Performance Analysis of High Capacity CC-CDMA using 1D-Logistic Map in AWGN

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Abstract— **High capacity systems, like the CDMA, are of utmost importance in future generation wireless systems especially in overloaded environments. Here, we analyze the performance of the chaotic-collaborative-CDMA (CC-CDMA) scheme, with chaotic codes generated, using the 1D-Logistic map, under the AWGN channel conditions. Similar to CC-CDMA, this scheme uses mutually orthogonal chaotic sequences, but, generated using the logistic differential equation. It provides comparable performance to the collaborative-CDMA scheme with better security in overloaded CDMA and MAI limited environments. The bandwidth as well as security constraints can be addressed using this scheme. The BER performance of the scheme, as the number of users per group is increased beyond the spreading length, is studied and results have been presented.**

Keywords— CC-CDMA, CDMA, multiple access interference, multiuser detection, AWGN, direct sequence spread spectrum, DS/CDMA, logistic map;

I. INTRODUCTION

To leverage the number of users beyond the system capacity has been an area of research for years, specifically in cellular mobile networks. The Code-Division Multiple Access (CDMA) scheme has been a success in such a scenario. However, the number of users in CDMA is limited to the number of pseudo-random (PN) sequences which in turn depends on the spread length. It is a well-known fact that the maximum number of users supported with many multi-user detection (MUD) techniques [1] are usually less than the spreading length. Unlike in the conventional CDMA, instead of using one sequence per user, the collaborative CDMA scheme in [2], group a number of users to share the same spreading sequence. Also, one can reuse the available orthogonal spreading sequences where their spread signals are scrambled by two distinct random scrambling sequences. At the receiver, various MUD techniques are used detect users' signals [3]. The work in [9] introduces a (DS/CDMA) concept in which the number of users accommodated is higher than the spreading length. As the number of users exceeds the spreading length, say M additional users, the M users reuse M spreading sequences. A group-based collaborative spreading CDMA scheme is proposed in [5], which allows the sharing of the same orthogonal sequence by more than one user. Also, group based MUD scheme in overloaded CDMA systems under additive white Gaussian noise (AWGN) channel has been studied [6].

The collaborative multi-user receiver consists of a group MUD stage to eliminate multiple-access interference (MAI) between the groups and a maximum-likelihood (ML) detection stage to recover the co-spread users' data [2]. Though the collaborative CDMA, uses PN sequences, provide sufficient security, it is possible to masquerade the transmission by decoding the PN sequences. Here, we exploit the security aspect of the chaotic sequences, similar to the CC-CDMA scheme, and use them as the spreading sequences instead of PN sequences.

Chaotic sequences are generated by differential equations and are totally sensitive to their initial conditions and parameters of the system. A very small change in these two factors can cause large deviation in the system states over time, which makes these systems difficult to intercept. They exhibit properties of stochastic process that meet the requirements of spread spectrum communications. Binary sequences with good pair wise cross-correlation generated by various chaotic maps, like the logistic map, can be used in CDMA systems [10]. Since the proposed system operates based on the direct sequence spread spectrum (DSSS) using chaotic sequence, it inherits all advantages such as interference rejection, anti-jamming, fading reduction, multi-access potential, and low probability of interception from the conventional DSSS system [7]. The methods to obtain binary sequences from chaotic trajectories generated by nonlinear ergodic maps has been proposed in [8].

II. SYSTEM MODEL

A. Logistic CC-CDMA multiuser transmitter design

A baseband model of the proposed scheme for an AWGN channel, which exploits the chaotic sequences (generated using 1D Logistic differential equation) as the spreading sequences, is shown in Fig. 1. At the transmitter, the

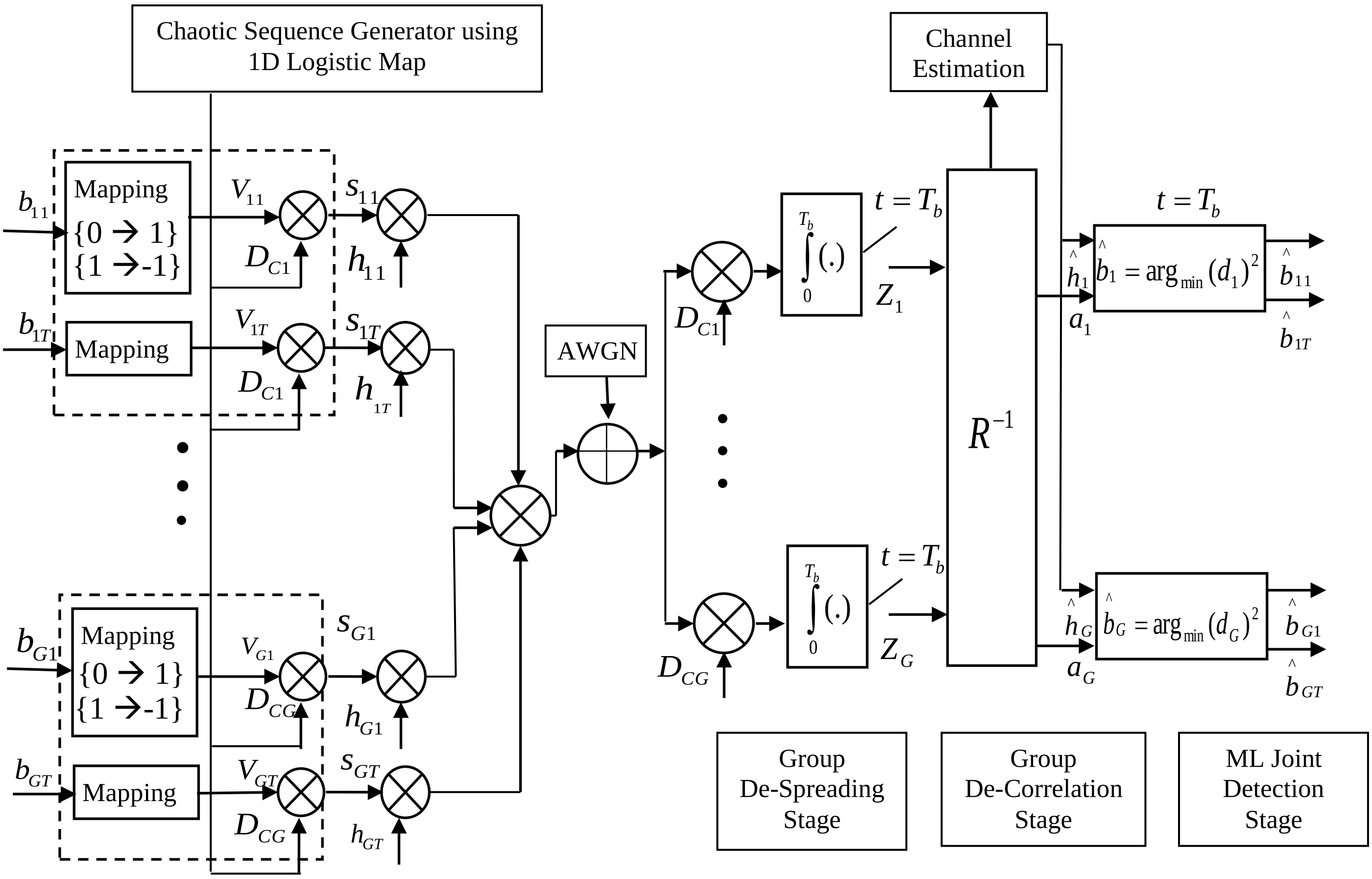

Fig.1. Proposed Chaotic-Collaborative CDMA system block diagram

total K users are divided into G groups, each consisting of T users. Each user within a group is assumed to use the same chaotic-spreading sequence. Chaotic sequences of length 1xN are generated (where N is the order of the spread code matrix) with the 1D-Logistic Map (1), represented by

$$x_{n+1} = rx(1 - x_n) \qquad (1)$$

Where, r is the parameter of the logistic map. The map shows chaotic behavior in the range $3.56995 < r < 4.0$. The chaotic sequences, of length 1xN, generated using a specific initial condition is mapped as the ith row of the NxN matrix. The elements of the ith row acts as the spreading sequences to the ith group in the collaborative CDMA scheme.

The total transmitted signal is given by

$$S_{kl} = \sum_{k=1}^{G} \sum_{l=1}^{T} P_{kl} * V_{kl} * D_{Ck} \qquad (2)$$

Where, P_{kl} is the signal power, V_{kl} is binary phase shift keying (BPSK) mapped signal of the user's data b_{kl} of period T_b, D_{Ck} is the chaotic spreading sequences generated using 1D-logistic map with a processing gain of T_b/T_c.

The flow diagram of the generation of orthogonal-chaotic spreading sequence is shown in Fig.2. The number of initial conditions of the 1D-logistic map correspond to the maximum

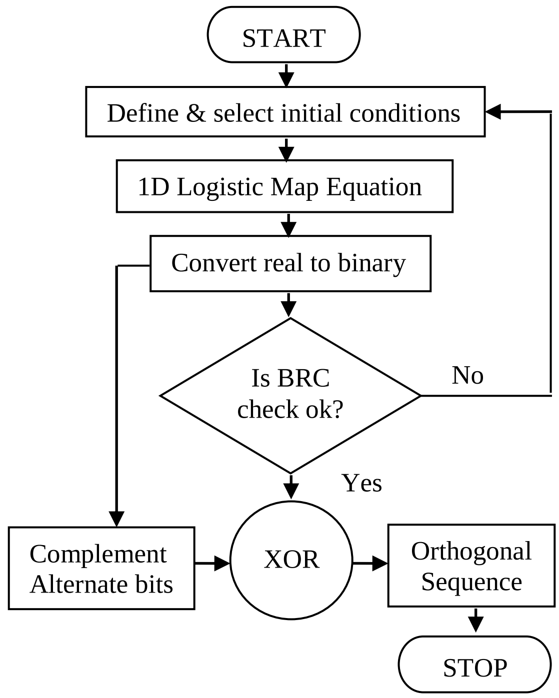

Fig.2. Flow Diagram of 1D-Orthogonal Chaotic Sequence Generation

number of groups. The initial conditions, mapped to a 1xN matrix, are selected such that the logistic map will generate chaotic values. These values are converted to its equivalent binary and compared with its 'alternate-bit- complemented' version , in order to get the orthogonal sequences. The sequences generated are finally tested for balance, run and correlation (BRC) properties.

B. Logistic CC-CDMA multiuser receiver design

The receiver design is similar to that of [2] except for the difference that the chaotic sequences, as a stored reference, is use to de-spread the received signal.

The received signal is given by

$$r = \sum_{k=1}^{T}\sum_{l=1}^{G} h_{kl} * S_{kl} + w \qquad (3)$$

Where, h_{kl} 1 is the channel gain of the kl^{th} user, and is modelled as complex Gaussian random variable with zero mean and unit variance. w = $[w_1, w_2, \dots, w_N]^T$ is the AWGN vector with two sided power spectral density $N_0/2$. The transmitted signal undergoes flat fading. The system is asynchronous at the group level but, the users within each group need to be synchronized to enable sharing of the same sequence.

Group De-spreading Stage

Assuming, kl^{th} user data has to be recovered, the received signal is first de-spread by using group spreading chaotic sequences D_{Ck}, $1 \leq k \leq G$ to form a vector of output signals $z = [z_1, z_2, \dots, z_G]^T$. In a matrix form it can be written as:

$$z = Rh + w \qquad (4)$$

Where, R is the cross-correlation matrix of dimension G × G, $h = [h_1, h_2, \dots h_G]^T$ is the vector consisting of products of users' data and channels obtained from parent matrix H,

$$H = \begin{bmatrix} h_{11}v_{11} & h_{12}v_{12} & \dots & h_{1T}v_{1T} \\ h_{21}v_{21} & h_{22}v_{22} & \dots & h_{2T}v_{2T} \\ . & . & & . \\ . & . & & . \\ h_{G1}v_{G1} & h_{G2}v_{G2} & \dots & h_{GT}v_{GT} \end{bmatrix} \qquad (5)$$

The rows of the matrix H in (5) contain the signals T co-spread users' independent data multiplied by their corresponding channels.

Group De-correlation Stage

Non-orthogonal nature of users received signal cause MAI to be a dominant source of disturbance. In order to remove MAI, we orthogonalize the chaotic spreading sequences as well as employ a group de-correlation stage similar to the collaborative CDMA case. The de-correlator output signal vector in (6) is obtained by multiplying the inverse of the cross-correlation matrix.

$$a = R^{-1}z = \bar{h} + R^{-1}\bar{w} \qquad (6)$$

The vector '**a**' is free from MAI but, suffers from the noise-enhancement that increases linearly with increase in the number of users because of the diagonal elements of R^{-1} being higher than unity [1, 5]. The individual elements of the vector are then sent to a bank of G maximum-likelihood (ML) joint detectors to estimate the data of T co-spread users'.

Maximum Likelihood (ML) Joint Detecion Stage

ML joint detection stage computes the a posteriori probability for all the transmitted data vectors and provides the final estimates of users' data by selecting the vector with maximum probability. The data vector for the k^{th} group is obtained as

$$\left\{d_k^{(q)}\right\}^2 = |a_k - \sum_{l=1}^{T} \hat{h}_{kl} v_l^{(q)}|^2 \qquad (7)$$

Where, $q \in [1, L]$ and $L = M^T$ possible data combinations to search for T co-channel users modulated by M-ary symbols.

The detector estimates the final group data from the vector in (8), which yields the minimum Euclidian distance as

$$\hat{b}_k = \arg_{\min} \left\{d_k^{(q)}\right\}^2 \qquad (8)$$

III. Performance Analysis and Simulation Results

In this section, the BER performance of Logistic CC-CDMA is investigated for different spread length and users sets. In Fig.3 the BER curve for Logistic CC-CDMA system for six different user configurations is plotted. The users are grouped accordingly as G= [10, 14] and T= [1, 2, 3] users per group with a spreading factor of 15. As it is noticed, for a particular SNR value (say at 25dB), the BER for 10x2 users is 9.48×10^{-4}. At the same time, it is 5.527×10^{-3} for 14x2 users. At SNR value of 30dB, Logistic CC-CDMA with 10x3 users gives a BER of 1.12×10^{-2} whereas with 14x2 gives a BER of 2×10^{-3}. This means that for an increased number of users, the proposed Logistic CC-CDMA system shows a comparable performance to that of the collaborative CDMA scheme, at higher SNR range as the number of users per group increases, as well as, providing better security. In Fig.4. The system performance is analyzed with the spreading factor of 7. Here, for the SNR value = 25 dB, the system 4x2 users shows BER value of 3.7×10^{-3} whereas it is 6.7×10^{-3} for 6x2 users. At SNR of 30dB, the system 4x3 users shows BER value of 1.2×10^{-2} and for 6x2 users it is 1.9×10^{-3}.

This imply that the performance of the system with spreading factor of value 15 is better than that with a value of 7. Thus the system shows satisfactory performances at higher spread lengths and that the transmitted data could be successfully recovered at the receiver even if the number of users per group, is increased, with chaotic spreading. The BER performance shows a little degradation as the number of users per group is increased. However, the performance can be improved at higher SNR region.

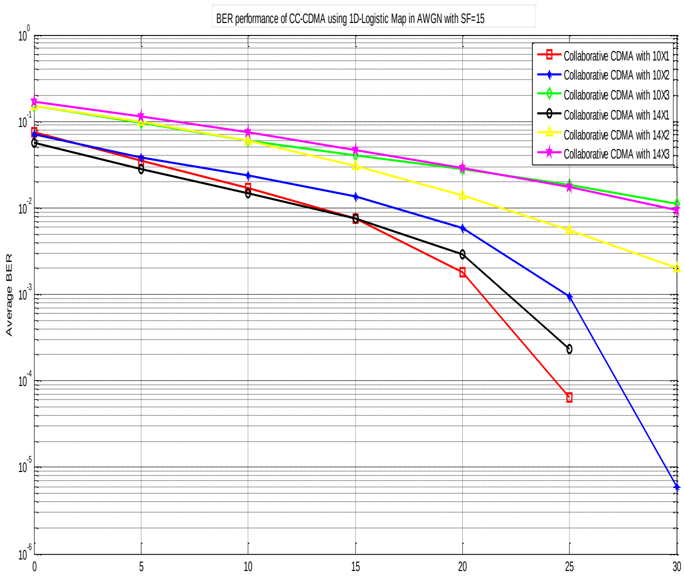

Fig.3. BER performance of CC-CDMA using 1D-Logistic Map in AWGN with SF=15

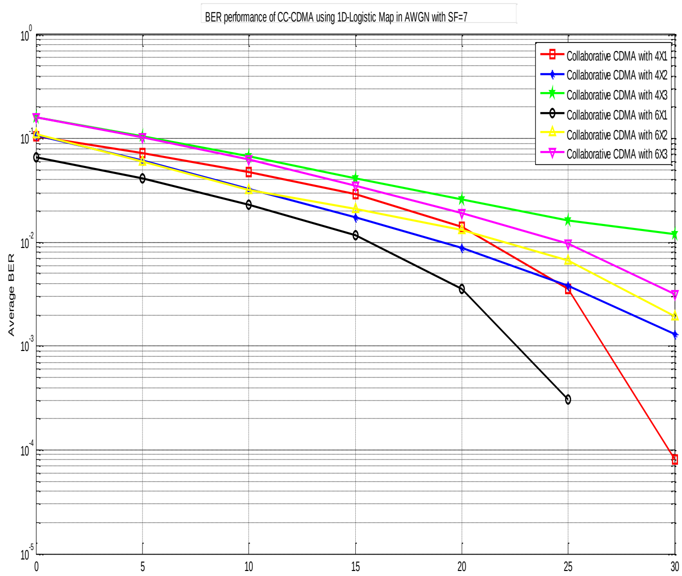

Fig.4. BER performance of CC-CDMA using 1D-Logistic Map in AWGN with SF=7

IV. CONCLUSION AND FUTURE SCOPE

The performance of Logistic CC-CDMA, with chaotic codes generated, using the 1D-Logistic map has been studied under the AWGN channel conditions. Similar to CC-CDMA, this scheme uses mutually orthogonal chaotic sequences, but, generated using the logistic differential equation. It provides comparable performance to the collaborative-CDMA scheme with better security in overloaded CDMA and MAI limited environments. Thus, the bandwidth efficiency has been improved as well as the security. The BER performance degrades as the number of users per group is increased. As an ad-on to this work, the synchronization of this scheme can be investigated.

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