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The Analysis of DS-CDMA Receiver with Code Tracking in Phase Unknown Environments by using new non-coherent MMSE (Minimum mean-square error)

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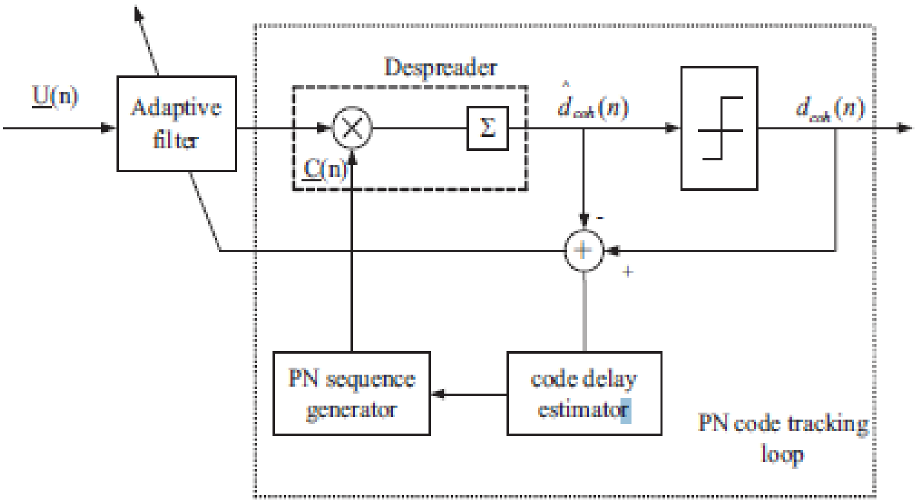
***Abstract*— In this paper, we propose and analyse a new non coherent receiver with PN code tracking for direct sequence code division multiple access (DS-CDMA) communication systems in multipath channels. We employ the decision-feedback differential detection method to detect MDPSK signals. An "; error signal"; is used to update the tap weights and the estimated code delay. Increasing the number of feedback symbols can improve the performance of the proposed non coherent receiver. For an infinite number of feedback symbols, the optimum weight can be derived analytically, and the performance of the proposed non coherent receiver approaches to that of the conventional coherent receiver. Simulations show good agreement with the theoretical derivation.**

***Keywords*— CDMA, non coherent minimum mean-square error (MMSE), decision-feedback differential detection.**

I. Introduction

Spread-spectrum communication needs to synchronize the spreading waveforms in transmitting and receiving ends. If the two waveforms are out of synchronization by a little chip time, insufficient signal energy will reach the receiver, the performance of data demodulation is thus degraded. Synchronizing the DS-SS system includes a two step procedure, code acquisition and code tracking. Although code acquisition is an important problem, the development of some techniques for accurate code tracking plays an equally important role in supporting the acquisition process once the code has been acquired. In [1]-[4], some adaptive code tracking techniques were proposed. In [1], the authors have proposed the scheme that performed both acquisition and tracking with the same circuitry, therefore a significant simplification in the overall DS-SS receiver structure is gained. In [2], an FIR adaptive filter that mitigates the effect of multipath on delay estimation was utilized. The tap weight vector of this adaptive filter can be used to provide accurate estimation of the multipath delays. Hosemann *et al.* [3] presented a new tracking scheme for handling multiple access interference (MAI) effect without the requirement of a pilot channel or training symbols. In [4], a coherent timing error detector embedded in a code tracking loop for Rake reception was presented. Its filter coefficients are computed online in order to minimize an interference cost function.

PN code tracking



Loop

Fig 1: The conventional coherent receiver - joint detection and PN code tracking.

Effects are not considered simultaneously this paper deals with tracking issue and assumes successful initial acquisition before tracking process. Therefore, the received signal has only a small timing offset (1/2 chip duration) from the correct timing. In this paper, we refer to the adaptive Pseudo-Noise (PN) code tracking scheme proposed in [5][6] with well-known coherent detection as conventional coherent (closed-loop time-delay estimation) receiver. The conventional coherent receiver deals with data detection and PN code timing recovery jointly is described in Fig. 1. PN code tracking can be categorized into coherent and non coherent loops. When the demodulation is coherent, a coherent carrier reference must be generated prior to demodulation. The generation of coherent reference at low signal-to-noise ratio is difficult. This difficulty is from the fact that any communication system must convey information from transmitter to the receiver. This implies that the carrier is in some way modulated with this information. In contrast to coherent case, the non coherent detection is less complex and more robust\ against carrier phase variations. Sehier *et al.* [7] proposed to combine a linear equalizer with conventional differential detection, whereas Masoomzadeh-Fard *et al.* [8] considered decision-feedback equalizer with conventional differential detection. All of those schemes suffer from a significant loss in power efficiency compared to coherent case. Schober *et al.* [9] proposed the non coherent minimum mean-square error (MMSE) receiver for DS-CDMA in a non dispersive channel. The receiver is related to the non coherent linear MMSE equalizer reported in [10], i.e., the first stage of the receiver is a linear filter for interference suppression and the second stage is a decision-feedback differential detector. The receiver uses a certain observation window to generate a non coherent decision variable. Varying the size of this observation window

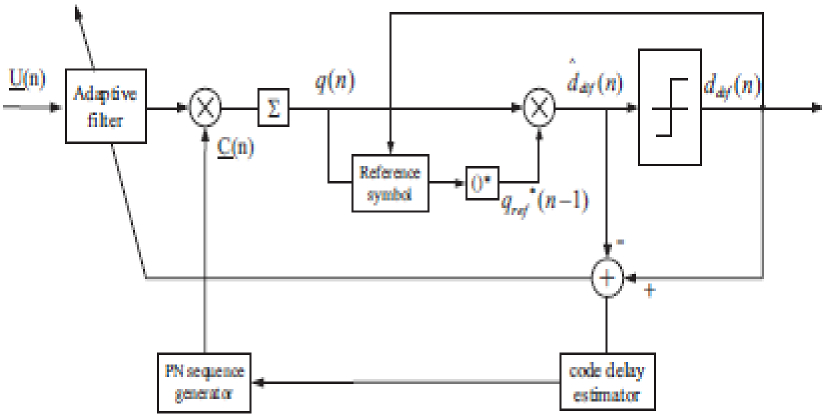


Fig 2: The proposed non coherent differential detection receiver with PN code tracking.

Can provide gain in the power efficiency. For this reason, we apply the decision-feedback differential detection method in our proposed non coherent receiver that is described in Fig. 2. This non coherent detection requires the differential encoding in the transmitter and the reference symbol is needed for decoding in the receiver. In chip-level differential encoding/detection techniques for DS-SS signal to cope with frequency-nonselective fast fading channels were proposed. Also, the decision feedback differential detection for DS-CDMA with multi-chip differential encoding was proposed to enable a large performance gain. Because the computational loading for chip-level differential detection is heavy in both encoding and decoding, we select the symbol level differential encoding as in [9]. In [9], the taps of the adaptive filter act as a despreader for code adjustment without considering a multipath channel, so the length of the adaptive filter is the same as code length. For our structure, the filter taps are used to estimate a set of chip signals at one symbol time. In other words, [9] is the symbol-level signal estimation algorithm, while our proposed scheme is the chip-level signal estimation algorithm. In our proposed receiver, the adaptive Filter is used to estimate the desired signal and suppress the multipath and MAI effects based on the received signals. Simultaneously, we use the LMS algorithm to estimate the code delay through the same error signal. In addition to above process, the non coherent receiver employs the decision feedback differential detection to recover the MDPSK signal. This paper is organized as follows. In section II, we first describe the DS-CDMA multiuser communication system model. The conventional coherent receiver with PN code tracking is given in section III. In Section IV, the proposed non coherent receiver with PN code

II. THE PROPOSED NONCOHERENT RECEIVER

Fig. 2 shows the block diagram of the proposed noncoherent receiver that combines the differential detection with PN code tracking for DS-CDMA systems. The i.e. information sequence *{ak (n)}* is first differentially encoded. The resulting MDPSK symbols *bk* (*n*) are given by

$$b_k(n) = a_k(n)b_k(n-1) \qquad (13)$$

And the transmitted signal model is the same as (1). The received sample sequence *{ri}* is also expressed as (2). Here, the constant phase shift Θ is unknown. At the receiver, the sampled signals are first passed through the transversal filter and then despreaded by the local PN sequence. The tap weight vector *W*(*n*), local PN code vector *C*(*n*), and the received sample matrix *U*(*n*) can be described as equations (3), (4), and (5), respectively. The normalized despreader output *q*(*n*) is the same as (7), and can be represented as *q*(*n*) = *WH*(*n*)*U*(*n*)*C*(*n*)*/β.* In the next stage, the differential detection is necessary to recover the MDPSK information sequence. The decision variable *ddif* (*n*) is obtained by noncoherent processing of the despreader output *q* (*n*), *ddif* (*n*) = *q* (*n*) *q∗ref* (*n* − 1) where the reference symbol *qref* (*n* − 1) is generated as follows

$$q_{ref}(n-1) = \frac{1}{N-1}\sum_{l=1}^{N-1} q(n-l)\prod_{m=1}^{l-1} d_{dif}(n-m) \quad (14)$$

Where *N*, *N* ≥ 2, is the number of despreader output symbols used to calculate *ddif* (*n*). *ddif* (*n*) is the hard decision result of *ddif* (*n*). Note that for *N* = 2, *qref* (*n* − 1) = *q*(*n* − 1), *ddif* (*n*) is the decision variable of a conventional differential detection. However, for *N* > 2, a significant performance improvement can be obtained. We can use the cost function

$$J_{dif} = E\left[\left|d_{dif}(n) - \hat{d}_{dif}(n)\right|^2\right].$$

The error signal can be defined as *edif* (*n*) *def* = *ddif* (*n*) − ˆ *ddif* (*n*). Here, *edif* (*n*) at the *n*-th symbol time also depends on past tap weight vectors *W* (*n*−*v*)*, v* ≥ 1. For the derivation of the adaptive algorithm, these past tap weight vectors are treated as constants since *|edif* (*n*) |2 is differentiated only with respect to *W* (*n*). The cost function of differential detection *Jdif* can be written as

$$\begin{aligned} J_{dif} = E[&d_{dif}(n)d^*_{dif}(n) \quad (15)\\ &-d_{dif}(n)\frac{q_{ref}(n-1)}{\beta}\underline{C}^T(n)\underline{U}^H(n)\underline{W}(n)\\ &-d^*_{dif}(n)\frac{q^*_{ref}(n-1)}{\beta}\underline{W}^H(n)\underline{U}(n)\underline{C}(n)\\ &+\frac{|q_{ref}(n-1)|^2}{\beta^2}\underline{W}^H(n)\underline{U}(n)\underline{C}(n)\underline{C}^T(n)\underline{U}^H(n)\underline{W}(n)] \end{aligned}$$

The gradient of the cost function with respect to the tap weight vector is

$$\begin{aligned} \frac{\partial J_{dif}}{\partial \underline{W}} &= -\frac{2}{\beta}q^*_{ref}(n-1)d^*_{dif}(n)\underline{U}(n)\underline{C}(n)\\ &+ \frac{2}{\beta^2}\left|q_{ref}(n-1)\right|^2\underline{U}(n)\underline{C}(n)\underline{C}^T(n)\underline{U}^H(n)\underline{W}(n)\\ &= -\frac{2}{\beta}q^*_{ref}(n-1)e^*_{dif}(n)\underline{U}(n)\underline{C}(n) \quad (16) \end{aligned}$$

And the gradient of the cost function with respect to the code delay is

$$\begin{aligned} \frac{\partial J_{dif}}{\partial \tau} &= -d_{dif}(n)\frac{q_{ref}(n-1)}{\beta}\frac{\partial \underline{C}^T(n)}{\partial \tau}\underline{U}^H(n)\underline{W}(n)\\ &\quad -d^*_{dif}(n)\frac{q^*_{ref}(n-1)}{\beta}\underline{W}^H(n)\underline{U}(n)\frac{\partial \underline{C}(n)}{\partial \tau}\\ &+\frac{|q_{ref}(n-1)|^2}{\beta^2}\underline{W}^H(n)\underline{U}(n)\\ &\times\left(\frac{\partial \underline{C}(n)}{\partial \tau}\underline{C}^T(n) + \underline{C}(n)\frac{\partial \underline{C}^T(n)}{\partial \tau}\right)\underline{U}^H(n)\underline{W}(n) \quad (17) \end{aligned}$$

The gradient vector ∂*C*(*n*) ∂*τ* is the same as (10). The tap weight of the noncoherent adaptive filter is updated by

$$\underline{W}(n+1) = \underline{W}(n) + \mu\left[\frac{2}{\beta}q^*_{ref}(n-1)e^*_{dif}(n)\underline{U}(n)\underline{C}(n)\right] \quad (18)$$

and the code delay τ is updated by $\tau(n+1) = \tau(n) - \lambda\frac{\partial J_{dif}}{\partial \tau}$.

III. Simulation Results

From the above discussion, we know that the selection of the chip waveform and the sample number *D* are the factors to control the performance of the system. The effect of the gradient of chip waveform about the code delay in on the performance of the system can be large. However, as the dependence of the system performance on the chip waveform is usually very complicated, it is generally difficult to evaluate this effect. Therefore, we use simulation to compare the effectiveness of different chip waveforms. In this section, the following time-limited chip waveforms are considered:

1) Raised-Cosine (rct) :

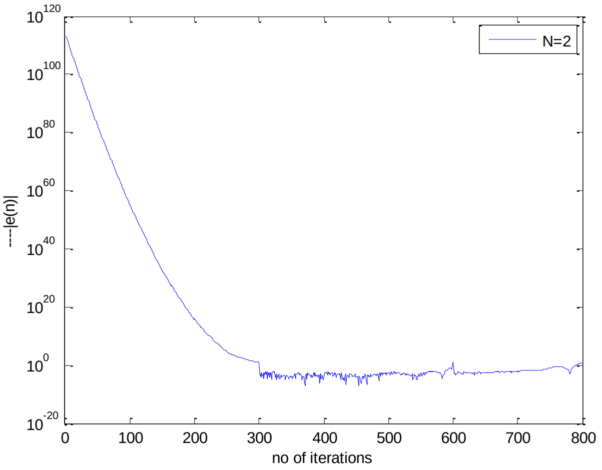
$$\Psi(t) = \sqrt{\frac{2}{3}}\,[1 - \cos(2\pi t/T_c)]\,\zeta_c(t)$$

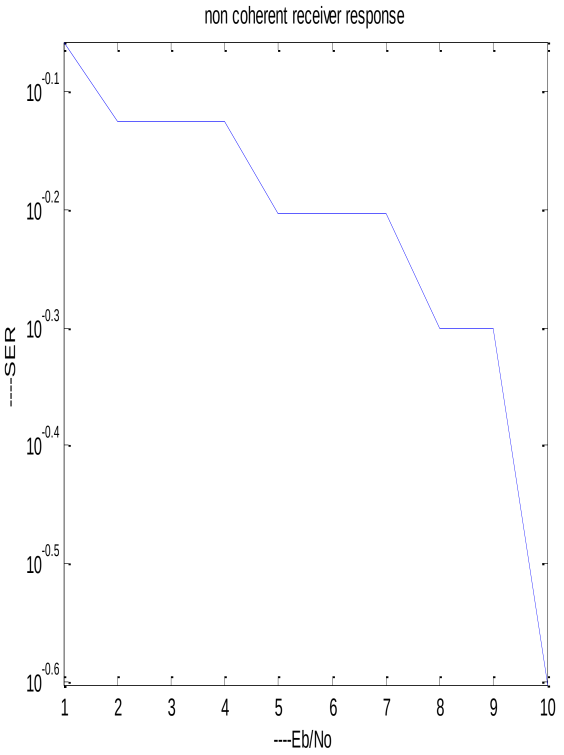
2) Blackman (bm):

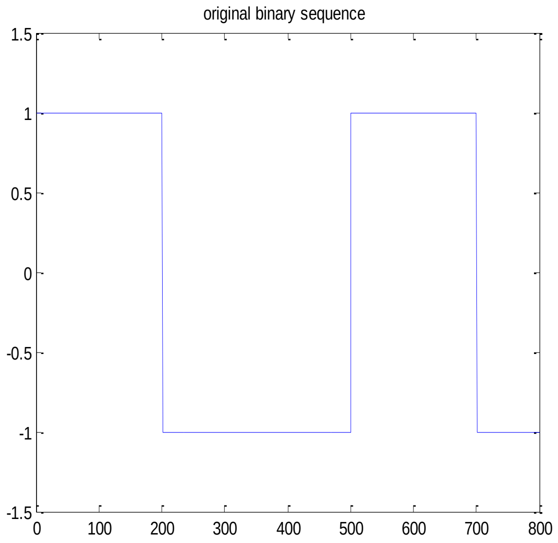
$$\Psi(t) = \epsilon\,[\varepsilon_1 - \varepsilon_2\cos(2\pi t/T_c) + \varepsilon_3\cos(4\pi t/T_c)]\,\zeta_c(t)$$

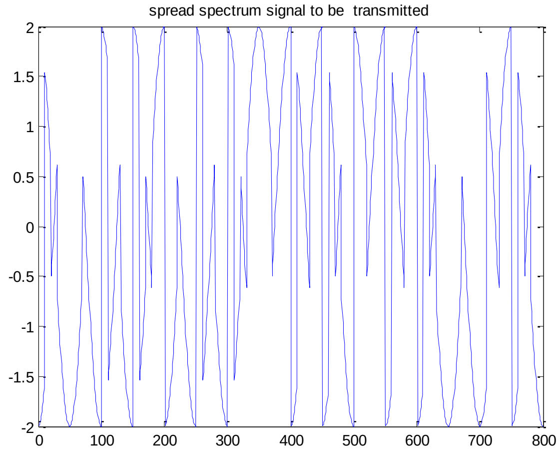
where $\epsilon^2 = (\varepsilon_1^2 + \varepsilon_2^2/2 + \varepsilon_3^2/2)^{-1}$ and $\varepsilon_1 = 0.42$, $\varepsilon_2 = 0.5$, and $\varepsilon_3 = 0.08$

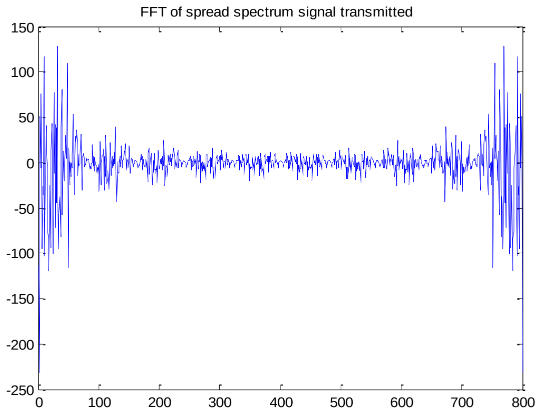
Results

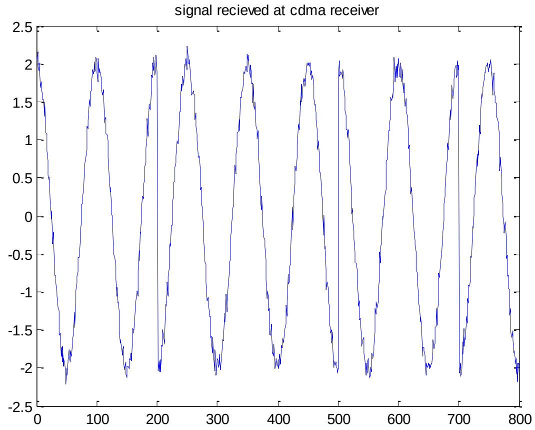


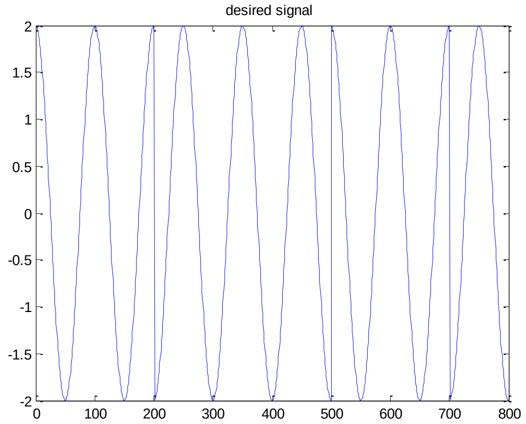

non coherent receiver response

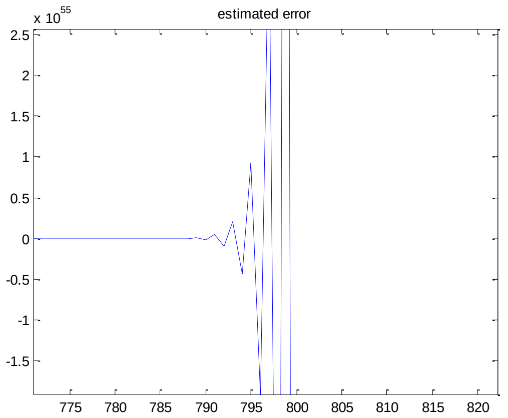

original binary sequence

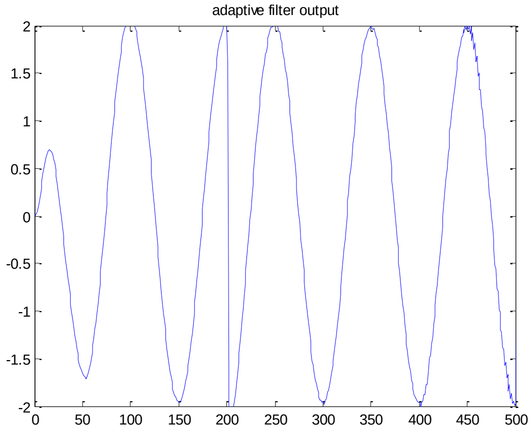

spread spectrum signal to be transmitted

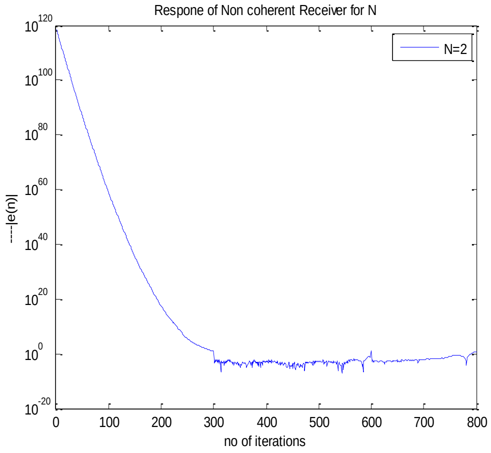

FFT of spread spectrum signal transmitted

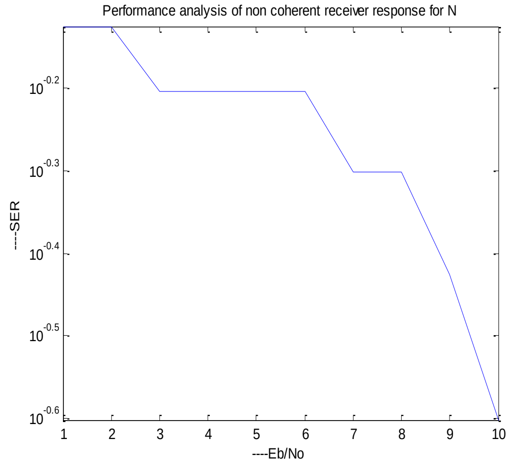

signal recieved at cdma receiver


desired signal


estimated error


adaptive filter output


Respone of Non coherent Receiver for N


Performance analysis of non coherent receiver response for N

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IV. CONCLUSION:

A novel non coherent receiver for joint timing recovery and data detection in DS-CDMA systems is proposed in this work. It estimates the desired signal and code delay by LMS algorithm at the same time. The MMSE solution of the proposed receiver is analysed theoretically and by computer simulations. Three different chip waveforms are simulated in two different multipath channels with different numbers of active users. It is shown that the timing offset can be rapidly tracked even if the mismatch is up to half chip time interval. The loss of non coherent detection compared with conventional coherent detection is limited and can be adjusted via the generation of the reference symbol for the decision-feedback differential detection. The performance of the non coherent receiver can approach the performance of the conventional coherent receiver if an infinite number of feedback symbols is used, as has been shown analytically. Furthermore, simulations show that the proposed receiver in an asynchronous situation approaches the performance as that of the receivers with perfect synchronization.

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