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Robust synchronization for asynchronous multi-user chaos-based DS-CDMA

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ABSTRACT

In this paper we propose two systems for achieving synchronization in asynchronous multi-user chaos-based DS-CDMA. For the first system, synchronization process is realized thanks to a binary code used as an additive pilot sequence to the spreaded signal. Gold sequences are used as pilot signals for the different users to accomplish the synchronization. For the second synchronization system, the synchronization is made through a binary code used as a multiplicative pilot signal for the spreaded data sequence. These synchronization processes are evaluated under the assumption of an additive white Gaussian noise channel together with multi-user interferences. In this paper we will focus on the initial synchronization phase (code acquisition) and we assume that the system can achieve correctly the code tracking after this first synchronization phase. The code acquisition for the two systems is evaluated in terms of the probability of detection and probability of false alarm.

1. Introduction

Within the past decade, several research efforts have addressed the use of chaotic signals in digital communications. Chaotic signals can offer very attractive properties such as the security of transmission and low probability of interception [1]. In addition, the improvement of the system performance when chaotic sequences are applied instead of conventional binary codes for spreading spectrum motivates the developments of chaos-based DS-CDMA transmission techniques [1,2]. The major problem of chaos based DS-CDMA systems remains the synchronization of the received chaotic signal with the local chaotic signal generated in the receiver despread information. The intensive work of Pecora and Carroll in synchronization field [3] has opened the way for chaotic transmission systems implementation [4–7]. For classical DS-CDMA using binary pseudo-noise (PN) codes, an other synchronization method has been proposed in the literature [8–11]. The synchronization problem is solved via a two-step approach: An acquisition search is first activated in order to align the local sequence to the received sequence within an uncertainty of a half time chip duration [8]. The time uncertainty, which is basically determined by the transmission time of the transmitter and the propagation delay, can be much longer than a chip duration. As initial acquisition is usually achieved by a search through all possible phases (delays) of the sequence, a larger timing uncertainty means a larger search area. Moreover, in many cases, initial code acquisition must be accomplished in low signal-to-noise-ratio (SNR) environments and in presence of jammers. The acquisition procedure is possible when the spreading sequence exhibits some kind of periodicity. Given the initial acquisition, code tracking takes place and is usually accomplished by a delay lock loop (DLL). The tracking loop keeps on operating during whole communication period. If the channel changes abruptly, the DLL lose track of the

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correct timing and initial acquisition will be re-performed [8]. Sometimes, we perform initial code acquisition periodically no matter whether the tracking loop loses track or not.

This classical synchronization technique has been applied for chaos-based DS-CDMA systems in [12–22]. In [13,14] the authors have studied the performance of the acquisition process when a Markov chaotic sequence is used as a spreading code for DS-CDMA. They have shown in [13] that the Markov code outperforms the independent and identically distributed code in acquisition and bit error rate (BER) frameworks. The authors have shown in [12] that the Bernoulli and tailed shift map give a better performance in the acquisition phase than Gold sequences. Noise perturbations have not been included in [12,16,18,22] in order to study the effects of the multi-user interferences on the acquisition process. However, the presence of noise is inevitable for any real communication system and we have included it in the study of the system performance. In most cases, when evaluating the sequence synchronization of chaos-based DS-CDMA systems only code acquisition is analyzed [12–16,18–22].

Jovic et al. presented in [23] a new method for achieving and maintaining synchronization for synchronous multi-user chaos-based DS-CDMA. This method called code aided synchronization (CAS) is proposed and evaluated in the presence of additive white Gaussian noise (AWGN) and multi-user interferences. Code acquisition and tracking phases are studied and analyzed in [23]. The synchronization system proposed in [23] uses a single pseudo-random binary sequence as pilot signal to achieve and maintain the synchronization. The use of a binary periodic pilot signal (PPS) for chaos-based DS-CDMA synchronization system in [23] is to show that robust synchronization of a chaos-based DS-CDMA system is possible. They also show in [23] that in terms of code acquisition, the binary pilot signal outperforms the logistic and Bernoulli chaotic maps. The authors have proposed in their paper a multi-user chaos based DS-CDMA system with a synchronization unit to achieve and maintain fine synchronization of chaotic sequences.

In many papers, chaos-based communication systems are mainly studied for showing the attractive properties of chaotic sequences in the spreading spectrum framework [24–27]. A lower attention is put on the implementation techniques. In order to implement practical chaos-based DS-CDMA systems, it is necessary to develop robust synchronization techniques which are able to work in low SNR environment. In our paper we have focused our attention on such robust synchronization.

In our paper we are interested in the synchronization system proposed in [23]. We proposed here two synchronization systems. The first system is the extension of the synchronous CAS method of [23] to an asynchronous multi-user case. In this system, a PN signal will be used for synchronization purpose, like in [23], as an additive periodic pilot sequence. This synchronization procedure is called asynchronous CAS with additive pilot sequence (ACAS-A).

In the second system, the PN code is used also for the synchronization purpose but instead of being an additive sequence as in ACAS-A and in [23], we have used it as a multiplicative one. This synchronization procedure is called asynchronous CAS with multiplicative pilot sequence (ACAS-M). This second approach outperforms the ACAS-A in terms of synchronization and BER performances.

In our paper we have focused on the first synchronization phase (acquisition) of the chaotic sequence. The mathematical model of the code tracking loop is presented for the chaos-based DS-CDMA system in [23].

The paper is organized as follows. In Section 2 we have first presented chaos-based DS-CDMA system with the synchronization unit. First of all, the initial synchronization is presented and analyzed in terms of probability of detection (P_d) and probability of false alarm (P_{fa}). Simulation results together with some conclusive remarks are then given. In Section 3 the chaotic communication system with the ACAS-M unit is presented. Then, the synchronization performance is shown in Section 3.3, simulation results and comparisons with the ACAS-A system are provided. The final section reports some conclusive remarks.

2. Chaos-based DS-CDMA system with additive pilot signals (ACAS-A)

2.1. Chaotic generator

Throughout the paper, a Chebyshev polynomial function of order 2 is chosen as chaotic generator:

$$x_{k+1} = 1 - 2x_k^2 \tag{1}$$

The choice of this map is related to its simplicity for generating chaotic sequences. Moreover, it is shown in [23,28,29] that it allows better performances than many other maps for chaos-based DS-CDMA systems. Chaotic sequences are normalized such that their mean values are all zero and their mean squared values are unity, i.e., $E[x_k] = 0$ and $E[x_k^2] = 1$.

2.2. Transmitter structure

The studied system is a DS-CDMA communication system with M asynchronous users. This system is the extension of the system studied in [23]. The system of [23] is used only for the chaotic sequence synchronization in synchronous mode, but our system can be used for asynchronous mode. As shown in Fig. 1(a), a stream of data symbols from user m ($s_i^{(m)}$) with period T_s are spreaded by a chaotic signal $x^{(m)}(t)$ generated from Eq. (1) at the emitter side. Symbols of different users are independent of one another. Chaotic sequences of all users are generated using the same chaotic generator with different initial conditions. A new chaotic sample (or chip) is generated every time interval equal to T_c ($x_k^{(m)} = x^{(m)}(kT_c)$).

As shown in Fig. 1(a), system a Gold code $p^{(m)}(t)$ is added to each user, and is used as the PPS with period equal to T. Gold codes have been chosen for PPS because of their good properties concerning cross-correlation in