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A Fast Code Acquisition Scheme for O-CDMA Systems

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Abstract—This paper proposes a fast code acquisition scheme for optical code division multiple access (O-CDMA) systems. Unlike the conventional scheme, the proposed scheme employs multiple thresholds providing a shorter mean acquisition time (MAT) performance. The simulation results show that the MAT of the proposed scheme is shorter than that of the conventional scheme.

Keywords—Optical CDMA, acquisition, MAT, multiple-shift

I. Introduction

The code synchronization is one of the most important tasks in code division multiple access (CDMA) based communication systems [1]. Generally, the code synchronization consists of two stages: code acquisition and tracking. In code acquisition, the ultimate performance measure is the mean acquisition time (MAT), which is a mean time that elapses prior to acquisition.

An optical CDMA (O-CDMA) system uses an optical orthogonal code (OOC) as a spreading code [2]. Due to its good autocorrelation and crosscorrelation properties, the OOC has been widely used for various CDMA based systems including O-CDMA systems [3], [4]. Keshavarzian and Salehi introduced the serial-search (SS) [3] scheme using the OOC, which is simple; however, its MAT increases as the code length becomes longer. Thus, the SS scheme is not suitable for rapid acquisition of a long code that is essential for multi-user environments. In order to overcome this drawback, in [4], the same authors proposed the multiple-shift (MS) scheme using the OOC, which consists of two stages and offers a shorter MAT compared with that of the SS scheme.

In this paper, we propose a faster code acquisition scheme referred to as the enhanced multiple-shift (EMS). The EMS scheme also consists of two stages like the MS scheme, however, by using multiple thresholds and modified local code, the EMS scheme provides a shorter MAT compared with that of the MS scheme.

The remainder of this paper is organized as follows. Section II describes the system model. In Section III, we present the conventional MS and proposed EMS schemes. In Section IV, the simulation results show the MATs of MS and EMS schemes in single-user and multi-user environments. Section V concludes this paper.

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II. System Model

In an O-CDMA channel, there exist various kinds of impairments such as noise, multipath signals, and multiple access interference (MAI). The influences of noise and multipath signals can be almost completely mitigated by using fiber-optic medium; however, that of MAI should be alleviated in the receiver [5], [6]. In this paper, thus, we consider a multi-user environment without the influences of noise and multipath signals. Then, the received signal $r(t)$ can be written as

$$r(t) = \sum_{n=1}^{N} s^{(n)}(t - \tau^{(n)}), \tag{1}$$

where $s^{(n)}(t)$ is the transmitted signal of the nth user; $\tau^{(n)} \in [0, T_b)$ denotes the time delay of the nth user with bit duration T_b; and N is the number of total users. We consider the on-off-keying (OOK) modulation and assume that the bit rate is the same for all users. Thus, transmitted signal $s^{(n)}(t)$ can be expressed as

$$s^{(n)}(t) = \sum_{i=-\infty}^{\infty} b_i^{(n)} c^{(n)}(t - iT_b), \tag{2}$$

where $b_i^{(n)}$ is the ith binary data bit of the nth user and $c^{(n)}(t) = \sum_{j=0}^{F-1} a_j^{(n)} p(t - jT_c)$ is the OOC of the nth user with chip duration T_c and sequence $a_j^{(n)} \in \{0, 1\}$ of length F and weight K (the total number of '1's in $a_j^{(n)}$) with the rectangular pulse $p(t)$ of length T_c defined as

$$p(t) = \begin{cases} 1, & 0 \le t < T_c, \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

Generally, the OOC can be denoted by its parameters, i.e., $(F, K, \lambda_a, \lambda_c)$, where λ_a and λ_c are autocorrelation and crosscorrelation constraints, respectively [2]. For ideal strict orthogonality of OOC, both λ_a and λ_c have to be zero; however, since an OOC consists of 0 and 1, the ideal strict orthogonality cannot be satisfied. Thus, in this paper, both λ_a and λ_c are set to 1.

III. Code Acquisition Schemes

A. Conventional MS Scheme

In the MS scheme, total F cells in the search space are divided into Q groups, each of which contains M cells. The relation of Q and M is given by

$$Q = \left\lceil \frac{F}{M} \right\rceil, \tag{4}$$

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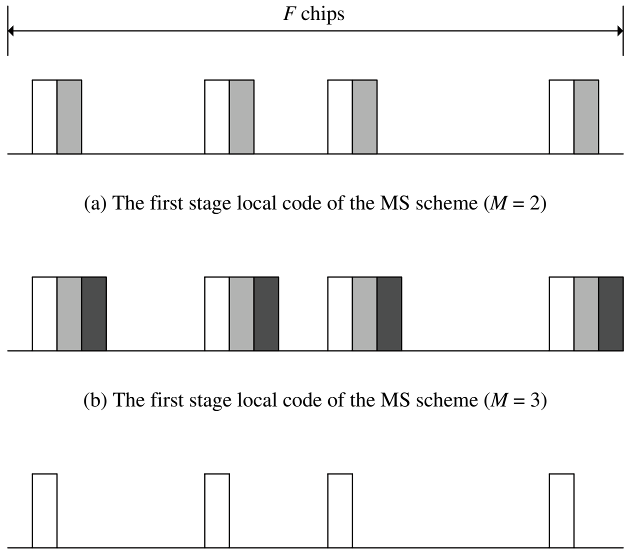
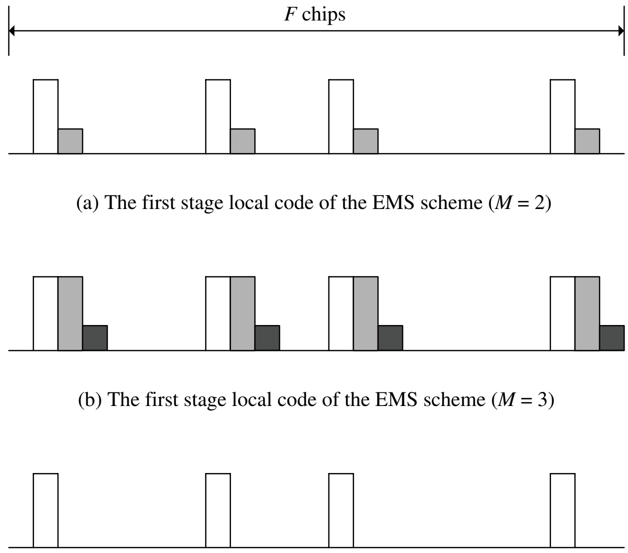


(a) The first stage local code of the MS scheme (M = 2)

(b) The first stage local code of the MS scheme (M = 3)

(c) The second stage local code of the MS scheme (original OOC)

Fig. 1. The local codes of the MS scheme when OOC of (32,4,1,1) is used.



(a) The first stage local code of the EMS scheme (M = 2)

(b) The first stage local code of the EMS scheme (M = 3)

(c) The second stage local code of the EMS scheme (original OOC)

Fig. 2. The local codes of the EMS scheme when OOC of (32,4,1,1) is used.

where $\lceil \cdot \rceil$ denotes the ceiling operation. Note that the upper closest integer to the ratio of F/M is chosen as the value of Q when M is not a divisor of F.

The MS scheme consists of two stages. In the first stage, the received signal $r(t)$ is correlated with the first stage local code shown in Fig. 1. The correlation is repeated on a group-by-group basis. If the correlation value corresponding to a certain group exceeds a given threshold $TH_{MS,first}$, the group is declared to be the correct group having the time delay $\tau^{(n)}$ and the process is transferred to the second stage. In the second stage, the correlation-based search is performed again with the second stage local code (original OOC) on a cell-by-cell basis over M cells in the correct group. As in the first stage, when the correlation value corresponding to a certain cell exceeds a given threshold $TH_{MS,second}$, which is different from the value in the first stage, the cell is declared to be an estimate of the time delay $\tau^{(n)}$.

Using the definition in [4], the MAT of MS scheme T_{MS} is given by

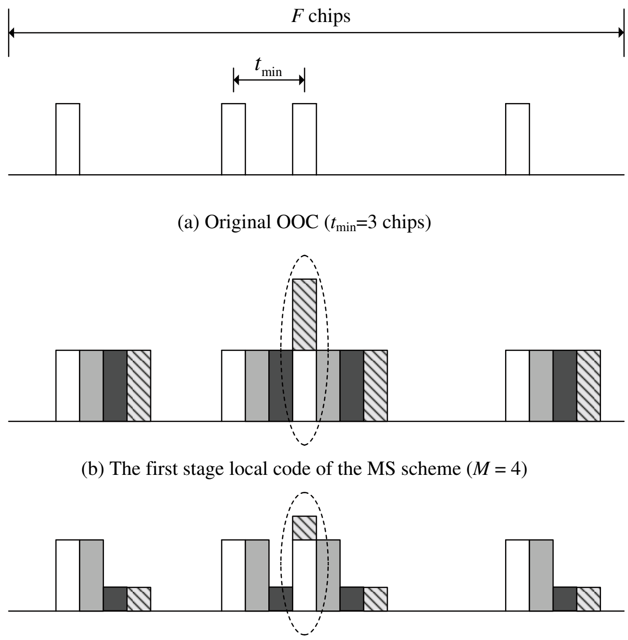
$$T_{MS} = \frac{Q+1}{2} + \frac{M+1}{2}. \tag{5}$$

From (4) and (5), we can find that the minimum value of T_{MS} equals to $\sqrt{F}$ when $M = \sqrt{F}$.

B. Proposed EMS Scheme

The EMS scheme proposed in this paper also consists of two stages as the MS scheme. However, using multiple thresholds and modified local code, the EMS scheme has a shorter MAT than that of the MS scheme.

In the first stage, the first stage local code shown in Fig. 2 is used instead of the conventional local code for EMS scheme. The first stage local code consists of large and small chips.



(a) Original OOC ($t_{\min}$=3 chips)

(b) The first stage local code of the MS scheme (M = 4)

(c) The first stage local code of the EMS scheme (M = 4)

Fig. 3. The local codes of the MS and EMS scheme when $M > t_{min}$.

When M is an even number, the number of large chips is equal to the number of small chips; otherwise, the number of large chips is larger by 1 than the number of small chips. The power of the small chips is determined with the following conditions

$$\text{Conditions of } \alpha = \begin{cases} \alpha < 1, \\ \alpha > \frac{\lambda_a}{K}, \\ \alpha > \frac{\lambda_c}{K}, \end{cases} \tag{6}$$

where α represents the power of small chips. On the other hand, the power of large chips is always set to 1.

The correlation is repeated on a group-by-group basis as in the first stage of the MS scheme. If the correlation value corresponding to a certain group exceeds a given thresholds $TH_{EMS,first}$ or $th_{EMS,first}$, the group is declared to be the correct group having the time delay $\tau^{(n)}$ and the process is transferred to the second stage. In the second stage, the correlation-based search is performed again with the second stage local code (original OOC) on a cell-by-cell basis over M cells in the correct group. As in the first stage, when the correlation value corresponding to a certain cell exceeds a given threshold $TH_{EMS,second}$, the cell is declared to be an estimate of the time delay $\tau^{(n)}$.

In the first stage, if the correlation value of the correct group is equal to or larger than $TH_{EMS,first}$, we only search the first half of M cells of the correct group in the second stage; otherwise and if the correlation value of the correct group is equal to or larger than $th_{EMS,first}$, the search is performed over the second half of M cells of the correct group in the second stage. In the EMS scheme, two thresholds, $TH_{EMS,first}$ and $th_{EMS,first}$ can be determined based on the power of large and small chips in the first stage local code.

Using the definition in [4], the MAT of EMS scheme T_{EMS} is given by

$$T_{EMS} = \frac{Q+1}{2} + \frac{M+2}{4}. \tag{7}$$

As we can see in (7), the MAT in the second stage is reduced by half and the minimum value of T_{EMS} equals to $\sqrt{F/2}+1$ when $M = \sqrt{2F}$.

For a correct operation of the proposed EMS and conventional MS schemes, M has to be equal to or smaller than t_{min}, where t_{min} is the minimum chip interval of the OOC. Otherwise, chips of local code are overlapped as shown in Fig. 3, where $t_{min} = 3$ and $M = 4$. In this case, the EMS scheme cannot guarantee a correct operation and good performance.

IV. Simulation Results

In this section, we compare the MAT of the conventional MS scheme with that of the proposed EMS scheme in single-user and multi-user environments. Simulation parameters are as follows: $F = 200$; $K = 5$; $\lambda_a = \lambda_c = 1$; $N = 1 \sim 4$; $\alpha = 0.75$; $TH_{MS,first} = TH_{MS,second} = TH_{EMS,first} = TH_{EMS,second} = K$; $th_{EMS,first} = \alpha K$; and the penalty time for acquisition is 10. We assume that each user transmits the data 1 or 0 with equal probability and chip is synchronized perfectly.

Fig. 4 shows the MAT performance of the MS and EMS schemes as a function of M in a multi-user environment. From Fig. 4, we can observe that the MAT of the EMS scheme is shorter than that of the MS scheme, and the difference of MAI between the MS and EMS schemes increases as M increases as in the single-user environment.

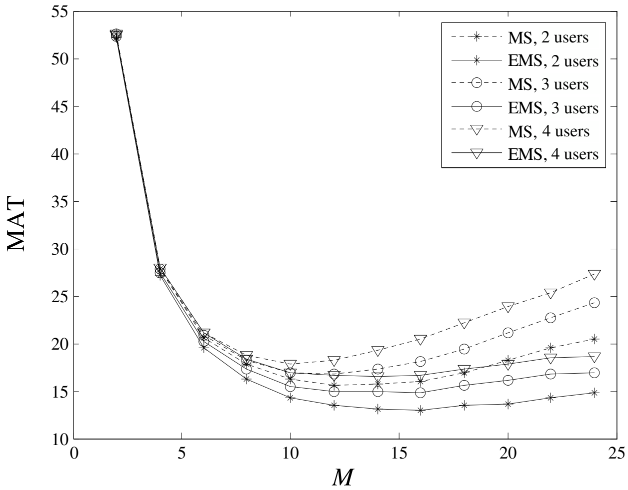


Fig. 4. The MATs of the MS and EMS schemes in a multi-user environment.

V. Conclusion

In this paper, we have proposed a novel code acquisition scheme called EMS for O-CDMA systems. Exploiting the multiple thresholds and modified local code, the proposed EMS scheme can provide a shorter MAT compared with that of the MS scheme. The performance of the EMS scheme has been analyzed using the circular flow graph diagram. The simulation results have confirmed that the EMS scheme offers a shorter MAT compared with that of the MS scheme in both single-user and multi-user environments.

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