Serial PN Acquisition Using Smart Antenna and Censored Mean Level CFAR Adaptive Thresholding for a DS/CDMA Mobile Communication

Nour Alhariqi, Mourad Barkat, *Fellow IEEE*, and Aghus Sofwan
Department of Computer Engineering
King Saud University
Riyadh, Kingdom of Saudi Arabia
noor.ksu@gmail.com , mbarkat58@gmail.com , and aghus.sofwan@gmail.com

***Abstract*— In [1], a novel approach using smart antenna with adaptive thresholding constant false alarm rate (CFAR) in pseudo-noise (PN) code acquisition for direct sequence code division multiple access (DS/CDMA) communication systems in Rayleigh slowly fading multipath channel was proposed. In this paper, we consider the use of the censored mean level detector constant false alarm rate (CMLD-CFAR) algorithm as an adaptive threshold processor for DS/CDMA in multiuser signals situations. Under mobile communication environments, multipath signals and other users' signals affect the performance of the PN code acquisition. Fixed threshold techniques are unable to adapt to these varying environments. Accordingly, a high false alarm rate and/or a low detection probability may result, and thus, adaptive thresholding techniques are essential. A smart antenna is an array of antenna elements that can modify the array pattern adaptively to minimize the effect of noise, multiple access interference (MAI) of other users, and multipath. The proposed system still considers PN code serial acquisition by using the smart antenna, but an adaptive threshold value based on a reference window of CMLD-CFAR processing. We derive an exact expression for the probability of false alarm for the proposed system, while the detection performance of the system is studied in terms of computer simulations under various parameters. The simulation results show that the system proposed is robust in a MAI environment.**

Keywords: Code Acquisition; CDMA; Adaptive CFAR; CMLD; Smart Antenna

I. Introduction

The pseudo-noise (PN) codes synchronization between the received code and the locally generated one is an essential step for the receiver to be able to demodulate properly the received signal in the direct sequence code division multiple access (DS/CDMA) communication system. The goal of this process is to align the locally generated dispreading PN code sequence with the incoming spreading PN code sequence. This process is performed in two stages; the PN acquisition stage, which coarsely aligns the two PN code sequences within a fraction of the chip duration, and then the PN tracking stage, which is a finer alignment that aims to reducing synchronization errors to an acceptable limit. In the acquisition stage, the receiver searches in an uncertainty region of phases. According to the search mechanism, the acquisition stage can be classified as: the serial search acquisition in which a one uncertainty code phase is tested at a time [2,3], the parallel search acquisition in which all possible code phases are tested simultaneously [4,5], and the hybrid search acquisition which combine the serial search with the parallel search [6,7].

In searching for synchronization, the correlation between the incoming and the locally generated PN codes is computed and compared to a threshold value to make the synchronization decision. In the mobile communications, the received signal levels are unknown and location varying [8]. Therefore, using a fixed threshold may cause too many false alarms and/or low detection probability according to the selected threshold value [9]. If the threshold value is too low, the false alarm probability will be increase seriously. On the other hand, if it is too high the probability of miss is increased. To overcome these problems, the threshold value should be set adaptively according to the surrounding environment. Using constant false alarm rate (CFAR) processing, which is well developed in automatic and adaptive radar signal detection [10], to set an adaptive threshold for the PN acquisition has been used in literature [8-11]. The main idea is to use the correlator outputs to estimate the background noise variance, which is not known, to set the threshold adaptively.

In the last few years there was a focus on utilizing a smart antenna to improve the PN code acquisition process [1, 12-14]. The smart antenna is a combination of an antenna array and a digital signal processing (DSP) unit. In [1], a novel approach for the PN code acquisition has been provided that combined the smart antenna with the adaptive

978-0-7695-4749-7/12 $26.00 © 2012 IEEE
DOI 10.1109/HPCC.2012.175

thresholding trimmed-mean (TM) CFAR processing. In this paper, we consider the system proposed in [1] where adaptive thresholding CFAR processing is adopted and is based on the censored mean level detector (CMLD) CFAR in a Rayleigh slowly fading multipath communication channels. In mobile communications it is known that the receiver receives multiple copies of the transmitted signal from several paths with different attenuations and time delays, furthermore multiple access interference (MAI) signals are common in DS/CDMA systems. All these interfering signals have serious effects on the PN code acquisition performance. Hence, one way to circumvent those problems is the use of smart antenna since smart antenna has a good ability in combating MAI signals, tracking mobile signals, reducing multipath fading, and improving signal power gain. The main idea is to receive the signals by all elements of the smart antenna that use the least mean square (LMS) adaptive algorithm to adjust its weight vector, then the adaptive threshold value is computed and used to make the synchronization decision. Under the presences of multipath and MAI signals, setting the adaptive threshold based on the cell averaging (CA) CFAR algorithm is not effective [1]. In the CMLD-CFAR, the outputs from the reference cells are rank- ordered according to their magnitude and the highest cells which correspond to multipath replicas and interferences from the other users are censored before to estimate the background noise power level and use it as a threshold value, as will be explained in the next section. The CMLD proved to be robust under an environment with multiple interfering signals [15, 16]. This paper is organized as follows. In Section 2, we describe the proposed acquisition system and derive a closed form expression for the probability of false alarm. The simulated detection performance of the proposed system and discussions are presented in Section 3. The conclusion is given in Section 4.

II. Description and Analysis of the Proposed Acquisition System

The block diagram of the proposed PN acquisition system is shown in Fig. 1. The system consists of a smart antenna with M antenna elements, each antenna element followed by a correlator that correlates the received PN code sequence with the locally generated PN code sequence. The outputs of the M correlators serve as inputs to the LMS beamformer to adjust the smart antenna's weight vector. After getting the optimum beamforming weight vector, the spatial correlation outputs from the LMS are fed into the CMLD-CFAR processor, which is a tapped delay line, to set the threshold adaptively in order to make a final decision about whether there is acquisition or not.

In this communication system considered we assume that there are D users from simultaneous transmitters. The first user is the initial synchronization user, while the other $D-1$ users may be considered as interferers to the first user.

A. The received signal model

The communication channel model considered consists of L tapped delay lines that correspond to the number of

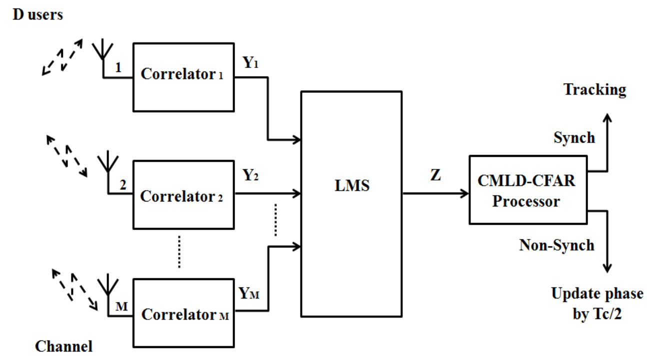

Figure 1. Block diagram of the proposed system

resolvable multipath with a Rayleigh distributed amplitude α_{il} and a phase ζ_{il}, $i=1,....,D$ and $l=0,....,L-1$.

Taking into account the effect of channel fading, the received signal consists of the signal from the first user, multiple access interferences from the others, and an AWGN $n(t)$. Thus, the received signal at the mth antenna element of the array is [17]:

$$r_m(t)=\sqrt{2P_s}\left\{\sum_{l=0}^{L-1}\alpha_{1l}c_1(t-\tau_1-lT_c)\exp\left(j(\phi_{1l}-\pi(m-1)\sin\theta)\right)\right\}+$$
$$\sqrt{2P_I}\left\{\sum_{i=2}^{D}\sum_{l=0}^{L-1}\alpha_{il}c_i(t-\tau_i-lT_c)\exp\left(j(\phi_{il}-\pi(m-1)\sin\theta)\right)\right\}+n(t) \quad (1)$$

where c_i , $i=1,....,D$ is the spreading sequence, P_s is the received signal power of the first user during initial synchronization, P_I is the average received power of the interfering signal, τ_i is the relative time delay associated with the asynchronous communication channel model, ϕ_{il}, $l=0,...,L-1$, are the phases in the demodulator of the receiver, which are independent and identically distributed random variables and uniformly distributed on the interval [0,2π], and T_c is the chip duration.

B. The Correlator

The received signal is first down-converted into in-phase (I) and quadrature phase (Q) components. These components are then multiplied by the locally generated PN code $c(t-jT_c/2)$, $j=0,1,...,N_c$ (N_c represent the reference window size), and integrated over dwell time interval $\tau_D=RT_c$ seconds, where R is the correlation length integer, to yield respectively the I and Q branch components Y_{ci} and Y_{si}, which are squared to give the correlator output Y, $Y=|Y_{ci}|^2+|Y_{si}|^2$. In case the received signal is aligned with the local PN code (H_1 hypothesis), the output Y will result in a high correlation value. Otherwise, it will be a negligible value due to the nonalignment case (H_0 hypothesis). The probability density function (pdf) of the output Y under the aligned hypothesis is given by [18]:

$$f_y(y|H_1)=\frac{1}{2\sigma_0^2(1+v)}\exp\left(-\frac{y}{2\sigma_0^2(1+v)}\right) \quad ,y\geq 0 \qquad (2)$$

where $v=9\sigma_f^2/(32/\sigma_0^2)$. σ_f^2 is the Rayleigh fading channel power while the variance σ_0^2 is given by [3]:

$$\sigma_0^2=\frac{(L-1)\psi}{3R}+\frac{L(D-1)\beta\psi}{3R}+\frac{1}{2RS_c} \qquad (3)$$

β represents the average received power of the interfering signal to the signal power of the first user ratio and is defined as $\beta=P_I/P_S$, while S_c represents the $SNR/chip$ and is given by $S_c=T_cP_s/N_0$, and $\psi=2\sigma_f^2$. Under the non-aligned hypothesis, the conditional pdf under the null hypothesis $f_Y(y|H_0)$ is obtained by replacing $\sigma_0^2(1+v)$ with σ_0^2 in (2).

C. Smart Antenna

As mentioned in the previous section, the receiving antenna array consists of M identical elements for signal reception and PN code acquisition. The space d between two antenna elements is equal to half the wavelength of the carrier transmitted signal λ_c $(i.e.\, d=0.5\lambda_c)$. In our case, the smart antenna performs adaptive beamforming using the LMS algorithm for directing the main array pattern towards the first user signal and creating nulls in the directions of the interfering signals. We chose the LMS algorithm because of its simplicity, ease of implementation, and relatively good convergence properties. The outputs Y_m , $m=1, 2, ..., M$ from the M branches of the correlator are inputs to the LMS processor as shown in Fig. 1. The LMS algorithm computes iteratively the optimum beamforming weight vector based on the minimum squares error (MSE) criterion between the desired signal value and the LMS processor output. Once the minimum MSE is attained, the weight vector is then used to generate a spatial correlation output Z. If the output Y_m of the considered correlator is under the aligned hypothesis, we assume the DOA of the desired signal can be located optimally by the smart antenna. The pdf of the decision variable Z corresponding to the aligned hypothesis is then given by [12]:

$$f_Z(z|H_1)=\frac{1}{2\sigma_0^2(M+M^2v)}\exp\left(-\frac{z}{2\sigma_0^2(M+M^2v)}\right) \quad , \quad z\geq 0 \qquad (4)$$

When the output Y_m of the correlator is under a non-aligned hypothesis consideration, it is assumed that the smart antenna tracks in a different angle than the desired signal. Therefore, the pdf of the non-aligned hypothesis $f_Z(z|H_0)$ is obtained by replacing $\sigma_0^2(M+M^2v)=\sigma_0^2M$ in (4).

D. CMLD-CFAR Processor

The outputs of the LMS beamformer are serially fed into a shift register of length N_c+1 as shown in Fig. 2. The first register, denoted as Z_0, stores the current output of the LMS beamformer. The following N_c registers, denoted by Z_c , $c=1,2,...,N_c$ are called the reference cells. The contents of these reference cells are sorted in ascending order according to their magnitude to form the ordered samples $Z_{(j)}$, $j=1,2,...,N_c$. Then k cells are censored from the upper end (where k is number of the assumed interfering cells $=(L-1)+(D-1)L$), and the remaining ones are combined to get an estimate of the background noise level U :

$$U=\sum_{j=1}^{N_c-k} Z_{(j)} \qquad (5)$$

The adaptive threshold value U is scaled by the threshold multiplier T to achieve the design false alarm probability. If Z_0 is larger than the threshold TU , a PN code acquisition is declared, and the tracking loop is triggered. Otherwise, the acquisition scheme shifts the locally generated PN code phase and the search continue until a correct PN code phase is found.

Next, we will derive an expression for the probability of false alarm for the proposed system. The probability of false alarm is the probability that a correlation of a non-alignment tested phase is greater than the threshold value. It is given by:

$$P_{fa}=E_U\{P(Z_0>TU|H_0)\}=M_U\left\{\frac{T}{2\sigma_0^2M}\right\}=M_U\left\{\frac{T}{a}\right\} \quad ,a=2\sigma_0^2M \qquad (6)$$

where M_U is the moment generation function (MGF) of the estimate U . As in [19], we will define independent random variables $W_i=(N_c-k-i+1)Z'_i$, $i=1,...., N_c-k$, where $Z'_i=Z_{(i)}-Z_{(i-1)}$, $Z_{(0)}=0$. Then the estimate U can be written as:

$$U=\sum_{i=1}^{N_c-k} W_i \qquad (7)$$

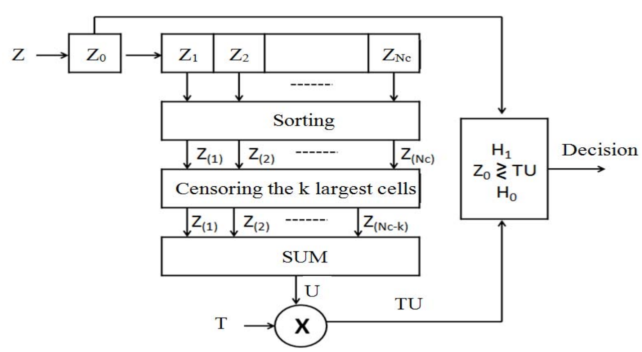

Figure 2. CMLD-CFAR processor

The MGF of U is simply the product of the individual MGF of the W_i's. Therefore, the probability of false alarm is:

$$P_{fa} = \prod_{i=1}^{N_c-k} M_{Wi}\left(\frac{T}{a}\right) \tag{8}$$

where

$$M_{W1}\left(\frac{T}{a}\right) = \frac{N_c}{(N_c - k)\left(T + \frac{N_c}{N_c - k}\right)} \tag{9}$$

and

$$M_{Wi}\left(\frac{T}{a}\right) = \frac{g_i}{T + g_i} \quad , \quad i = 2,....,N_c - k \tag{10}$$

The g_i's, $i = 2,...,\ N_c - k$ are given by:

$$g_i = \frac{N_c - i + 1}{N_c - k - i + 1} \tag{11}$$

III. Results and Discussion

In this section, the detection performance of the proposed system is evaluated in terms of the different parameters of the system of communication considered. The performance is studied using MATLAB simulations for a Rayleigh fading channel with the power normalized to one ($\sigma_f^2 = 1$). The design probability of false alarm is $P_{fa} = 10^{-3}$, the number of reference cells is $N_c = 24$, and the correlation length integer of the dwell time interval is set at value of $R = 128$. The threshold multiplier value T is readily obtained from the expression of the false alarm probability given in (8). It has been shown in [1] that the performance of the proposed system using CA-CFAR processing to set the adaptive threshold with $N_c = 24$ is comparable to the performance of the system proposed in [12] by Wang and Kwon . In Fig.3, we show again as in [1] that the detection performance of the system using CA-CFAR processing, where the adaptive threshold is the arithmetic mean of the reference cells, is seriously degraded in the presence of the interferences (multipath and the MAI signals). So the exclusion of or excising the interfering signals from the reference cells before estimating the noise power level of the environment will be an effective solution. This is in essence the CMLD-CFAR processing as explained earlier.

Fig. 3 shows the simulated detection probability P_d of the system against $SNR/chip$ under different numbers of censored cells. The number of antenna elements used is $M = 3$ and the number of interfering signals is $Inter = 4$, while the average received power of the interfering signal to the signal power of the first user ratio is $\beta = 0.3$. We observe that as the number of interfering signals censored increases, the detection performance improves as expected. This is due to the fact that the adaptive threshold computed after censoring becomes lower which yields a better detection probability. As we see, that all CMLDs ($k = 1,2,3$ and 4) have much better performance than the CA-CFAR ($k = 0$).

From Fig. 4, we observe that as the number of antenna elements in also increased, the probability of detection also increases. Three interfering signals are assumed present and censored before the computation of the adaptive threshold. The number of antenna elements is $M = 1,2,3,4,5$ and 6. We also note that the detection performance improves significantly and this is due to the nature of smart antenna which has the capability of improving signal power gain, combating MAI signals, and reducing multipath fading. As the number of antenna is more than M = 4, we observe that we start reaching saturation.

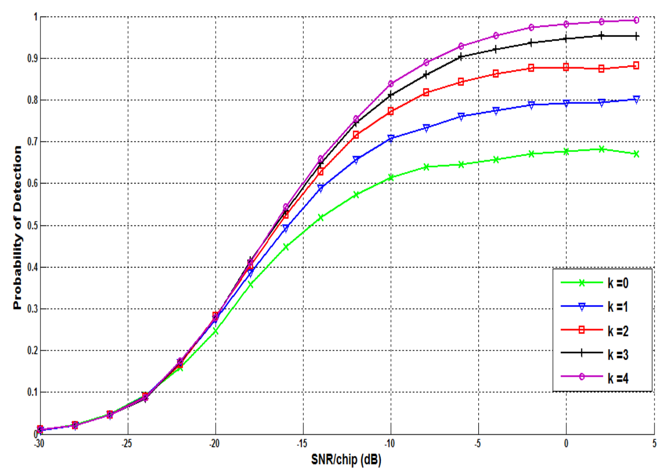

Figure 3. Comparison of P_d using CA-CFAR processing with CMLD-CFAR system after censoring; P_{fa}=10^{-3}, N_c=24, M=3, $Inter$=4, and β=0.3

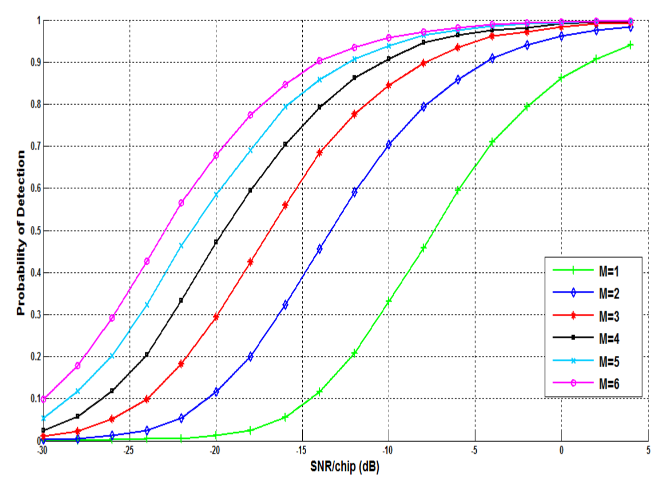

Figure 4. Effect of the number of antenna elements M on the detection performance; P_{fa}=10^{-3}, N_c=24, $Inter$=3, and k=3

Fig.5 shows the detection probabilities P_d of the system proposed with different number of antenna elements and for different numbers of censored cells. The number of antenna elements in the first system is $M = 2$, while in the second system is $M = 5$. The number of interfering signals is $Inter = 3$ with $\beta = 0.3$. We observe that as the number of antenna elements increases the probability of detection improves as expected. It should be noted though that the detection performance in the presence of two interfering signals when $M = 5$ and $k = 1$, is better than the case with $M = 2$ and $k = 3$ case, which is the case with no interfering signals, for all $SNR/chip$ values. We also observe a capture effect on the detection probability as it cannot reach $P_d = 1$ without censoring and this for all interfering signals. This emphasizes the robustness of the censoring algorithm which allows the probability of detection to reach asymptotically one as the $SNR/chip$ increases.

In Fig. 6, we plot the probability of detection P_d against the $SNR/chip$ for different number of reference cells $N_c = 16, 24,$ and 32 with different number of antenna elements $M = 3$ and 5. Three interfering signals are assumed to be present and censored before the computation of the adaptive threshold. As expected, increasing the window size N_c increases the detection probability as it gives estimate of the noise power in the cell under test. On the other hand, we observe that in the probability of detection for the same number of reference cells is substantial increased when the number of antenna elements is increased from 3 to 5. This indicates that the effect of the number smart antennas elements on the received signal power is much more pronounced on the probability of detection than the number of cells used in estimating the noise power. It also justifies the idea of combining both adaptive thresholding based on order statistics and censoring of interfering signals, and smart antenna.

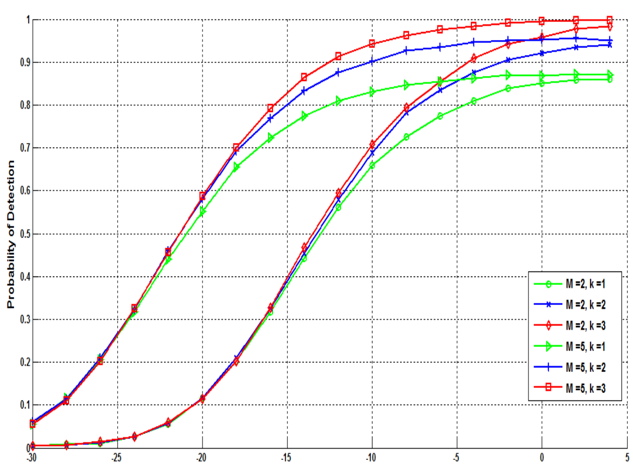

Figure 5. Comparison of P_d between two systems differ in the number of antenna elements M ; P_{fa}=10^{-3}, N_c=24, and *Inter*=3

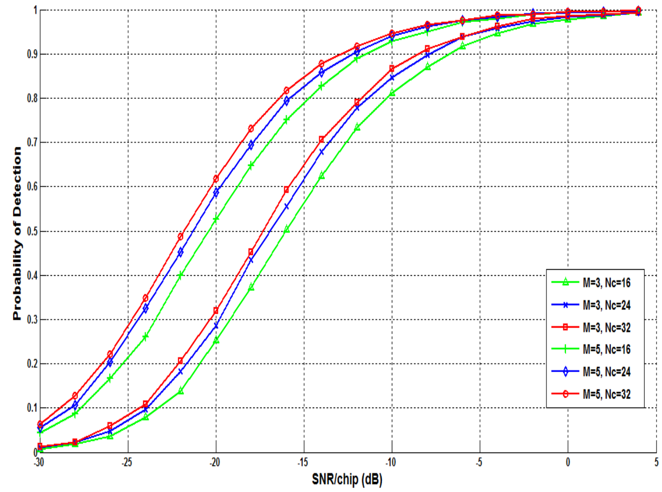

Figure 6. Effect of the number of refernce cells N_c on the detection performance; P_{fa}=10^{-3}, M =*3 and 5, Inter*=3, and *k*=3

IV. CONCLUSION

In this paper, we considered the problem of PN acquisition using smart antenna and adaptive threshold in DS/CDMA communications. An adaptive serial search acquisition system that employs all elements of the smart antennas and the CMLD-CFAR processing in a Rayleigh slowly fading multipath communication channels was proposed. An exact expression for the probability of false alarm for the proposed communication system was derived while the detection performance of the system was studied using MATLAB computer simulation. We observe that the system using the CMLD-CFAR based on rank ordering the reference cells and censoring the interferences samples was really robust in presence of MAI. Further analysis of such system will be considered in order to determine the mean acquisition time under different parameters, and hopefully obtain a closed form expression for the probability of detection

REFERENCES

[1] A. Sofwan and M. Barkat, “PN Code Acquisition Using Smart Antennas and Adaptive Thresholding Trimmed-Mean CFAR Processing for CDMA Communication”, *Spring World Congress on Engineering and Technology*, SCET2012, China, May 2012, *Accepted*.

[2] A. Polydoros and C. L. Weber, "'A Unified Approach to Serial Search Spread-Spectrum Code Acquisition--Part I: General Theory", *IEEE Transactions on Communications*, vol. COM-32, no. 5, pp. 542-549, May 1984.

[3] L. L. Yang and L. Hanzo, "Serial Acquisition of DS-CDMA Signals in Multipath Fading Mobile Channels", *IEEE Transactions on Vehicular Technology*, vol. 50, no. 2, pp. 617-628, March 2001.

[4] E. A. Sourour and S.C. Gupta, "Direct-Sequence Spread-Spectrum Parallel Acquisition in a Fading Mobile Channel", *IEEE Transactions on Communications*, vol. 38 , no. 7. pp. 992-998, July 1990.

[5] R. R. Rick and L. B. Milstein, "Parallel Acquisition in Mobile DS-CDMA Systems", *IEEE Transactions on Communications*, vol. 45, pp. 1466–1476, November 1997.

[6] W. Zhuang, "Noncoherent Hybrid Parallel PN Code Acquisition for CDMA Mobile Communications", *IEEE Transactions on Vehicular Technology*, vol. 45, no. 4, pp. 643-656, November 1996.

[7] A. Van Der Meer and R. Liyana-Pathirana, "Performance analysis of a hybrid acquisition system for DS spread spectrum", *TENCON 2003. Conference on Convergent Technologies for Asia-Pacific Region*, vol.1, pp. 121-125, October 2003.

[8] S. Benkrinah, M. Barkat, M. Benslama, A. Benmeddour, and R. Bekhakhecha, "Adaptive Acquisition of PN Sequence in Nonfading AWGN Channel", *African Physical Review*, vol. 2, pp. 120-122, 2008.

[9] C. J. Kim, H. J. Lee, and H.S. Lee, "Adaptive Acquisition of PN Sequences for DSSS Communications", *IEEE Transactions on Communications*, vol. 46, no. 8, pp. 993-996, August 1998.

[10] M. Barkat, *Signal Detection and Estimation*, 2nd edition, Boston, MA: Artech House, 2005.

[11] C. J. Kim, "Adaptive Acquisition of PN Code in Multipath Fading Mobile Channels", *Electronics Letters*, vol.38, no. 2, pp. 135-137, January 2002

[12] B. Wang, and H. M. Kwon, "PN Code Acquisition Using Smart Antenna for Spread-Spectrum Wireless Communications—Part I", *IEEE Transactions on Vehicular Technology*, vol. 52, no. 1, pp. 142-149, January 2003.

[13] B. Wang, and H. M. Kwon, "PN Code Acquisition for DS-CDMA Systems Employing Smart Antennas- Part II", *IEEE Transactions on Wireless Communications*, vol. 2, no. 1, pp. 108-117, January 2003.

[14] H. Puska, H. Saarnisaari, J. Iinatti, and P. Lilja, "Serial Search Code Acquisition Using Smart Antennas with Single Correlator or Matched Filter", *IEEE Transactions on Communications*, vol. 56, no. 2, pp. 299-308, February 2008.

[15] J. T. Rickard and G. M. Dillard, " Adaptive Detection Algorithms for Multiple Target Situations", *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-13, no. 4, pp. 338-343, July 1977.

[16] J. A. Ritcey, " Performance Analysis of the Censored Mean-Level Detector", *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-22, no. 4, pp. 443-454, July 1986.

[17] Y. S. Song, H. M. Kwon, and B. J. Min, "Computationally Efficient Smart Antennas for CDMA Wireless Communications", *IEEE Transactions on Vehicular Technology*, vol. 50, no. 6, pp. 1613-1628, November 2001.

[18] R. Bekhakhecha, M. Barkat, and S. Alshebeili "Adaptive Acquisition of a PN code Using OS-CFAR Detection and Antenna Diversity for a Multipath Rayleigh Fading Channel", *International Conerence. on Computer & Communication Engineering,* Malaysia*,* May. 2006.

[19] P.P. Gandhi, and S.A. Kassam, "Analysis of CFAR Processors in Nonhomogeneous Background", *IEEE Transactions on Aerospace and Electronic Systems*, vol. 24, no. 4, pp. 427-445, July 1988.