

A Robust PN Length Estimation in Down link Low- SNR DS-CDMA Multipath Channels

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Abstract— In this paper an efficient method is proposed for blind detection of multiuser spread spectrum signal and pseudo noise (PN) length estimation in downlink scenario. This method is based on fluctuating observation of second order statistic (SOS) estimator of received signal; estimating length of spreading code with no need to primary information based on observing second order peaks of correlation estimator is presented. In low SNR, the fading multipath phenomenon especially in length of small codes leads to problem in detecting place of correlation estimator peaks. In this paper besides expanding blind estimation to multiuser environment, by using searching method in updating the length of correlation window coordinated with length of spreading code and also choosing proper adaptive algorithmic thresholds for smoothing this difficulty is presented. In practice, like computing the number of users and estimating code of every user, knowing the length of code is required. Simulation results focus on efficiency of algorithm in detection and exact estimation of spreading code length in low SNRs and multipath environment.

Index Terms—DS-CDMA, PN code, Blind Detection, Autocorrelation Matrix, Second Order Statistic estimator,

I. INTRODUCTION

It is about six decades that spread spectrum transmission is investigated. Recently this transmission is used in military systems more than other fields because of its important feature: low probability of interception. In recent years, non-military systems exploit spread spectrum which enables them to share same frequency bandwidth with low interference probability.

Since in spread spectrum techniques, signal of data is distributed on a considerable wider bandwidth, it may bury in noise [2].

In case of interception or while receiver does not have primary information about transmitter, at first receiver has to estimate PN sequence then this estimated PN sequence will

be exploited to minimize multi access interference (MAI).

One type of spread spectrum systems is direct sequence that is used more than others because of simplicity of its transmitter/ receiver and its ability to face interception.

In this paper we propose a novel method for estimation the length of PN code which is one of the most important parameter of DS-Spread Spectrum signal. The importance of this detection appears in case of using DS-SS in multi user system such as CDMA (Code division Multiple Access). In these systems, especially in case of interception or blind detection, receiver does not know any information about PN sequence to omit Multi Access Interference (MAI) and estimate signal of favorite user.

There were few works on estimating the code length in DS-CDMA. In [2], a method is proposed to detect and estimate the length of PN code in case of existing BPSK-DS-SS signal.

In [3], the proposed method has been used to detect PN code period in DS-SS signal which has been modulated by residual carrier and transferred in dynamic environment. The proposed method uses power spectral density. Obviously, this method has more computational complexity because of using FFT/IFFT transforms.

In [5], a method is represented that is based on considering fluctuation of autocorrelation function of received signal by use of two different thresholds. Both of the defined thresholds in [5], are chosen as a fixed value which mainly depends on the length of data observation window. If the length of data observation window is not chosen appropriately, computation of these two thresholds will be so complicated.

In [6], a method has been presented to estimate PN code. Proposed method uses n -bit windows of received data and then calculates autocorrelation of any window with second possible PN code and chooses the PN code which causes maximum output of correlation function. It is clear that this method has very high computational complexity.

In [4], Nsiala Nzeza and co-authors proposed a method to detect multiuser and multi rate CDMA signal and estimate code duration.

The optimal detector of PN code is known as the maximum

likelihood sequence estimator [1]. This estimator has good performance with cost of computational complexity. This culminates in considering linear detectors which have acceptable performance and lower computational complexity. Among all linear detectors, blind methods are often suitable for bandwidth- constrained system. It is very important that a detector has this ability to track channel deviation in a reasonable time. Second order blind estimator is a linear detector that can converge in different channel conditions. According to this purpose, many of previous works have considered performance evaluation of correlation estimator. The Proposed method is based on correlation estimator in which length of window that correlation has been calculated in it, is chosen in novel adoptive algorithm.

This paper is organized as follow. In Section II, we describe the mathematical model of the system, Section III contains our theoretical basis on which the proposed method relies. In Section IV, performance of the proposed method is evaluated by simulation, and Section V concludes the paper.

II. MATHEMATICAL MODEL

A. Notations

The notation employed in this paper is standard. The operators $(\cdot)^T$ and $(\cdot)^H$ denote transpose and hermitian operations, respectively

B. System Model

In a DS-CDMA system, the waveform received by a given terminal consists of superimposed data modulated signals in the ambient channel noise. Without loss of generality, we use the baseband signal model,

$$y_c(t) = s_c(t) + w_c(t), \quad -\infty < t < \infty, \quad (1)$$

where $s_c(t)$ contains the useful signals, and $w_c(t)$ is the additive white gaussian noise. Consider a P -user system with a data frame size of M symbols. In most studies on DS-CDMA systems, the continuous-time transmitted signal¹ $s_c(t)$ is modeled as the product of two waveforms for each user. Finally, the summation of P signals arrives at the receiver, as in the following:

$$s_c(t) = \sum_{i=1}^P d_{c_i}(t) \tilde{c}_{c_i}(t), \quad (2)$$

where $d_{c_i}(t)$ is the information bearing signal of users i before spreading of user i , and $\tilde{c}_{c_i}(t)$ is the spreading code waveform of user i that has typically a very larger bandwidth than $d_{c_i}(t)$.

Despite its simplicity, this formulation does not reveal the multi-rate nature of the spreading operation and does not lend itself to the derivation of convenient discrete-time

models. Since the spreading procedure is typically performed in discrete-time, it will be useful in the following to describe it as a multi-rate convolution. Let $c_i(k)$, $k = 0, 1, \dots, N_c - 1$ be the i -th user's spreading code chip sequence of length N_c , and suppose that the information sequence $d_i(k)$ modulate $c_i(k)$ with a spreading factor of N_c chips per information symbol. Then, the transmitted discrete-time signal at the chip rate is:

$$s(n) = \sum_{k=-\infty}^{\infty} \sum_{i=1}^P d_i(k) c_i(n - kN_c), \quad (3)$$

where $d_i(k)$ is oversampled by N_c and filtered by $c_i(k)$. This discrete-time model isolates the spectral spreading operation from the details of modulation and transmission of the chip sequence $s(n)$.

The signal $d_{c_i}(t) \tilde{c}_{c_i}(t)$ is transmitted through a possibly dispersive channel at a chip rate $1/T_c$. Let $h_{c_i}(t)$ denote the i -th user's complex baseband representation of the overall impulse response of the channel which includes multipath effects along with the transmitter and the receiver spectral shaping filters. The received signal at the receiver is:

$$y_c(t) = \sum_{n=-\infty}^{\infty} \sum_{i=1}^P s(n) h_{c_i}(t - nT_c - \tau) + w_c(t) \quad (4)$$

where τ is the propagation delay and $w(t)$ is additive white Gaussian noise. Substituting $s(n)$ from (3) to (4), we obtain:

$$y_c(t) = \sum_{n=-\infty}^{\infty} \sum_{i=1}^P d_i(n) g_{c_i}(t - nN_cT_c - \tau) + w_c(t) \quad (5)$$

$$g_{c_i}(t) \triangleq \sum_{n=0}^{N_c-1} c_i(n) h_{c_i}(t - nT_c - \tau), \quad (6)$$

where $g_{c_i}(t)$ is the combined impulse response of the channel and the spreading code of the i -th user. If the received signal is sampled at the chip rate (every T_c second), then the discrete-time received signal is:

$$y(n) = y_c(t) \Big|_{t=nT_c} = \sum_{k=-\infty}^{\infty} \sum_{i=1}^P d_i(k) g_i(n - kN_c - \tau) + w(n), \quad (7)$$

where $g_i(k) \triangleq g_{c_i}(kT_c)$ is the i -th user's sampled overall impulse response, and $w(n) \triangleq w_c(nT_c)$. In addition, from (6) the i -th user's sampled overall impulse response is computed as in the following:

$$g_i(k) = \sum_{n=0}^{N_c-1} c_i(n) h_i(k - n) = c_i(k) * h_i(k) \quad (8)$$

where $*$ denotes the convolution operation. By defining the following vectors:

¹ Subscript c is used to denote continuous time signals, and index t denotes continuous-time.

$$\bar{g}(n) \triangleq [g_1(n), g_2(n), \dots, g_p(n)]^T, \quad (9)$$

$$\bar{d}(n) \triangleq [d_1(n), d_2(n), \dots, d_p(n)]^T, \quad (10)$$

assuming users are asynchronous, we are able to neglect τ and we can consider $y(n)$ as in the following form:

$$y(n) = \sum_{k=-\infty}^{+\infty} \bar{d}^T(k) \bar{g}_i(n - kN_c) + w(n) \quad (11)$$

III. CODE LENGTH ESTIMATION

C. Fluctuating of second order statistic estimator

As mentioned before, spread spectrum systems can be modelled by a cyclo-stationary signal. This is due to the fact that PN code pattern is repeated in each of its periods and also its mean and variance also have periodic structures. By considering this fact, we can calculate the code length while using second order moment of the correlation estimator. Meanwhile, statistical properties of the spreading code are periodic due to periodic nature of PN codes. Considering independent signal and noise sources as well as independent noise samples, second-order statistics of the received data is achieved by computing the autocorrelation matrix of $y(n)$ as in the following:

$$\begin{aligned} \mathcal{R}_y &= E \{ y(n) y^H(n) \} = \\ &\bar{g}(n) E \{ \bar{d}(n) \bar{d}^H(n) \} \bar{g}(n)^H + \sigma_w^2 I \end{aligned} \quad (12)$$

where $E(\cdot)$ is the mathematical expectation or statistical average. As it is clear, computing mathematical expectation of data is not possible practically, but we can use time averages instead. Therefore, the second-order statistics estimator of the received data is computed as in the following:

$$\hat{\mathcal{R}}_y^n(m) = \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{n=0}^{N-1} y(n) y(n-m)^H \quad (13)$$

where N is the number of observations or observation window length. In (12), n is the number of window. The mean of autocorrelation function of M data observation window can be considered as fluctuating of second order statistic estimator:

$$\rho(m) = E \left\{ \left| \hat{\mathcal{R}}_y^n(m) \right|^2 \right\} = \frac{1}{M} \sum_{n=0}^{M-1} \left| \hat{\mathcal{R}}_y^n(m) \right|^2 \quad (14)$$

$\rho(m)$ is a measure of the fluctuations of $\hat{\mathcal{R}}_y^n(m)$. We are illustrated simulation of fluctuating of second order statistic estimator ($\rho(m)$) for DS-CDMA System with 4users in AWGN Channel (code length=31chip) in figure1. These statistical properties can be simply exploited by observing the periodic peaks of fluctuations of the autocorrelation function. But practice, these peaks cannot be easily detected,

especially in multiuser scenarios, because of large number of users as well as the presence of the multipath and channel fading effects (in low SNRs) which will lead to the degradation of the performance of such estimators. Fig. 2 shows the problem of detecting the signal properties in the presence of multipath fading versus the detection in AWGN channel for SNR = -5 dB (with compare Fig.1 and 2).

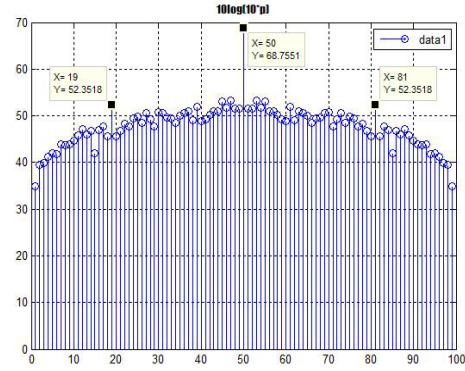


Fig. 1: Fluctuating autocorrelation function Output for DS-CDMA System with 4users in AWGN Channel (code length=31chip) Above results are represented for $N_c = 31$ (code length), $N = 50$ (window size).

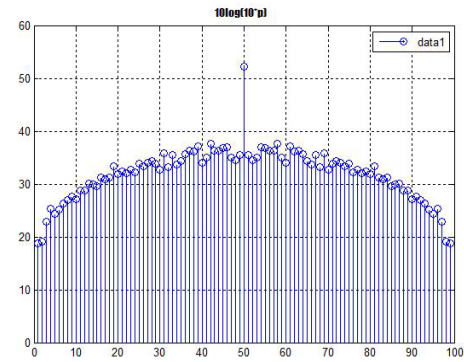


Fig. 2: Fluctuating autocorrelation function Output for DS-CDMA System with 4users in Rayleigh Channel (code length=31chip)

D. Proposed approach for the mentioned problem

Since the noise and the signal are centered and uncorrelated, we can write (13) as following:

$$\begin{aligned} \hat{\mathcal{R}}_y(m) &\approx \hat{\mathcal{R}}_s(m) + \hat{\mathcal{R}}_w(m); \\ \hat{\mathcal{R}}_s(m) &\triangleq \sum_{k=1}^P \hat{\mathcal{R}}_{s_k}(m) \end{aligned} \quad (14)$$

It has been shown in [4] that SNR at the output of the detector is:

$$SNR_{out} = 20 \log \left(\frac{m_p^{(s)}}{\sigma_p^{(w)}} \right) \quad (15)$$

$\sigma_p^{(w)} = E \left\{ \left| \hat{\mathcal{R}}_w(m) \right|^2 \right\}$ is the standard deviation of the

fluctuations where consider noise alone (no spread spectrum signal is hidden in the noise) and $m_{\rho}^{(s)} = E \left\{ \left| \widehat{\mathcal{R}}_s(m) \right|^2 \right\}$ is the average value of fluctuations where consider signal alone.

As it can be seen from (15), the performance of their proposed method which uses autocorrelation estimator is dependent on the length of observation data window but they do not present a method to choose an optimal window. This choice can have major effect on computational complexity.

Our proposed method in comparison to other methods using autocorrelation function has better performance and ability to estimate the length of PN codes in lower SNR. besides, since the length of data observation window is chosen in adaptive algorithm, computational complexity is reduced to reasonable value rather than other considered algorithms.

The proposed approach is consisted of two parts.

- 1) Choosing an adaptive window
- 2) Choosing an appropriate threshold level for better observation of ordered peaks with average spacing of estimated code length.

It is notable that, since the sampling is done by the chip rate, the symbol period is equal to code length.

1) Choosing an adaptive window

The chosen window length is a determinant parameter in the output of the correlations, since the information about the code sequences is hidden in the received bit stream. Thus, for a better observation of main peaks, the window length should be chosen corresponding to code length. However, in practice there exists no prior knowledge about the code length. Thus we have to use the sequential search method to find it. To this purpose, we start this process with a minimum window length and in each step we increase it by considering the threshold levels, which are defined in the following. By such a process, the best possible window length corresponding to the code length can be detected.

In this method, we consider two different threshold levels (i.e. Tr_1 and Tr_2) to resolve the ambiguity involved in the detection of the main peaks.

It is worth to mention that this threshold level varies by the variation of the window length, because the second-order moment estimator is sensitive to window length. Therefore, this threshold level is updated adaptively.

2) Choosing the first threshold level Tr_1

The first threshold level is chosen in the following manner. Average of the output of second-order moment of correlation estimator is calculated and an adaptive compensator ($C_{adaptive}$) is used to choose a more precise value for the threshold level:

$$Tr_1(k) = \frac{1}{N} \sum_{i=1}^N \rho(i + K - 1) + C_{adaptive} \quad (16)$$

In the above equation, N is the number of data samples in

each window, $\rho(i)$ is the i -th sample of autocorrelation function in each window and $C_{adaptive}$ will be used to adjust the first threshold in every window.

After choosing Tr_1 , the peaks beyond this threshold are kept and if the number of these peaks are lower than a threshold value (Tr_2), the window length is increased, previous steps are repeated and also $C_{adaptive}$ is increased until the number of peaks over the Tr_1 become more than Tr_2 . Since, we are using the cyclo-stationary properties of the received signals after the input filter; the window length should be large enough to give us the ability of observing at least two successive peaks. then, in order to be able to see enough peaks we have to increase the window length. The population of the peaks around the main peaks for $N_C = 1023$ is illustrated in Fig. 3.

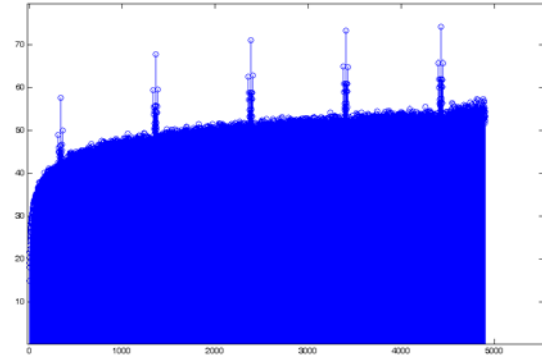


Fig. 3: Population of the Peaks Around the Main Peaks

As mentioned before, while choosing Tr_2 , the multiple peaks are visible in the processing window. In Fig. 4-a, second order moment of the correlation estimator and Tr_1 are depicted at first stage of calculation. Fig.4-b depicts the first threshold and appropriate length of window which shows PN code length. In this simulation $N_C = 31$, $P = 4$, $N_b = 1000$ and $SNR = -5dB$.

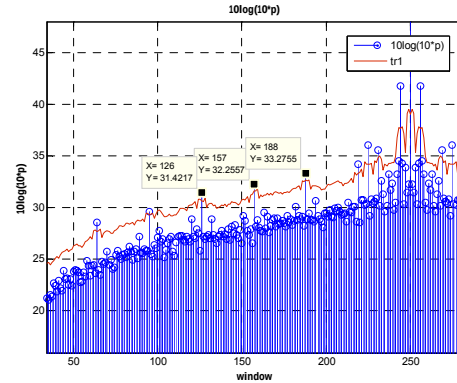


Fig. 4-a: Second Order Moment of the Correlation Estimator and Tr_1 at First Stage of Calculation

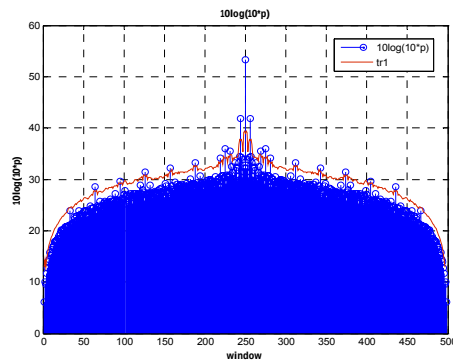


Fig. 4-b: Second Order Moment of the Correlation Estimator and Tr1 After Adaptation of Tr1

IV. SIMULATION RESULTS

In this section we evaluate the proposed adaptive algorithm by using computer simulations.

In Fig. 6 bit error rate (BER) versus SNR is illustrated. The results for $N_C = 31, 127$ and 511 and for $N_b = 1000$ and for five synchronous users over Rayleigh fading channel is demonstrated.

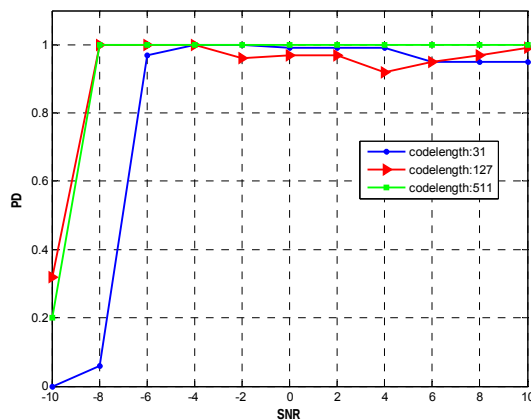


Fig. 5: Error Probability in estimation of Code length of 31, 127, 511 chips

As it can be seen from Fig.5, simulation results confirm that our proposed algorithm can be exploited to estimate code length of any users in multiuser system. Also, it has shown that codes with longer periods can be estimated in lower SNR better than ones with shorter periods, as we expected.

V. CONCLUSIONS

In this paper an adaptive algorithm for detection of CDMA signals without any prior information about the code characteristics was proposed. The proposed algorithm was based on observation of autocorrelation function fluctuations.

the proposed method was widely used because of its reasonable value of computational complexity. To optimize this computational complexity, data observation windows must be chosen properly to achieve faster and less complex algorithm. This paper mainly focuses on this idea. As it was shown in the simulation results, the proposed adaptive algorithm was capable of extracting the code length for multipath Rayleigh fading channel. Meanwhile, simulation results showed that in negative SNRs and for code lengths, the proposed algorithm worked very well. The code length was used for estimation of the number of users and decoding the users' code.

REFERENCES

- [1] P., Liu and Z., Xu, "Blind MMSE-Constrained Multiuser Detection", IEEE Trans. on Vehicular Technology, Vol. 57, No. 1, Jan. 2008
- [2] J., Yan and J.J., Hongbing "A Cyclic-Cumulant Based Method for DS-SS Signal Detection and Parameter Estimation", Proceedings of IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, 2005
- [3] T., Zhang, W., Zhang, S., Dai, G., Ma, Q., Jiang, "A Spectral Method for Period Detection of PN Sequence for Weak DS-SS Signals in Dynamic Environments", Proceedings of Int. Conference on Networks Security, Wireless Communications and Trusted Computing, 2009
- [4] Nsiala Nzéza, R. Gautier, and G. Burel, "Blind Multiuser Detection in Multirate CDMA Transmissions Using Fluctuations of Correlation Estimators", Proceedings of IEEE GLOBECOM, 2006
- [5] S., Ghavami, B., Abolhassani, "Detection of DS-SS Signals over Fading Channels without Prior Knowledge of Spreading Sequence by Measuring Signal Nongaussianity", Proceedings of The 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'06), 2006
- [6] Z., Dong, H., Hu, "Robust Detection of DSSS Signals in Non-Cooperative Context", Intl. Conference on Communication Technology, ICCT'06, 2006
- [7] F., Bandiera and G., Ricci, "A GLR-based Group Detection Strategy for Synchronous CDMA Systems over Frequency-Selective Fading Channels", Conference Record of the Thirty-Sixth Asilomar Conference on Signals, Systems and Computers, 2002
- [8] Z., DONG and M., LI, "A Method for the Detection of Long Pseudo-Random Code DSSS Signals Based on the Processing of Delay-Multiply (I) The Estimation of the Pseudo-Random Code Period and the Chip Width", Proceedings of 11th IEEE Intl. Conference on Communication Technology, 2008
- [9] T., Zhang, S., Dai, L., Yang and X., Li, "Estimate and Track the PN Sequence of Weak DS-SS Signals", Proceedings of International Conference on Computational Intelligence and Security, 2007
- [10] G. Burel, "Detection of Spread Spectrum Transmission Using Fluctuation of Correlation Estimator", IEEE-ISPACS, 2000
- [11] S., Talakoub and B., Shahrava, "Iterative Group-Blind Multiuser Detection and Decoding With Signal Rank Estimation for Coded CDMA Systems", IEEE Trans. On Vehicular Technology, Vol. 58, No. 5, Jun 2009
- [12] R., Dinis and P., Silva, "Iterative Detection of Multicode DS-CDMA Signals with Strong Nonlinear Distortion Effects", IEEE 64th Vehicular Technology Conference VTC-2006, 2006
- [13] S., Buzzi, and V., Massaro, "Parameter Estimation and Multiuser Detection for Bandlimited Long-Code CDMA Systems", IEEE Trans. On Wireless Communication, Vol.7, No.6, Jun 2008