

PAPER

Performance Analysis of MDSS Code Acquisition Using SLS for Optical CDMA Systems

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SUMMARY We propose a multiple dwell serial search (MDSS) code acquisition for optical code-division multiple-access (O-CDMA) systems and theoretically analyze its performance. The search/lock strategy (SLS) is used as verification scheme for the multiple dwell detector. The operation of SLS is modeled by finite Markov chain to analyze the performance of the proposed system. Effect of system parameters, such as number of users, threshold and mean photon count per chip, on the performance of the proposed system is investigated. The theoretical result shows that the performance of the proposed system is less sensitive to parameter settings than the conventional single dwell serial search (SDSS) code acquisition system is. In addition, the proposed MDSS code acquisition system offers shorter mean acquisition time than that of conventional SDSS system.

key words: code acquisition and synchronization, search/lock strategy, optical code-division multiple-access, optical orthogonal code

1. Introduction

1.1 Motivation

Over the past decade or so, there has been an ever-increasing interest in direct detection optical code-division multiple-access (O-CDMA) technique for fiber-optic communication, especially for local area and access network environment [1]–[7]. It is because O-CDMA offers asynchronous access, which is suitable for busy traffic in such environment. In addition, by using optical signal processing, O-CDMA is able to alleviate electronic processing bottleneck and provides ultra-high speed connections. Besides, O-CDMA network can support a large number of users with an increased security over other multiple access techniques.

One of the most important problems for any digital communication system is signal synchronization. In spread spectrum systems, sequence synchronization, i.e. code synchronization, is additionally required for the receiver to despread the received signal. Code synchronization has been widely studied for the wireless CDMA [8]. Typically, there are two stages to establish the code synchronization between the transmitter and receiver. The first one is *code acquisition*, where the coarse alignment between the desired signal's code and its local replica within a small fraction, e.g. a chip duration, is achieved. The second stage is *code tracking*, where the fine alignment is achieved and maintained

based on the found coarse alignment. Of these two, code acquisition is the more challenging task because the spreading code in spread spectrum system is usually very long.

In the domain of O-CDMA communications however, most papers assumed that the code synchronization between the transmitter and receiver is ideal. The problem of code synchronization was first reported by Yang [9], where the severe performance degradation was seen in the presence of imperfect code synchronization. This work therefore highlights the necessity of studying the code synchronization techniques for O-CDMA systems.

1.2 Related Works and Our Proposal

Several authors have published their works on code acquisition for O-CDMA systems [10]–[12]. In these works, the serial search code acquisition was proposed with different detector structures, including single-, dual-threshold sequential detectors (i.e. variable dwell detector) [10], [11], and single dwell detector [12]. It is seen that the performance of single dwell serial search (SDSS) code acquisition is severely sensitive to parameter settings, such as threshold and number of users. The performance of SDSS code acquisition system is severely degraded if the threshold is not properly selected and/or when the number of users increases.

In this context, it is interesting to explore the possibility of using the multiple dwell serial search code acquisition (MDSS) for O-CDMA systems. While there is only a fixed observation in the SDSS, many such observations are available in the MDSS system. This would help to improve the acquisition performance by allowing quicker discard of incorrect code phases [8].

There are two approaches to implement the verification scheme. The first approach attempts to implement more than one parallel detectors with different dwell times [13]. In this type of MDSS code acquisition, a code phase position corresponding to an incorrect synchronization condition is immediately rejected or dismissed as soon as there is a failure at any detector. Another approach, which is often referred to as search/lock strategy (SLS), explores the use of algorithms, which require repeated threshold testing of a given dwell output [14]. In comparison with the first, the second approach is simpler and requires less resource.

In this paper, we propose the MDSS code acquisition using SLS for O-CDMA systems and theoretically analyze its performance. Averaging approach is used to derive mean

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acquisition time, in which users' delays as well as the distribution of interfering pulses on the desired user are considered as random variables. We also use the serial-search algorithm for the proposed system because of its proved advantage to achieve simplicity and performance trade-off in the low signal-to-noise environment compared to other search methods, such as maximum-likelihood or sequential estimation [8], [15]. We show that the proposed system can improve the system performance's sensitivity to parameter settings in the conventional SDSS system [12]. We also show that the proposed system can achieve a shorter mean acquisition time than that of conventional one.

In the next section of this paper, we present the descriptions and operation of the proposed system. Theoretical analysis of the proposed system is presented in Sect. 3. Section 4 presents the effect of various system parameters, such as threshold, mean photon count per chip, dark current, and number of users, on the performance of the proposed system. The improvement of the proposed system over SDSS system is also shown. Finally, we give our conclusion in Sect. 5.

2. System Model

2.1 Descriptions

Figure 1 shows a pair of transmitter and receiver in the O-CDMA system using on-off keying (OOK) signaling. The code synchronization system, which consists of code acquisition and code tracking system, is also included. The number of users that shares the same optical fiber is denoted as N . Multiple-access is achieved by assigning each user with a unique spreading code. Length and weight of spreading codes are denoted as F and K , respectively. In this paper, we use the optimum OOC [3] as spreading codes, i.e. OOC with cross- and off-peak auto- correlations bounded by only

one. The correlation properties of optimum OOC can be expressed as follows.

$$|R_{c^{(n)}, c^{(m)}}(l)| = \left| \sum_{j=0}^{F-1} c_j^{(n)} c_{j+l}^{(m)} \right| = \begin{cases} K & \text{for } l = 0 \\ \leq 1 & \text{for } 1 \leq l \leq F-1, \end{cases} \quad (1)$$

$$|R_{c^{(n)}, c^{(m)}}(l)| = \left| \sum_{j=0}^{F-1} c_j^{(n)} c_{j+l}^{(m)} \right| \leq 1, \quad \text{for } 0 \leq l \leq F-1, \quad (2)$$

where $c_j^{(n)}, c_j^{(m)} \in \{0, 1\}$, sequences $c^{(n)} = (c_j^{(n)})$, $c^{(m)} = (c_j^{(m)})$ represent OOC codes of n -th and m -th users, respectively, and $R(l)$ is the correlation characteristic function.

The signal from n -th user $s_n(t)$ is expressed as

$$s_n(t) = \sum_{i=-\infty}^{\infty} b_i^{(n)} c^{(n)}(t - iT), \quad (3)$$

where $b_i^{(n)}$ is the i -th binary data, $c^{(n)}(t)$ represents OOC pattern of n -th user that can be expressed as $c^{(n)}(t) = \sum_{j=-\infty}^{\infty} c_j^{(n)} P_{T_c}(t - jT_c)$, where $P_{T_c}(t - jT_c)$ is a unit rectangular pulse of duration T_c . The received signal at the input of receiver $r(t)$ including multiple-access interference (MAI) and noise can be expressed as

$$r(t) = \sum_{n=1}^N s_n(t - \tau_n) + n(t), \quad (4)$$

where $n(t)$ represents noise, τ_n is the unknown delay associated with the n -th user's signal, $\tau_n \in [0, T)$, in which T is duration of one bit.

The task of code synchronization system is to determine the correct delay of the desired user's signal so that

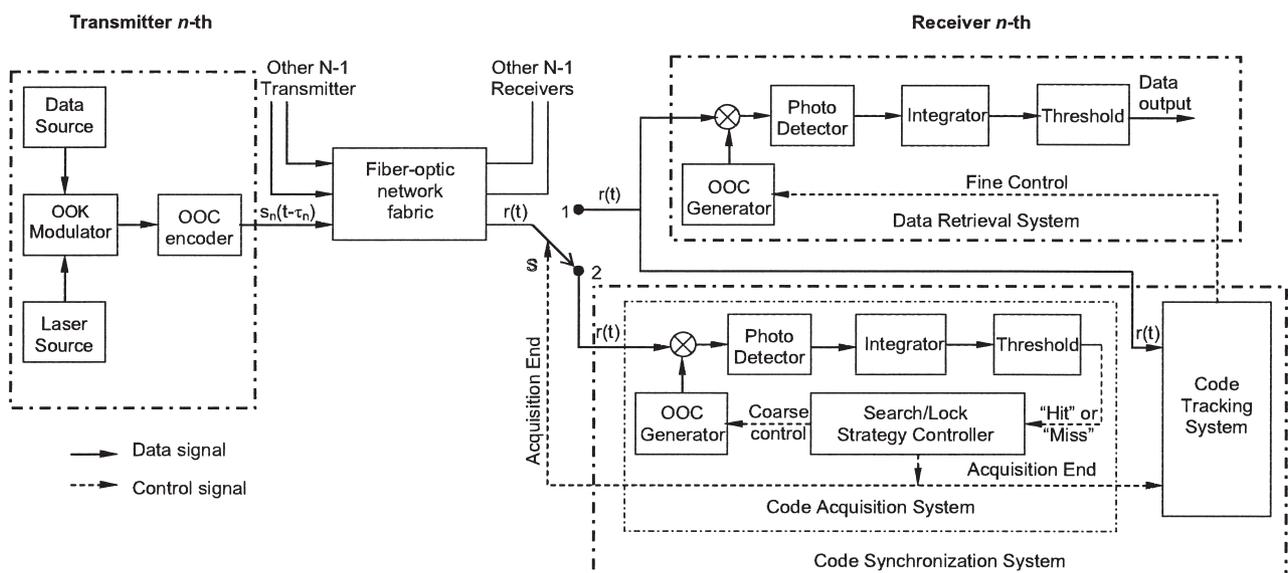


Fig. 1 Description of the O-CDMA system using OOK signaling with code synchronization.

the receiver's correlator could work accurately. In Fig. 1, the upper part of the receiver is the data retrieval system. Code synchronization system, which consists of code acquisition and code tracking, is at the lower part. Prior to the actual data transmission, switch \mathbb{S} is at position 2 to enable the code acquisition system. Once the coarse alignment is achieved by the code acquisition system, \mathbb{S} , initialized by *acquisition end* control signal from acquisition system, is switched to position 1. From here, code tracking system traces and maintains the best possible alignment by a closed loop operation.

Note that the user signal's delay τ_n can be decomposed of an integer number of chip durations $T_C = T/F$, and a residue $|\delta_n| \leq T_C$. Because we only consider the code acquisition system in this paper, it is assumed that the synchronization is achieved when the delay with a residue within a half code chip is found, hence $|\delta_n| \leq T_C/2$. Moreover, in order to simplify the mathematical analysis, we assume the chip synchronous case, which results in upper bound on the system performance [3], for all interfering users. As a result, all interfering users have delays with zero residues, i.e. $\delta_n = 0$ for interfering users.

2.2 Operation of MDSS Code Acquisition System

The operation of MDSS code acquisition system can be described as follows. First, a series of bit ones, called *training bits*, is sent by the transmitter to the receiver. The receiver has full, but delay, knowledge of the spreading code (OOC code) used by training bits. The correctness of OOC code phase can be tested using these training bits. In the serial search parlance, code phases are usually referred to as *cells*. The cell that results in the best coarse alignment is called the correct cell. When the serial search algorithm is employed for the acquisition system, cells are serially tested until the correct one is found.

To test a certain cell, the received signal is first correlated with the local replica of the desired signal's code at the OOC decoder. The correlated signal is converted into electrical signal by the photodetector then integrated over a bit duration T . Decision on the cell's correctness is made by comparing the integrated signal with a threshold. The decision could be a "hit" or "miss" when the integrated signal is higher or lower than the threshold, respectively.

Because the decision is not always reliable due to noise and interferences, a "hit" may turn out to be a "false alarm." In SDSS code acquisition system, no verification is employed. Instead, the acquisition system uses a fixed penalty period for any "false alarm" happens. In the MDSS code acquisition system however, verification scheme is employed to verify the decision of cell's correctness. In this paper, the SLS is used as verification algorithm. The operation by SLS is illustrated in Fig. 2. When there are two consecutive "hits" from the initial test, the SLS controller will enter the lock mode; and alternatively, any failure of comparison ("miss") will lead the SLS controller to dismiss that cell and continue search mode with the next cell, i.e. OOC generator

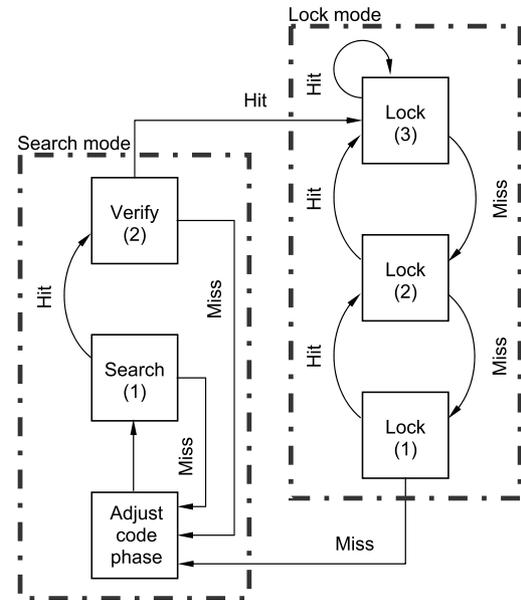


Fig. 2 SLS operation diagram.

adjusts to next cell. When the lock mode is achieved, the SLS controller maintains the attained coarse alignment for tracking system to trace for the fine alignment. From here, if there are three consecutive misses from lock mode, the SLS controller comes back the search mode with the next cell.

It is important to note that when the correct cell is observed, the output of the receiver's correlator at time T can be expressed as

$$\begin{aligned} Z_n &= \frac{1}{T_c} \int_0^T r(t)c_n(t - \delta_n)dt \\ &= K \left(1 - \frac{|\delta_n|}{T_c} \right) + I_n + W_n, \end{aligned} \quad (5)$$

where the first term represents desired signal, I_n and W_n represent MAI from interfering users and noise. Because $|\delta_n| \leq T_c/2$, from (5) we have $Z_n \geq K/2$, i.e. we can obtain at least $K/2$ chips at the correlator's output when the correct cell is observed.

3. Performance Analysis

In investigation of code acquisition systems, acquisition time, i.e. the time required to complete the acquisition operation, is the most important parameter. Especially in O-CDMA systems, because spreading sequences are usually exceedingly long, the task to locate the correct cell is thus very challenging. The excessive acquisition time results in a large overhead that is unacceptable in practical communications. As acquisition time is a random variable and difficult to quantify, its mean value is usually used instead.

We assume that the dwell times per tested cell in search and lock mode of SLS are the same, and equal to one bit time, i.e. dwell time = T . The mean acquisition time therefore can be represented by the number of training bits that

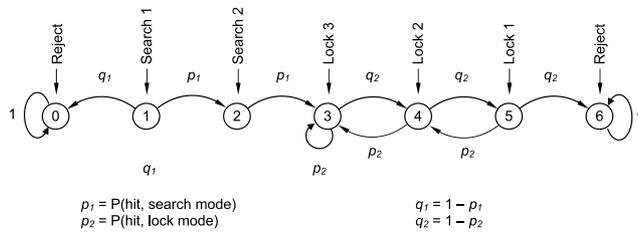


Fig. 3 Markov chain model of the proposed SLS.

receiver needs in order to perceive of the delay of its desired user. From this point, when time is mentioned, it is understood to be represented by equivalent number of bits.

There are two important parameters in the verification stage: probabilities of detection P_D and false alarm P_{FA} . Both of these parameters are involved with “hit” resulting from the threshold comparison. However, while P_D is probability of “hit” when the correct cell is observed, P_{FA} is probability of “hit” for an incorrect cell. Note that the values of P_D and P_{FA} depend on the distribution of interfering chip pulses at the tested cell and the desired user’s delay (τ_n), both of which are assumed to be random variables. The detail investigation of these two terms will be discussed later, in Sect. 3.2.

To derive the mean acquisition time, we use a finite Markov chain with absorbing boundaries as depicted in Fig. 3 to model the operation of the proposed SLS. In this figure, p_1 and p_2 are probabilities of “hit” in search and lock mode respectively. There are two absorbing states 0 and 6, i.e. the states where there is no exit. In the theory of Markov chain, the absorbing time is defined as the period (or number of bit) required to reach an absorbing state from any initial transient state. We apply this concept to our problems where the absorbing time can be interpreted as time to reject a cell or time to lose a lock depending upon the initial state and whether the correct cell is assumed. For example, the time to lose a lock is the absorbing time when initial state is state 3, and the correct cell is observed; in this example, the absorbing state is state 6.

Without loss of generality, we assume the probability of locating the correct cell at any cell to be the same and equal to $1/F$, with F is code length. The mean time to acquire the correct cell for the first time is hence $F\bar{n}_d/2$, where \bar{n}_d is mean dwell time for incorrect cells, i.e. mean time to dismiss incorrect cells. If the first detection is missed, $F\bar{n}_d$ bits are required to reach the correct cell, and so on. Therefore, the mean acquisition time, which is represented by the number of training bits \bar{N}_{ACQ} can be derived as

$$\begin{aligned} \bar{N}_{ACQ} &= \frac{F\bar{n}_d}{2} + F\bar{n}_d P_{L_1}(1 - P_{L_1}) \\ &\quad + 2F\bar{n}_d P_{L_2}(1 - P_{L_2})^2 + \dots \\ &= F\bar{n}_d \left[\frac{1}{2} + \sum_{j=1}^{\infty} j(1 - P_{L_j})^j P_{L_j} \right], \end{aligned} \quad (6)$$

where P_{L_j} is probability of entering lock at j th search attempt. Assuming the probability of detection P_{D_j} be con-

stant (i.e. time-invariant) during observation period, i.e. P_{D_j} is the same for all tests in an observation, P_{L_j} can be derived as

$$P_{L_j} = P_{D_j}^2. \quad (7)$$

3.1 Mean Dwell Time

The mean dwell time for an incorrect cell, denoted as \bar{n}_d is the mean number of training bits required to dismiss an incorrect cell. The mean dwell time is determined by identifying the event contributing to a dismissal of an incorrect cell starting in search state 1, and then assigning the appropriate dwell time and probability of occurrence to each of these events.

There are two types of dismissal events starting from state 1. First is the dismissal event without entering lock mode, i.e. dismissed at the first test or second test. In the Markov chain model, it is the event that initializes from state 1 and is rejected at state 0 without a transience to state 3. The second is the dismissal event that dismissed after entering lock mode, i.e. the event initializes from state 1, transits via state 3 then is rejected at state 6. There two types of dismissal events correspond to two portions of the mean dwell time, which are denoted as \bar{n}_{d1} and \bar{n}_{d2} , respectively. Using the theory of Markov chain, these two portions can be calculated with an assumption of time-invariant false alarm probability P_{FA} , as

$$\begin{aligned} \bar{n}_{d1} &= 1 - P_{FA} + 2P_{FA}(1 - P_{FA}) \\ &= 1 + P_{FA} - 2P_{FA}^2, \end{aligned} \quad (8)$$

$$\bar{n}_{d2} = (2 + n_p)P_{FA}^2, \quad (9)$$

where n_p is penalty bits of entering lock mode; n_p is determined by the number of bits required to go from state 3 to state 6 in the Markov model. Using Mason’s rule [16], we have

$$\bar{n}_p = \frac{3 - 4P_{FA} + 2P_{FA}^2}{(1 - P_{FA})^3}. \quad (10)$$

From (8), (9) and (10), the mean dwell time can be expressed in number of bits as follow.

$$\bar{n}_d = 1 + P_{FA} + \frac{3 - 4P_{FA} + 2P_{FA}^2}{(1 - P_{FA})^3} P_{FA}^2. \quad (11)$$

Finally, from (6) and (11), and after simplification we have the mean number of training bits can be expressed as.

$$\begin{aligned} \bar{N}_{ACQ} &= F \left[\frac{1}{2} + \sum_{j=1}^{\infty} j(1 - P_{L_j})^j P_{L_j} \right] \\ &\quad \times \left[\frac{1}{(1 - P_{FA})^3} - \frac{2}{(1 - P_{FA})^2} \right. \\ &\quad \left. + \frac{3}{1 - P_{FA}} - P_{FA} - 1 \right]. \end{aligned} \quad (12)$$

3.2 Probability of False Alarm and Detection

In this section, we calculate the probabilities of false alarm P_{FA} and detection P_D using photon counting technique [17]. The number of incoming photons is obtained by counting the released electrons at the output of photodetector. The electron count, which often referred to as photon count, can be modeled by a Poisson process. Denote m_v as the mean photon count, the photon count probability κ can be expressed as,

$$P_{OS}(\kappa, m_v) = \frac{m_v^\kappa e^{-m_v}}{\kappa!}. \quad (13)$$

The photon count over each integration period consists of electrons released by desired user's chips, interfering chips and dark current. According to (5), when the correct cell is observed, the desired user contributes at least $K/2$ chips, with OOC's code weight K . Assuming the equal transmission of bit "0" or "1" for each user, the number of interfering chips k can be expressed as a binomial variable

$$k|m \sim \binom{m}{1/2}, \quad (14)$$

where m is the number of available interfering chips that equivalent to the number of interfering users because the optimum OOC is used.

The probabilities of false alarm P_{FA} and detection P_D can be calculated based on the probability that the photon count is higher than a preset threshold for the observation of either an incorrect or the correct cell, respectively. Denoting Th as the detection threshold, P_{FA} and P_D with a given m can be derived as

$$(P_{FA}|m) = P_r(\kappa \geq Th|m) = \sum_{k=0}^m \binom{m}{k} \left(\frac{1}{2}\right)^m \times \sum_{\kappa=Th}^{\infty} e^{-(km_s+m_d)} \frac{(km_s+m_d)^\kappa}{\kappa!}, \quad (15)$$

$$(P_D|m) = P_r(\kappa \geq Th|m) = \sum_{k=0}^m \binom{m}{k} \left(\frac{1}{2}\right)^m \times \sum_{\kappa=Th}^{\infty} e^{-((k+\frac{K}{2})m_s+m_d)} \frac{((k+\frac{K}{2})m_s+m_d)^\kappa}{\kappa!}, \quad (16)$$

where κ is the probability of photon count with shot noise effect, m_s is mean photon count per chip, and m_d is mean number of electrons generated by dark current.

We note that m consists of interfering chips caused by cross-correlation with interfering users and/or chips from off-peak auto-correlation. We assume that users' delays are uniformly distributed over F code chip so that the probability of interference with cross-correlation is K^2/F . The probability of interference with off-peak auto-correlation is $(K^2 - K)/F$, because K chips of peak auto-correlation are not counted as interference. In order to simplify mathematical analysis, we approximate the probability of interference

with off-peak auto-correlation as K^2/F . This approximation does not affect much to the calculation result as $K \ll K^2$, and actually causes slightly worse system performance (i.e. upper bound). As a result, the variable that represents the number of interfering chips at a certain cell, m_i , can be expressed as a binomial

$$m_i \sim \binom{N}{K^2/F}. \quad (17)$$

As both P_{FA} and P_D are conditional on the number of interfering chips, which is also a random variable, we try to average \bar{N}_{ACQ} over m_i . To assume m_i s at tested cells (in any search attempt) mutually independent, the average value of \bar{N}_{ACQ} over m_i can be calculated based on its independent portions as follows,

$$\begin{aligned} E_{Ave}\{\bar{N}_{ACQ}\} &= F \left[\frac{1}{2} + E \left\{ \sum_{j=1}^{\infty} j(1 - P_{L_j})^j P_{L_j} \right\} \right] \\ &\times \left[E \left\{ \frac{1}{(1 - P_{FA})^3} \right\} - E \left\{ \frac{2}{(1 - P_{FA})^2} \right\} \right. \\ &\left. + E \left\{ \frac{3}{1 - P_{FA}} \right\} - E\{P_{FA}\} - 1 \right]. \end{aligned} \quad (18)$$

To calculate these portions of $E_{Ave}\{\bar{N}_{ACQ}\}$, we note that the mean of a random variable $y = g(x)$ with \mathbf{x} is a discrete random variable, which can be expressed as,

$$E\{g(x)\} = \sum_i g(x_i) P\{\mathbf{x} = x_i\}. \quad (19)$$

Applying Eq. (19) to the portions of $E_{Ave}\{\bar{N}_{ACQ}\}$ to average over m_i , after simplifying, we have

$$\begin{aligned} &E \left\{ \sum_{j=1}^{\infty} j(1 - P_{L_j})^j P_{L_j} \right\} \\ &= E_m \left\{ \sum_{j=1}^{\infty} j(1 - P_D^2)^j P_D^2 | m_j = m \right\} \\ &= \sum_{m=0}^N \binom{N}{m} \left(\frac{K^2}{F}\right)^m \left(1 - \frac{K^2}{F}\right)^{N-m} \left(\frac{1}{P_D^2} - 1\right), \end{aligned} \quad (20)$$

$$\begin{aligned} &E \left\{ \frac{1}{(1 - P_{FA})^z} \right\} \\ &= E_m \left\{ \frac{1}{(1 - P_{FA})^z} | m_i = m \right\} \\ &= \sum_{m=0}^N \binom{N}{m} \left(\frac{K^2}{F}\right)^m \left(1 - \frac{K^2}{F}\right)^{N-m} \frac{1}{(1 - P_{FA})^z}, \end{aligned} \quad (21)$$

and,

$$\begin{aligned}
 E\{P_{FA}\} &= E_m\{P_{FA}|m_i = m\} \\
 &= \sum_{m=0}^N \left[\binom{N}{m} \left(\frac{K^2}{2F}\right)^m \left(1 - \frac{K^2}{2F}\right)^{N-m} \right. \\
 &\quad \left. \times \sum_{n=Th}^{\infty} e^{-(mm_s+m_d)} \frac{(mm_s+m_d)^n}{n!} \right]. \tag{22}
 \end{aligned}$$

Here the simplification of (22) was proved in [12]. Substituting (20), (21) and (22) to (18), with $z = 1, 2$ and 3 , the mean number of training bits averaging over m_i is given.

4. Numerical Results

In this section, we discuss the analytical results obtained in the previous sections. Effect of some parameters to the proposed acquisition system performance is investigated. Furthermore, we also show the improvements of acquisition system using serial search with SLS (MDSS scheme) for O-CDMA systems over the SDSS scheme proposed in [12].

First, Figs. 4–6 show the mean number of training bits

versus normalized threshold defined as

$$Th_N = \frac{Th - m_d}{Km_s}. \tag{23}$$

In these figures, the mean number of training bits are evaluated against different values of dark current m_d , mean photon count per chip m_s and code weight K . The corresponding results of SDSS system are also shown. System parameters of both schemes are set as: $F = 2000, K = 9, N = 25$. For the SDSS system, the number of false alarm penalty bits, denoted as L , is fixed and set to 20, same as [12]. In the SDSS system, this number of penalty bits should be large enough to cover the worst situation, e.g. when there is a very high probability of false alarm.

It is seen in these figures that the mean number of training bits is lower limited by about half code length. This is due to the nature of serial search algorithm. It is said that the optimum operation is achieved when the mean number of training bits requires reaches this limit.

As shown, the mean number of training bits required in the proposed system is fewer than that of the SDSS system. Moreover, the range of threshold that allows optimum performance is much wider in case of with SLS considering all parameter values. This is a reasonable outcome because the SDSS scheme uses a fixed observation, which must be long enough to cover the worst situation, e.g. when the false alarm is very high. The proposed system however allows examination interval needed not be fixed but variable depending upon probability of false alarm hence can quickly discard the incorrect cell and return the system back to the search operation.

Actually, the optimum normalized threshold, i.e. the normalized threshold corresponding to optimum operation, of SDSS system is around 0.35 to 0.45, i.e. the threshold can be selected between $0.35Km_s + m_d$ and $0.45Km_s + m_d$, and system performance will be severely degraded outside this range [12]. On the other hand, the proposed system allows normalized threshold be selected from 0.15 to 0.45, which is about 200 percents wider. This improvement re-

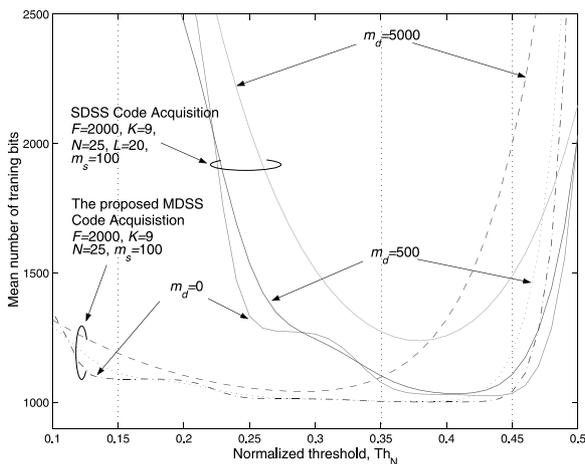


Fig. 4 Mean number of training bits vs. normalized threshold for different m_d .

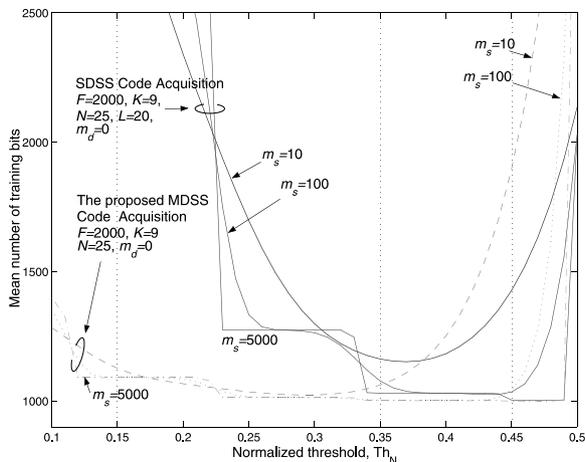


Fig. 5 Mean number of training bits vs. normalized threshold for different m_s .

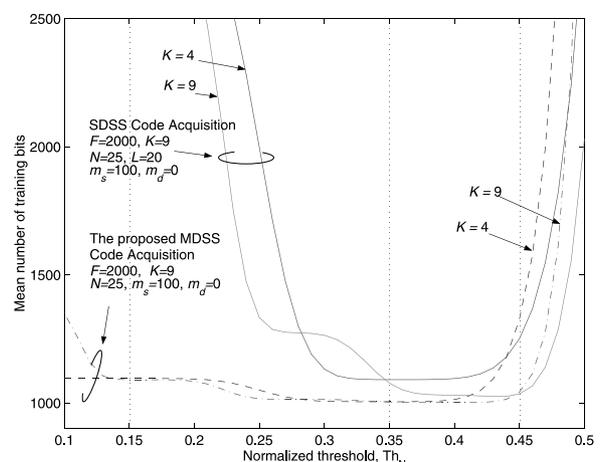


Fig. 6 Mean number of training bits vs. normalized threshold for different K .

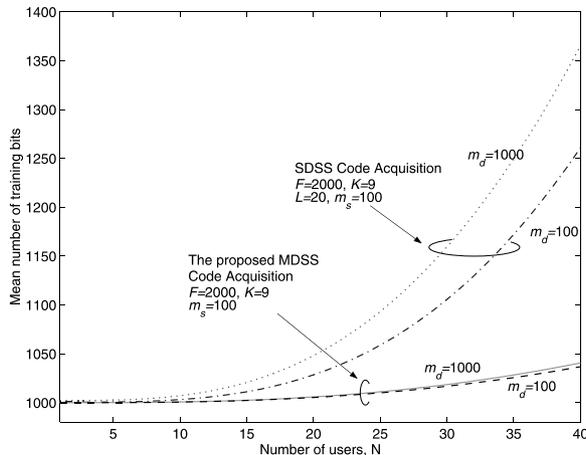


Fig. 7 Mean number of training bits vs. number of user (with optimum threshold).

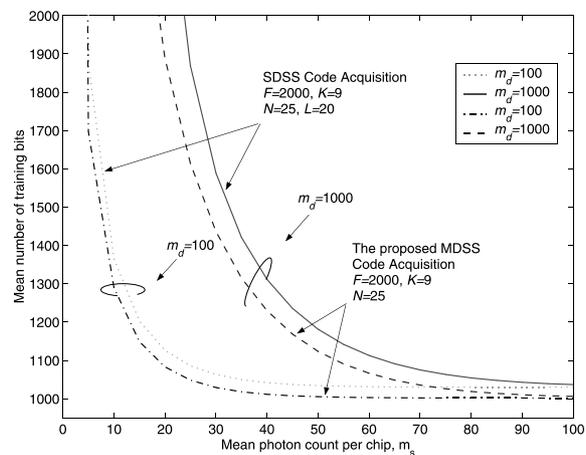


Fig. 8 Mean number of training bits vs. mean photon counts per chip (optimum threshold).

sults much more flexible system parameter settings than the conventional SDSS system.

Next, the effect of the number of users to system performance is shown in Fig. 7. The system parameters of both schemes are also the same for the comparison, $F = 2000$, $K = 9$, $N = 25$. Mean photon count per chip m_s is 100 and dark current is set to be 100 and 1000. An optimum normalized threshold is used. In Fig. 7, a significant improvement of the proposed system can be seen, especially when the number of simultaneous user increases. As a matter of fact, when the number of user in the system increases from 1 to 40, the system performance is severely degraded in SDSS system. As shown in Fig. 7, there is a considerable improvement in the proposed system in terms of mean number of training bits. Even when the number of users changes from 1 to 40 users, the mean number of training bits increases less than 5 percents in comparison with 25-35 percents in the SDSS system.

Finally, we evaluate the effect of mean photon counts per chip to the system performance in Fig. 8. It is shown

that, similar to SDSS scheme, system performance is improved when there is higher photon counts per chip arrived. The required photon count to reach the optimum performance is similar in both systems. However, with the same settings, the optimum performance of the proposed system is better than that of SDSS system. As shown in Fig. 8, the optimum performance of the proposed system is about 4 percents better than that of the SDSS system.

5. Conclusion

We have proposed the MDSS code acquisition system for O-CDMA systems. Search/lock strategy is used as the verification scheme for the proposed MDSS system. Theoretical analysis is carried out taking into account MAI, shot noise and dark current. By evaluating various system parameters, such as threshold, number of users, dark current and mean photon counts per chip, it is seen that the proposed system outperforms the conventional SDSS system. In fact, the proposed system offers a 200 percents wider range of optimum threshold, which can alleviate the system performance's sensitivity to threshold. Moreover, the proposed system can maintain a more stable performance when the number of users increases. Finally, the proposed system requires less number of training bits to achieve the acquisition state than that of the conventional SDSS system.

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