Performance Evaluation of Different DS-CDMA Receivers Using Chaotic Sequences

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***Abstract*-Spreading codes play an important role in multiple access capacity of DS-CDMA system. M-sequences, gold sequences etc., has been traditionally used as spreading codes in DS-CDMA. These sequences are generated by shift registers, which are periodic in nature. So these sequences are less in number and this limits the security. This paper presents an investigation on use of new type of sequences called chaotic sequences for DS-CDMA system. This paper compares the performance of different types of simple receivers with chaotic codes. The different types of receivers analyzed are MMSE receiver, MF receiver, Rake receiver, Volterra receiver and, FLANN receiver.**

***Keywords*- Chaos, Code division multiple access, Functional Link Artificial Neural Network receiver, Volterra receiver.**

I. Introduction

The last part of the past millennium witnessed the introduction of mobile cellular communication. Ever since the inception there has been a surge in the demand for this technology. Due to limitations of available radio frequency bandwidth, multiple access techniques have been used to provide the users access to the communication channel. First generation communication systems used frequency division multiple access (FDMA) where as second generation systems like IS-54 and GSM used time division multiple access (TDMA) along with FDMA. The third generation systems like IS-95, Universal Mobile Telecommunications System (UMTS) used direct sequence code division multiple access (DS-CDMA) techniques. CDMA systems assign uncorrelated codes to each mobile user, enabling them to transmit continuously over time using the full bandwidth over the complete call duration. DS-CDMA systems use both long and short spreading sequence to provide better capacity [1].

In order to spread the bandwidth of the transmitting signals, pseudo-noise (PN) sequences [2] have been extensively used in spread spectrum communication systems. Obviously, the maximal length shift register sequences (M-sequences) and Gold sequences are the most popular spreading sequences in spread spectrum systems. The M-sequences have very desirable autocorrelation properties. However, large spikes can be found in their cross-correlation functions, especially when partially correlated. Another limiting property of M-sequences is that they are relatively small in number. Therefore, the number of sequences is usually too small and not suitable for spread spectrum systems. Furthermore, another method for generating PN sequences with better periodic cross-correlation properties than M-sequence has been developed by Gold [3]. The Gold sequences are constructed by taking a pair of specially selected M-sequences.

This paper analyses use of a different type of spreading sequence for use in DS-SS systems called chaotic sequences. These sequences are created using discrete, chaotic maps [4] and are of two categories (a) Logistic map [5] and (b) Tent map [6]. The sequences so generated with both Logistic map and Tent Map are well-known as, even though completely deterministic and initial sensitive, have characteristics similar to those of random noise. Surprisingly, the maps can generate large numbers of these noise-like sequences having low cross-correlation. Generally these sequences have been used in CDMA systems. The noise-like feature of the chaotic spreading code is very desirable in a communication system. This feature greatly enhances the LPI (low probability of intercept) performance of the system. This paper investigates BER performance of different linear and nonlinear receivers for DS-CDMA system using chaotic sequences.

Following the introduction, in section II the DS-CDMA system model is outlined. Section III discusses on the background of chaotic nonlinear systems and generation of chaotic sequences. Section IV discusses receivers that have been investigated in this paper. Section V provides the performance analysis of these receivers for DS-CDMA using chaotic sequences. The paper ends with concluding remarks.

II. An Overview Of DS-cdma System

System model for DS-CDMA considered here is presented in Fig. 1. It shows the downlink scenario, where the mobile unit receives signal $y(kL+n)$ from the base station. The information bits corresponding to the desired user i out of U users are denoted as $x_i(k)$. $x_i(k)$ takes the values ± 1 with equal probability and k denotes the time index of user transmitted symbols. The information bits transmitted by each user are then convolved with each of their mutually orthogonal spreading sequences $C_{i,n}$ where $1 \le i \le U$ (number of users active) and $1 \le n \le L$ (spreading sequence length). The spread signal from each user are then combined to form

$$s(kL+n) = \sum_{i=1}^{U} C_{i,n} x_i(k) \tag{1}$$

where $s(kL+n)$ is the signal, at time $t = nT_{bit}$ constructed by coherently summing the spreading sequence of each user and this is then transmitted through the non-dispersive channel. Channel adds AWGN to the signal. With this the received signal $y(kL+n)$ can be represented as

$$y(kL+n)=\sum_{i=1}^{U} C_{i,n}x_i(k)+n(kL+n) \quad (2)$$

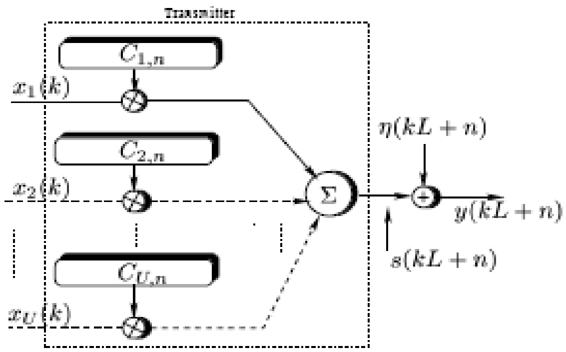

Fig. 1. Conventional synchronous DS-CDMA downlink transmitter for U transmitting users

At the point where bit k , and chip n is received. $n(kL+n)$ is the noise component at chip rate. In the AWGN case there is no need to consider n outside the range $1 \le n \le L$ as outside this time the signal will contain no information relating to data bit k .The job of the receiver is to estimate the transmitted signal $x_i(k)$ Of the desired user using the information content in the $y(kL+n)$. As the input signal is processed at chip rate n, it is called chip level based (CLB) receiver.

III. Chaotic System

A chaotic dynamical system is an unpredictable, deterministic and uncorrelated system that exhibits noise-like behavior through its sensitive dependence on its initial conditions, which generates sequences similar to PN sequence. The chaotic dynamics have been successfully employed to various engineering applications such as automatic control, signals processing and watermarking. Since the signals generated from chaotic dynamic systems are noise-like, super sensitive to initial conditions and have spread and flat spectrum in the frequency domain, it is advantageous to carry messages with this kind of signal that is wide band and has high communication security. For this reason numerous engineering applications of secure communication with chaos have been developed.

A. Chaotic Sequences

A chaotic sequence [7] is non-converging and non-periodic sequence that exhibits noise-like behavior through its sensitive dependence on its initial condition. Chaotic systems have sensitive dependence on their initial conditions. A large number of uncorrelated, random-like, yet deterministic and reproducible signals can be generated by changing initial value. These sequences so generated by chaotic systems are called chaotic sequences. Chaotic sequences are real valued sequences. Since the spreading sequence in a chaotic Spread Spectrum (SS) is no longer binary, the application of the chaotic sequences in DS-CDMA is thus limited. A further attempt to transform continuous values to binary ones by using digital encoding technique is therefore used to adopt it in DS-CDMA. Some criteria are performed.

B. Generation of Chaotic Sequences

One of the simplest and most widely studied nonlinear dynamic systems capable of exhibiting chaos is the logistic map

$$F(x,r)=rx(1-x) \quad (3)$$

or written in its recursive form,

$$x_{n+1}=rx_n(1-x_n), 0 \le x_n \le 1, 0 \le r \le 4 \quad (4)$$

Here, F is the transformation mapping function, and r is called the bifurcation parameter. Depending on the value of r , the dynamics of system can change attractively, exhibiting periodicity or chaos.

One major difference between chaotic sequences and PN sequences is that chaotic sequences are not binary. Therefore chaotic sequences must be transformed into binary sequences. There are various methods of generating binary sequences from chaotic real sequences. Various types of binary function are defined to get binary sequences based on a chaotic real-valued orbit generated by ergodic maps.

METHOD 1: The generation of binary chaotic sequences is shown in Fig. 2. The chaotic sequences are transmitted into quantization and encoding block. The quantization performs an equal-interval quantization of the floating point input signal varying from -1 to +1. The output signal is quantized into whole units, the unit size determined by the number of bits used in the binary representation. The coding block converts the quantized signal into a stream of bits. The sequence obtained in this way is called chaotic bit sequence.

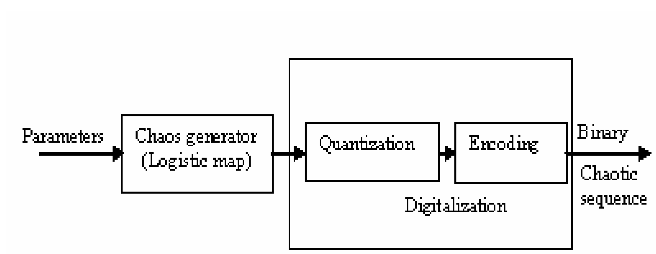

Fig. 2. Generation of binary chaotic sequences

METHOD 2: Let w be the real valued chaotic sequence. For transforming this real valued sequence to binary sequence, we define a threshold function $\theta_t(w)$ as

$$\theta_t(w)=\begin{cases}0, & w<t \\ 1, & w\ge t\end{cases} \quad (5)$$

where t is the threshold value. Using these functions, we can obtain a binary sequence which is referred to as a chaotic threshold sequence.

METHOD 3: Binary sequences (C_k) [8] can be obtained from a continuous chaotic signal $x(t)$ by defining

$$C_k = g\{x(t) - E_t(x(t))\}|_{t=kTd} \tag{6}$$

Where $g(x) = 1$ for $x \geq 0$ and $g(x) = -1$ for $x < 0$. $E(x(t))$ denotes the mean function over the continuous time and Td is the basic period of $x(t)$. By applying (6) to the logistic map in (3) in a chaotic regime, it is possible to obtain different by varying initial conditions or parameter values of the system. The sequences generated in this way are expected to have a low cross correlation.

C. Chaotic DS/SS system

In chaotic DS/SS system [9], each user is assigned a different initial value $x_{n,}0$, where n is the nth user. Each user starting with his unique initial value, keep on iterating the chaotic map and gets the real valued chaotic sequence. This real chaotic sequence is transformed to binary (± 1) for its use in DS/SS by using various methods as explained in part B of section 3. In case of tent map, each user is assigned a different bifurcation parameter whereas each user is assigned different initial value in case of logistic map. In this paper, logistic map has been used to generate the real valued chaotic sequences.

IV. Volterra and FLANN Receivers an Introduction

It has been found that the optimal receiver for a DS-CDMA system is non-linear in nature [10]. But this optimal receiver is computationally complex and is very nearly impossible to be implemented in a mobile unit. Volterra [11] and Functional Link Artificial Neural Network (FLANN) [12] receivers have been found to provide near optimal performance in DS-CDMA systems. In this paper these receivers have been tested using chaotic spreading codes.

In a Volterra receiver the received signal is expanded in the form of

$$\begin{aligned} v(kN+n) &= \sum_{a=0}^{N-1} h_1(a) y(kN+n-a) + \\ &\sum_{a=0}^{N-1} \cdot \sum_{b=0}^{N-1} h_2(b,a) y(kN+n-a) y(kN+n-b) + \\ &\sum_{a=0}^{N-1} \cdot \sum_{b=0}^{N-1} \cdot \sum_{c=0}^{N-1} h_3(a,b,c) y(kN+n-a) y(kN+n-b) y(kN+n-c) \end{aligned} \tag{7}$$

where $y(kN+n)$ denotes the filter input and $v(kN+n)$ the output for the K^{th} symbol of length N with $n = 1,2,...,N$ chips. The term h_0 in (7) denotes the 0th-order Volterra kernel (coefficients, or weights w) of the system. Without loss of generality, it can be assumed that the kernels are symmetric (e.g. $h_2(a,b) = h_2(b,a)$). The symmetric terms can be omitted since they do not contribute any additional information, which results in half the number of coefficients for h_0. Thus the Volterra kernels h_0 are fixed for any of the possible permutations. Hence, (7) can be rewritten for a symbol synchronized receiver:

$$\begin{aligned} \hat{D}_d(y(k)) = \operatorname{sgn}(&\sum_{a=0}^{N-1} h_1(a) y(kN-a) + \sum_{a=0}^{N-1} \cdot \sum_{b=0}^{N-1} h_2(a,b) y(kN-a) y(kN-b) + \\ &\sum_{a=0}^{N-1} \cdot \sum_{b=0}^{N-1} \cdot \sum_{c=0}^{N-1} h_3(a,b,c) y(kN-a) y(kN-b) y(kN-c)) \end{aligned} \tag{8}$$

where $\hat{D}_d$ stands for the K^{th} estimated transmitted bit of the desired user d. A possible filter structure is depicted in Fig. 3. It becomes apparent from (8), that the term in sgn(.) is a sum of products between a received sequence $y(k)$ and Volterra coefficients h_0.

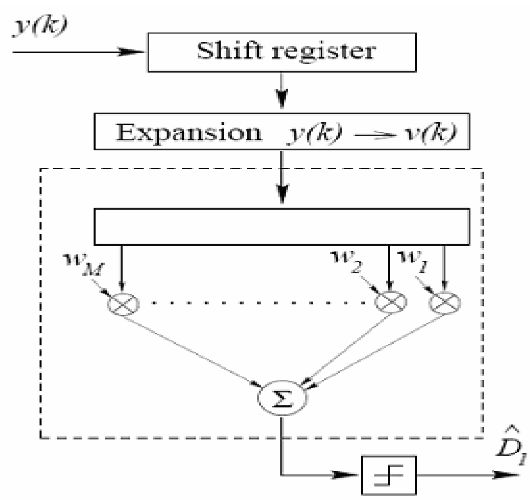

Fig. 3. Volterra based approach with M-tapes

The Volterra expansion and the expansion sequence are analyzed for a one user CLB CDMA system in AWGN. Due to the binomial growth in number of coefficients, the analysis is presented with a short spreading code of length $N = 3$. In order to apply the Volterra filter to the received signal $y(k)$, it must first be expanded to a larger sequence, denoted by $V(K)$.

In contrast, a FLANN receiver expands the input signal in the form of trigonometric expansion. Simple structure of FLANN is shown in Fig. 4. This can be represented as

$$s_i = \begin{cases} x_n & \text{for } i = 1 \\ \sin(l\pi x_n) & \text{for } i = 2,4,...,M \\ \cos(l\pi x_n) & \text{for } i = 3,5,...,M+1 \end{cases} \tag{9}$$

Two input sequences are given as input to this network. This sequence is expanded using trigonometric components.

The network weights are updated using adaptive algorithm like Least Mean Square (LMS).

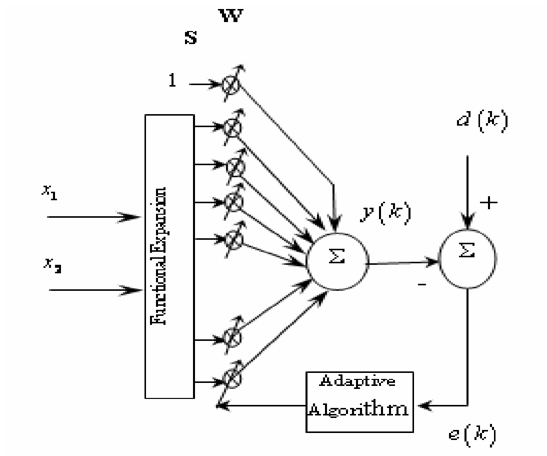

Fig. 4. Structure of the FLANN model

V. Performance Of Cdma Receivers Using Chaotic Sequences

In order to validate the proposed chaotic spreading sequences for DS-CDMA applications, extensive simulation studies were conducted. All the simulations are carried out in Matlab. During the training period the receiver parameters were optimized/ trained with 1000 random samples and the parameters so obtained were averaged over 50 experiments. The parameters of the receiver were fixed after the training phase. The receiver weights were trained using different algorithms.

Bit error rate (BER) was considered as the performance index. BER performance of the different linear receivers like matched filter (MF), minimum mean square error (MMSE) receiver and nonlinear receivers like Volterra receiver, FLANN receiver using chaotic spreading sequences is done. In all the experiments randomly generated +1/-1 samples were transmitted for each user. These samples were spread using chaotic spreading sequences of length 31 corresponding to each of the users. After spreading, the sequences were added and transmitted through the channel. The channel output was fed to the receiver. A total of 105 bits were transmitted by each user and a minimum of 100 errors were recorded. The tests were conducted for different levels of Eb/N0. Additionally tests were also conducted by varying number of active users in the system for fixed value of Eb/N0.

D. Performance comparison for channel without ISI

In this section, a non-dispersive channel is considered. In Fig. 5 performance of Volterra and FLANN receiver was investigated for varying Eb/N0 conditions and compared with that of linear receivers (Performance for Chaotic spreading sequences for 7 users are plotted). It is seen that Volterra receiver performs better than all other receivers. MMSE receiver performs better than MF receiver. FLANN receiver outperforms both MMSE and MF receiver.

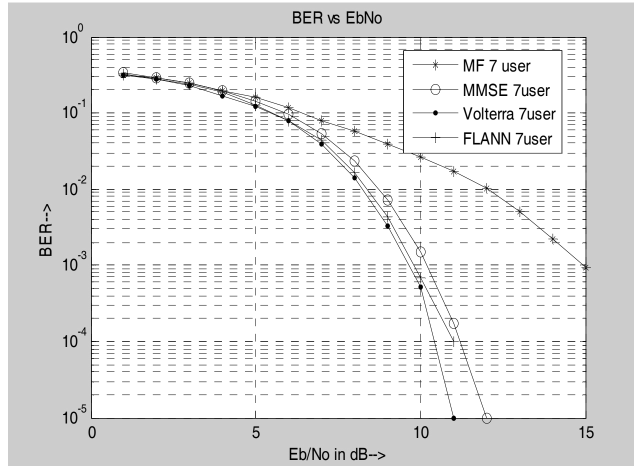

Fig. 5. Comparison of BER performance of different receivers for varying Eb/N0 for 7 users in AWGN using chaotic spreading codes with 31 chips.

Fig. 6 presents the BER performance of Volterra receiver and FLANN receiver using chaotic spreading sequences with that of linear receivers for varying number of active users. The chip length of the chaotic spreading codes is taken as 31 chips. Here Eb/N0 was fixed as 7dB.

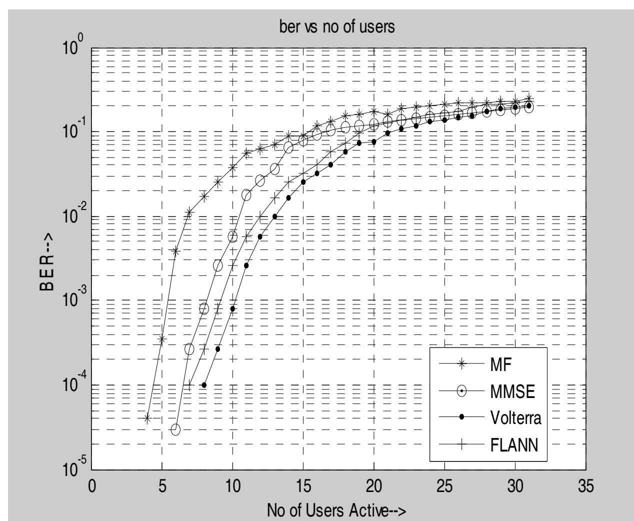

Fig. 6. BER against the number of users of different receivers in AWGN at Eb/N0=7dB using chaotic spreading sequences with 31chips

It is seen that Volterra receiver performs better than all other receivers. MMSE receiver performs better than MF receiver. FLANN receiver outperforms both MMSE and MF receiver. It is seen that nonlinear receivers (Volterra and FLANN) outperforms linear receivers.

E. Performance comparison for channel with ISI

In this section, we consider a stationary multipath channel $H_{ch} = 1 + 0.5Z^{-1} + 0.2Z^{-2}$. In AWGN, the number of chips transmitted, is number of chips of the spreading sequence i.e., 31 in this case. Hence all receiver structures exploit $N+(L-1)=31+(3-1)=33$ chips instead of 31.

In Fig. 7 performance of Volterra and FLANN receiver was investigated for varying Eb/N0 conditions and compared with that of linear receivers (Performance for Chaotic spreading sequences for 7 users are plotted). For this it is seen that there is 3dB performance penalty at BER of 10^{-3}. It is seen that Volterra receiver performs better than all other receivers. FLANN receiver performs better than MMSE receiver.

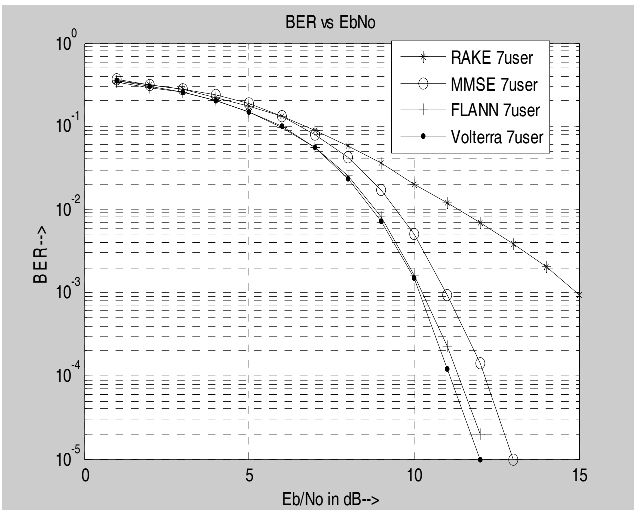

Fig. 7. Comparison of BER performance of different receivers for varying Eb/N0 for 7 users in stationary multipath Hch=1+0.5z-1+0.2z-2 using chaotic spreading codes with 31 chips.

Fig. 8 compares the BER performance of Volterra receiver and FLANN receiver using chaotic spreading sequences with that of linear receivers for varying number of active users. The chip length of the chaotic spreading code is taken as 31 chips. Here Eb/N0 was fixed as 7dB. It is seen that Volterra receiver performs better than all other receivers. FLANN receiver performs better than MMSE receiver. It is seen that nonlinear receivers performs better than linear receivers.

CONCLUSION

The simulation results presented, demonstrate that non-linear processing of input signal in terms of Volterra and FLANN receivers for chaotic code based CDMA receivers provide better performance than MMSE and RAKE receivers. This is in agreement with CDMA system using other types of coding like GOLD code, pseudorandom codes. It is seen that Volterra receiver performs better than the FLANN receivers.

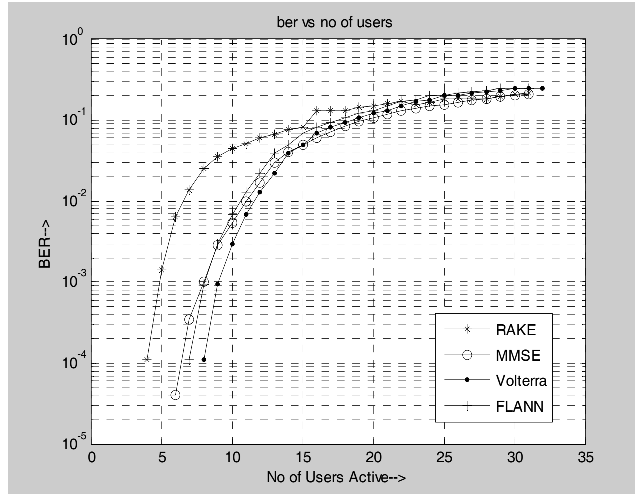

Fig. 8. BER against the number of users of different receivers in AWGN at Eb/N0=7dB using chaotic spreading sequences with 31chips in stationary multipath Hch=1+0.5z-1+0.2z-2

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