perfectly orthogonal, fixed power binary codes and are preferred for synchronous CDMA communications. Gold codes are nearly orthogonal and are preferred in asynchronous communication systems.

Different kinds of spreading sequences exhibit different properties, such as length of the sequence, code set size and auto and cross correlation values. Most of the available code sets yield degraded performance in multiuser conditions, especially when the system s heavily loaded and the channel is dispersive. Binary code sets have the chip levels (+1, -1) and hence result in constant envelope or fixed power modulating signal, which enables efficient use of the available RF power in CDMA. This is true only in the case of single user system. And in a multiuser scenario, this is not true when multiple binary signals are added together. Amplifiers usually operate as linear devices under small signal conditions and become more non-linear and distorted with increase in input signal level [4]. Increasing the input drive signal in turn increases the efficiency of the RF amplifier and thus increases the total transmitted power. Current research on RF amplifier design is aimed at increasing the linear range of RF amplifiers with lower distortion levels and higher efficiency. With such technological advances, implementation of varying power codes is becoming feasible for wireless and radio communications. The limitations of binary code sets discussed above lead to the design of new multi level (varying power) user codes.

Usage of multi level integer valued orthogonal codes for CDMA communications is initially proposed by R. Poluri in [8], where in an exhaustive search scheme to construct n-length multi level user codes is discussed. In this method, the multi level representations of integers from 1 to 2^{n-1} are checked for orthogonality to

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obtain a code set. This method is proved to be tedious as the length of the code increases. Multi level integer valued orthogonal code sets constructed by R. Poluri [8] are shown in Table 1.

Table-1

3-level, 6-length codes (RP 6)						**4-level, 8-length codes (RP 8)**							
-1	-1	-1	1	0	0	-3	-3	-3	-1	-1	-3	1	-1
0	0	1	1	-1	-1	-3	-1	1	3	-1	3	3	1
0	0	1	1	1	1	-3	1	3	-3	-1	1	-1	-3
1	-1	0	0	-1	1	-3	3	-1	1	-1	-1	-3	3
1	-1	0	0	1	-1	-1	-3	3	-1	3	-1	-1	3
1	1	-1	1	0	0	-1	-1	-1	3	3	1	-3	-3
						-1	1	-3	-3	3	3	1	1
						-1	3	1	1	3	-3	3	-1

There are few works addressing the design methods for multiple level user codes and their application to MC-CDMA systems [9]. Genetic algorithm based multi level orthogonal sequence design is discussed in [10]. The multi level spreading codes discussed in this paper are constructed using ternary and quaternary Gray and Inverse Gray codes

The construction methodology and their performance over AWGN channel is reported earlier [12].

Gray code, a unit hamming distance code of n-bit, is defined as a list of all 2^n bit strings such that successive code words differ in only one bit position [13] [14]. An 'n' bit Inverse Gray Code , is defined exactly opposite to Gray code, it is a list of all 2^n bit strings of length 'n' each, such that successive code words differ in (n-1) bit positions [15] [16]. By concatenating Gray and Inverse Gray codes, binary user codes are constructed. The procedure for constructing the codes and the performance of these codes have been reported earlier [17]. A similar technique for the construction of multilevel user codes using ternary and quaternary Gray and Inverse Gray codes is proposed in the present work.

Use of Rake receiver for communication over multi path channels is discussed in [18]. Rayleigh fading channels conditions and communication over such multiplicative channels is discussed in [19, 20]. Bit Error Probability performance of DS CDMA over Rayleigh fading channel is analyzed and presented in [21, 22].

Rest of the paper is organized in the following manner: Section II discusses the proposed technique for the construction of 3-level and 4-level user code sets from n-git ternary and quaternary Gray and Inverse Gray codes respectively. Performance analysis of the proposed codes over Rayleigh fading channel is presented in section-III and finally, Section-IV gives the conclusions.

II. Multilevel Spreading Codes :

In multi user Direct Sequence CDMA systems, spreading codes or user codes are used to distinguish users and spread signals. Spreading codes are also called as user codes. Binary user codes (2-level) are designed by mapping radix-2 elements {0, 1} to chip amplitude levels {-1, 1}. Similar procedure is adopted to construct multi level (>2) orthogonal codes. In multi level user codes, discrete amplitude levels, similar to pulse amplitude modulation (PAM) levels, are used as chip signals for spread spectrum codes. Chip amplitudes are chosen such that they have zero mean. In order to minimize the average transmitted energy and to obtain M signal amplitude levels symmetric about zero and equally spaced, the following formula is used.

$$A_m = (2m-1-M),\ m=1, 2, \ldots.., M.$$

For example, using the above specified formula, the obtained chip amplitude levels for a 3-level coding are {-1, 0, 1} and for a 4-level coding, chip amplitudes levels are {-3,-1,1,3}. The procedure to construct m-level, 2n-length orthogonal spreading code sets is summarized as follows:

Step 1: Generate n-git (generalized digit) (ternary or quaternary) Gray code using the algorithm discussed in [7] with any permutation.

Step 2: Using the same permutation generate n-git Inverse Gray code [9].

Step 3: Append Inverse Gray Code to the Gray Code to result in 2n-length Gray Inverse Gray (GIG) code. This GIG code comprises of 'r^n' code words (r=3 for ternary and r=4 for quaternary) of 2n-length each.

Step 4: Each row of this 2n-length GIG code is mapped to the 'm' chip amplitude levels to construct multi level code set.

Step 5: Select any one codeword as the first basis function of the orthogonal code set. A next code word is added to this orthogonal code set by checking the orthogonality with this first basis function. Two sequences are said to be orthogonal when the cross correlation between them is zero. If x and y are two code words the cross correlation is given by

Step 6: This search process is continued with remaining r^n-1 code words to obtain m-level, 2n length orthogonal spreading code set.

This procedure is repeated by selecting a different codeword as the first basis function to obtain another user code set. Number of unique code sets can be obtained using this procedure. Table. II displays the

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construction of 3-level, 4-length GIG code set using the permutation . Similarly, 4-level 8-length user code sets can be obtained using Quaternary GIG codes. Tables III and IV display 3-level, 4-length and 6-length user code sets respectively and in Table V, 4-level 8-length user code sets along with their decimal representations are shown. These short length codes can be used in wireless sensor networks or mesh networks where lower processing gains are required. Sensor networks operate with sufficiently close spacing (in the range of 10-75 m) between the communication nodes with less output powers and data rates (typically20-250 kbps). Generally these shorter.

Genetic algorithm based multi level orthogonal sequence design is discussed in [10]. In [11], Galois field transform based spreading sequence design is discussed. The multi level spreading codes discussed in this paper are constructed using ternary and quaternary Gray and Inverse Gray codes.

Table-II

2-git Ternary ray Code	2-git Ternary Inverse Gray code	2-git Ternary GIG Code	{0,1,2} mapped to {-1,0,1}			
00	00	0000	-1	-1	-1	-1
01	10	0110	-1	0	0	-1
02	20	0220	-1	1	1	-1
12	21	1221	0	1	1	0
10	01	1001	0	-1	-1	0
11	11	1111	0	0	0	0
21	12	2112	1	0	0	1
22	22	2222	1	1	1	1
20	02	2002	1	-1	-1	1

TABLE III.

	TERNARY GIG CODE				Decimal values	3-level, 4-length orthogonal codes Basis elements {-1,0,1} Norm^2 =4			
Set I	0	0	1	2	0	-1	-1	-1	-1
	0	2	1	1	24	-1	1	1	-1
	0	2	1	1	40	0	0	0	0
	0	0	1	2	68	1	0	0	1
Set II	0	1	1	0	12	-1	0	0	-1
	1	2	2	1	52	0	1	1	0
	1	0	0	1	28	0	-1	-1	0
	1	1	1	1	40	0	0	0	0
	2	1	1	2	68	1	0	0	1

TABLE IV.

	TERNARY GIG CODE						Decimal values	3-level, 6-length orthogonal codes Basis elements {-1,0,1} Norm^2 =4					
Set I	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1
	2	0	0	0	2	2	494	1	-1	-1	-1	1	1
	1	2	0	2	1	0	426	0	1	-1	1	0	-1
	0	2	1	0	1	2	194	-1	1	0	-1	0	1
	2	1	2	0	1	0	624	1	0	1	-1	0	-1
	1	0	2	2	1	0	316	0	-1	1	1	0	-1
Set II	1	0	0	0	1	1	247	0	-1	-1	-1	0	0
	1	2	0	2	1	0	426	0	1	-1	1	0	-1
	0	2	1	0	1	2	194	-1	1	0	-1	0	1
	1	1	1	2	2	2	377	0	0	0	1	1	1
	2	1	2	0	1	0	624	1	0	1	-1	0	-1
	1	0	2	2	0	1	316	0	-1	1	1	-1	0
Set III	2	0	0	0	2	2	494	1	-1	-1	-1	1	1
	0	1	0	1	0	1	91	-1	0	-1	0	-1	0
	1	2	1	0	2	0	438	0	1	0	-1	1	-1
	2	1	1	2	0	0	612	1	0	0	1	-1	-1
	1	1	2	0	0	2	380	0	0	1	-1	-1	1
	0	0	2	2	2	0	78	-1	-1	1	1	1	-1

Table-V

	QUATERNARY GIG CODE								Decimal values	4-level, 8-length orthogonal codes Basis elements {-3,-1,1,3} Norm2 = 20							
Set I	0	0	0	0	0	0	0	0	0	-3	-3	-3	-3	-3	-3	-3	-3
	3	0	0	0	0	3	3	3	49215	3	-3	-3	-3	-3	3	3	3
	2	3	0	0	3	2	1	1	45285	1	3	-3	-3	3	1	-1	-1
	0	2	3	0	1	3	2	1	11385	-3	1	3	-3	-1	3	1	-1
	2	2	2	1	1	1	1	2	43350	1	1	1	-1	-1	-1	-1	1
	1	0	2	1	3	0	2	3	18891	-1	-3	1	-1	3	-3	1	3
	2	1	2	2	1	2	1	1	39525	1	-1	1	1	-1	1	-1	-1
	2	2	2	2	2	2	2	2	43690	1	1	1	1	1	1	1	1
	1	2	2	2	2	1	1	1	27285	-1	1	1	1	1	-1	-1	-1
	2	2	1	2	1	1	2	1	42585	1	1	-1	1	-1	-1	1	-1
	0	2	0	3	1	2	1	3	9078	-3	1	-3	3	-1	1	-1	3
Set II	2	0	0	0	0	2	2	2	32810	1	-3	-3	-3	-3	1	1	1
	1	3	0	0	3	1	0	0	28880	-1	3	-3	-3	3	-1	-3	-3
	2	2	2	1	1	1	1	2	11385	1	1	1	-1	-1	-1	-1	1
	0	2	3	0	1	3	2	1	43350	-3	1	3	-3	-1	3	1	-1
	1	0	2	1	3	0	2	3	18891	-1	-3	1	-1	3	-3	1	3
	2	1	2	2	1	2	1	1	39525	1	-1	1	1	-1	1	-1	-1
	2	2	2	2	2	2	2	2	43690	1	1	1	1	1	1	1	1
	2	2	1	2	1	1	2	1	42585	1	1	-1	1	-1	-1	1	-1
	0	2	0	3	1	3	1	2	9078	-3	1	-3	3	-1	3	-1	1
Set III	1	0	0	0	0	1	1	1	16405	-1	-3	-3	-3	-3	-1	-1	-1
	2	3	0	0	3	2	1	1	45285	1	3	-3	-3	3	1	-1	-1
	0	2	3	0	1	3	2	1	11385	-3	1	3	-3	-1	3	1	-1
	2	2	2	1	1	1	1	2	43350	1	1	1	-1	-1	-1	-1	1
	2	0	2	1	3	1	3	0	35292	1	-3	1	-1	3	-1	3	-3
	2	1	2	2	1	2	1	1	39525	1	-1	1	1	-1	1	-1	-1
	2	2	2	2	2	2	2	2	43690	1	1	1	1	1	1	1	1
	1	2	2	2	2	1	1	1	27285	-1	1	1	1	1	-1	-1	-1
	2	2	1	2	1	1	2	1	42585	1	1	-1	1	-1	-1	1	-1
	0	2	0	3	1	3	1	2	9078	-3	1	-1	3	-1	3	-1	1

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III. Performance analysis over Rayleigh fading channel:

In DS-CDMA systems, the narrow band message signal indirectly multiplied with a spreading code. The resulting signal modulates the radio frequency (RF) carrier. Spreading sequence consists of a number of code bits called chips. Ratio of the spreading code chip rate to the original data bit rate is called the spreading factor or processing gain. In DS-CDMA systems, all users use the same transmitting carrier and simultaneously transmit their data. Receiver employs coherent demodulator to de-spread the received data using a locally.generated code sequence. To be able to perform the spreading, receiver needs to know both the spreading code and its same channel, signal detection at the receiver for each user is limited by the interference caused by other users known as multiple access interference (MAI). MAI depends on the cross-correlation values among the user codes, delayed versions of the code of interest due to multipath propagation, number of users, transmitted power levels of other users as well as their timing synchronization. Utilization of spreading codes for data spreading in a synchronized system eliminates MAI. Asynchronous system worsens MAI, resulting in lower system capacity. MAI in such situations can be lowered by choosing code sequences with lower cross-correlation values. In systems with lower number of users, interested user signal coming from farther distance will be masked if other user signals are received at higher power levels. This is classic near-far problem that exists in all CDMA systems and typically occurs when the signal of interest is coming from cell boundaries. To combat this problem, power control is provided at the base station which ensures signals from all mobiles are received at the same power level irrespective of their distance. In the current work all signals are assumed to be received with the same power level. Hence, their power levels are not considered in the detection process.

There are three basic mechanisms that impact signal propagation in a mobile communication system: reflection, diffraction and scattering. These mechanisms cause two types of fading effects that characterize mobile radio propagation: Large scale fading and small scale fading. Large scale fading represents the attenuation in the signal power due to motion over large areas. This phenomenon is caused by prominent

Terrain contours such as hills and forests between the transmitter and the receiver. The receiver is often said to be shadowed by such obstacles. The statistics of large scale fading provide a way of computing a prediction of path loss as a function of distance. This is described in terms of average path loss and a log normally distributed variation about the average. Small scale fading refers to the changes in the signal amplitude and phase that can be experienced as a result of small changes in the spatial positioning between a receiver and a transmitter. Small scale fading manifests itself into two mechanisms: time dispersion of the signal and time variant behaviour of the channel. Small scale fading is called Rayleigh fading if there are multiple reflective paths that are large number and there is no line of sight signal component. The envelope of such a mobile radio channel has a constant gain and linear phase response over a bandwidth smaller than that of the smutted signal, the transmitted signal is thought to undergo quench selective fading. In this case the received signal is distorted and dispersed, because it consists of multiple replicas of the transmitted signal, delayed and attenuated in time. This leads to time spreading of the transmitted symbols within the channel resulting in inter symbol interference (ISI). In this paper, two user DS CDMA communication over frequency nonselective and selective Rayleigh fading channel conditions are considered. When channel is frequency flat or nonselective, there exists only a single resolvable path and multiple paths exist for a frequency selective fading condition. Rayleigh fading is a ultiplicative distortion and received signal y(t) is modeled as y(t) = h(t) s(t) + n(t), where h(t) is the impulse response of the channel, s(t) is the transmitted signal; n(t) is the additive white Gaussian noise. For flat fading channel, h(t) consists of a single tap with zero delay. The impulse response h(t) is a wide-sense stationary complex Gaussian process with zero mean and unity variance. The resulting signal has Rayleigh distributed envelope and uniform phase distribution. Rayleigh probability density function is given byreceived signal is statistically described by Rayleigh probability density function. When a dominant direct signal component is present, the small scale fading envelope is described by a Rician probability density function. Small scale fading can be further classified as flat or frequency selective and slow or fast. A receiver is said to endure flat fading, if the mobile radio channel has a constant gain and a linear phase response over a bandwidth larger than the bandwidth of the transmitted signal. Under these conditions, the received signal has amplitude fluctuations due to the variations in the channel gain over time caused by multipath. On the other hand, if the mobile radio channel has a constant gain and linear phase response over a bandwidth smaller than that of the transmitted signal, the transmitted signal is thought to undergo frequency selective fading. In this case the received signal is distorted and dispersed, because it consists of multiple replicas of the transmitted signal, delayed and attenuated in time. This leads to time spreading of the transmitted symbols within the channel resulting in

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inter symbol interference (ISI). In this paper, two users DS CDMA communication over frequency nonselective and selective Rayleigh fading channel conditions are considered. When channel is frequency flat or nonselective, there exists only a single resolvable path and multiple paths exist for a frequency selective fading condition. Rayleigh fading is a multiplicative distortion and received signal y(t) is modelled as y(t) = h(t) s(t) + n(t), where h(t) is the impulse response of the channel, s(t) is the transmitted signal; n(t) is the additive white Gaussian noise. For flat fading channel, h(t) consists of a single tap with zero delay. The impulse response h(t) is a wide-sense stationary complex Gaussian process with zero mean and unity variance. The resulting signal has Rayleigh distributed envelope and uniform phase distribution. Rayleigh probability density functions.

Where 'r' is the envelope of the received signal.

Multi level integer valued 3-level, 6-length (RP 6) and 4-level, 8-length (RP 8) user codes proposed by R. Poluri [5] are considered for performance comparison along with binary valued Walsh and Gold codes. As Walsh codes are popularly used for synchronous communications, performance comparisons of the proposed codes for two user synchronous communication is done with Walsh codes of nearer length and are presented in Fig. 1 and Fig. 3. In asynchronous DS-CDMA communications with random delays Gold codes are popular. Hence, the performance comparison of the proposed codes and Gold codes for asynchronous communication with two users is presented in Fig. 2 and Fig. 4.

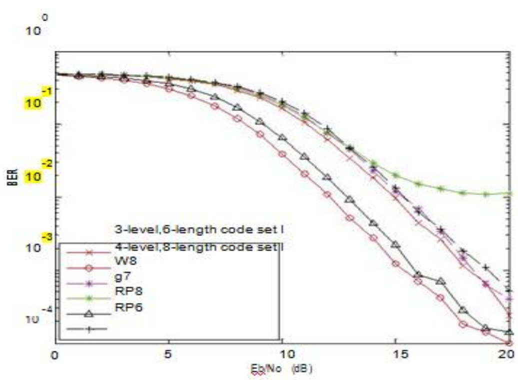

Fig. 1. BER performance of Walsh 8, Gold 7, RP 6, RP 8 and proposed 3-level, 6-length and 4-level, 8-length codes for 2-user synchronous DS CDMA over Rayleigh flat fading channel

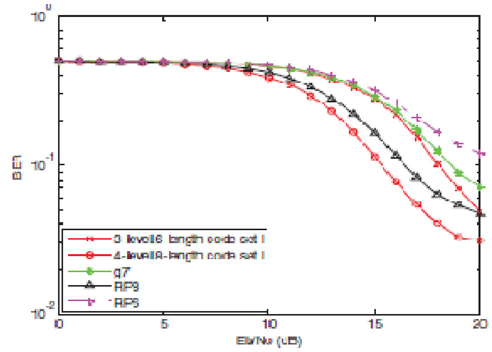

Fig. 2. BER performance of Gold 7, RP 6, RP 8 and proposed 3-level, 6-length and 4-level, 8-length codes for 2-user asynchronous DS CDMA over Rayleigh flat fading channel

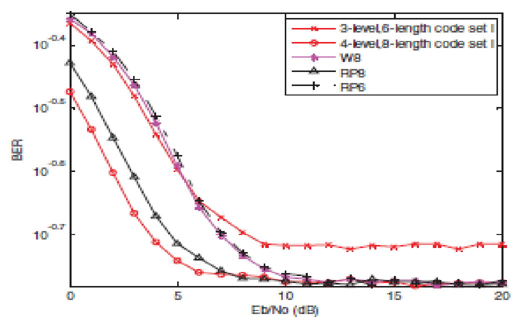

Fig. 3. BER performance of Walsh 8, Gold 7, RP 6, RP 8 and proposed 3-level, 6-length and 4-level, 8-length codes for 2-user synchronous DS CDMA over Frequency selective Rayleigh flat fading channel

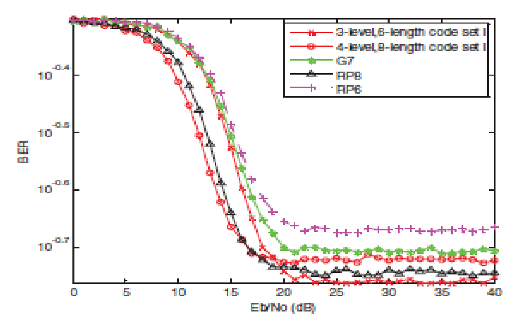

Fig. 4. BER performance of walsh 8, Gold 7, RP 6, RP 8 and proposed 3-level, 6-length and 4-level, 8-length codes for 2-user asynchronous DS CDMA over Frequency selective Rayleigh flat fading channel

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Conclusion:

A new multilevel spreading code constructed using ternary and quaternary Gray and Inverse gray codes for direct sequence CDMA communication is proposed in this paper.
The design technique gives constructing m-level, 2n-length user code sets. Radix -3 GIG codes result 3-level and 6-level code sets. Radix -4 GIG codes result 4-level and 8-level code sets. In this work multi level spreading codes are designed to 3&4 levels only. Spreading codes sets of higher levels(radix-5&6----) also constructed by using the same procedure. These code sets are useful in wireless sensor networks and mesh networks. The proposed code sets for synchronous multi user communication over Rayleigh fading channel gives better performance than existing Gold , Maximal and Walsh codes.

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