An Adaptive Hybrid double-dwell PN Code Acquisition in Rayleigh Fading Channels Using OS-CFAR algorithm

Benkrinah Sabra(1), Barkat Mourad(2), and Benslama Malek(3)

(1) Electronic Department, University of Ouargla, Algeria
(2) Department of Computer Engineering, King Saud University, Riyadh, KSA.
(3) Electronic Department, University of Constantine, Algeria
E-Mail: sabra32002@yahoo.fr / sbenkrinah@gmail.com

Abstract— **This paper proposes an adaptive non-coherent hybrid double dwell pseudo-noise (PN) acquisition scheme for code division multiple access (DS/CDMA) communication systems. Since existing acquisition systems have a fixed threshold value, they are unable to adapt to varying mobile communication environments resulting in a high false alarm rate or a low detection probability. Accordingly, an adaptively varying threshold scheme that uses an order statistic constant false alarm rate (OS−CFAR) algorithm is applied to a hybrid double-dwell system to improve the detection performance. Based on deriving formulas for the detection probability, miss detection probability, false alarm rate and mean acquisition time in Rayleigh fading channel, the performances of the proposed system are compared to the conventional hybrid system with fixed threshold and the adaptive serial system. This system is compared also to a hybrid system that using CA−CFAR algorithm.**

Key-Words— ***DS/SS, CDMA, CFAR, Rayleigh fading, hybrid search, doube-dwell.***

I. Introduction

Recently, there has been considerable interest in the application of direct-sequence spread-spectrum (DS/SS) multiple access, also known as code division multiple multiple access (CDMA), to cellular and personnal communication systems. CDMA has significant advantages in the areas of capacity, frequency planning, continuous call quality, privacyand resistance to multipath fading. Pseudo-noise (PN) code synchronizer is an essential element of CDMA mobile communication systems because data transmission is possible only after the spread spectrum receiver accurately synchronizes the locally generates PN code with the incoming PN code. The code synchronization is usually achieved in two steps, acquisition and tracking. Code acquisition is to achieve coarse alignment within some fraction of one code chip interval between the two PN codes, and the tracking process is to achieve fine alignment between PN codes, which further reduces synchronization error to an allowed limit. In the design of acquisition system, an important performance measure is the average of the time that elapses prior to acquisition, Tacq, and another major concern is the synchronizer hardware complexity.

Various techniques have been proposed for rapid code acquisition, which can be classified as either serial search or parallel search. Serial search steps through the uncertainty region of the incoming code phase sequentially. Polydoros and Weber [1] have proposed a rapid noncoherent I-Q detector for serial search in an AWGN channel which enables decisions to be made on the order of the DS code chip duration. On the other hand, parallel search uses a bank of matched filters; each matched to a different waveform pattern of PN code sub-sequences corresponding to all possible PN code phases, and then make a decision based on all the outputs of the filters. Sourour and Gupta [2] have analyzed parallel acquisition to fading channels.

In CDMA systems, whether parallel search or serial search should be used for code acquisition depends on system design criteria. The totally parallel acquisition scheme simultaneously tests all possible codes phase, therefore, can significantly reduce the code acquisition time. The hardware complexity, however, increases dramatically. The number of parallel noncoherent matched filters is equal to that of all possible (discrete) PN code phases, which can be very large number for a long PN code sequence. On the other hand, a serial search technique can achieve receiver hardware simplicity at the expense of code acquisition speed. The trade off between totally parallel search and serial search is the acquisition time versus system hardware cost; a hybrid method was suggested by Zhuang [3]. The resulting combination of serial and parallel acquisition improves the acquisition time and detection probability, plus reduces the hardware complexity of a parallel-type system. However all this conventional acquisition methods use a fixed threshold value, thereby resulting in varying detection probabilities and false alarm rates are relative to the environment.

Accordingly, this paper presents an adaptive threshold for a hybrid double dwell system. The proposed system uses an order statistic constant false alarm rate (OS-CFAR) algorithm to maintain a constant false alarm rate with a low computational complexity and can accommodate a variety of mobile communication environments. The performance is analyzed and compared to existing fixed threshold systems through deriving formulas for the detection probability, miss detection probability, false alarm rate and mean acquisition time of the proposed system.

This paper is organized as follows. Section 2 describes the acquisition scheme, and Section 3 presents the expressions for deriving the detection probability, miss detection probability and false alarm rate using the proposed adaptive threshold value method and the mean acquisition time expression is derived in Section 4.

II. SYSTEM DESCRIPTION

The proposed adaptive double-dwell hybrid PN code acquisition scheme for DS-CDMA is shown in Figure 1. The system consists of $2M$ correlatros, each M correlators are associated with an adaptive detector (AD) to make a decision. The internal structure of the correlators is shown in Figure2. The received signal is first down-converted to in-phase (I) and quadrature (Q) components. Two I-Q matched filters perform the correlation between the locally generated PN code and the I-Q base band signals. The I-Q matched filter correlator performs the multiplication of the I or Q component of the received signal with its locally generated code replica $c(t_j T_c)$, and integrates it over the interval $T_{d_j} = N_j T_c$, $j = 1,2$, where, T_{d_j}, $j = 1,2$, represents the dwell times, Tc the chip time of the code, and Nj, $j = 1,2$, the correlation sizes. The outputs of the I-Q filters are squared and summed to give the variable $z_{i,j}$, $i=1,\ldots,M$, and $j = 1,2$, corresponding to the(i,j) correlator.

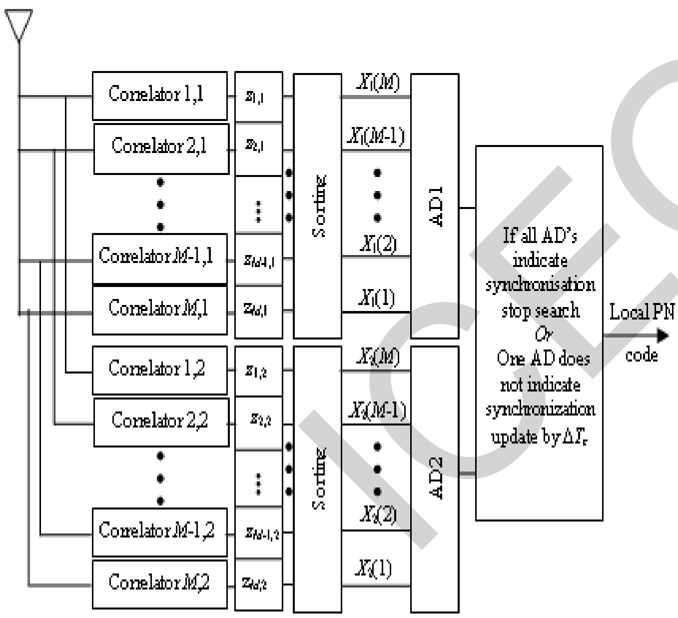

Figure 1. An adaptive noncoherent hybrid double-dwell PN code acquisition system.

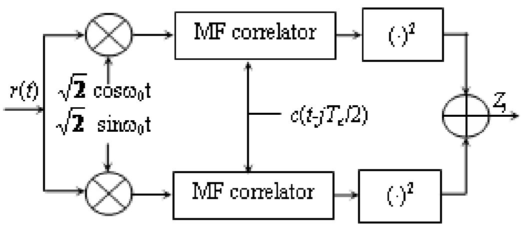

Figure 2. I-Q noncoherent matched filter.

The uncertainty region L_c is partitioned into $P_I = [L_c/M]$ subregions. $2M$ correlation results are taken at a time. Therefore, the system takes P_I iterations to investigate the whole region as shown in Figure 3.

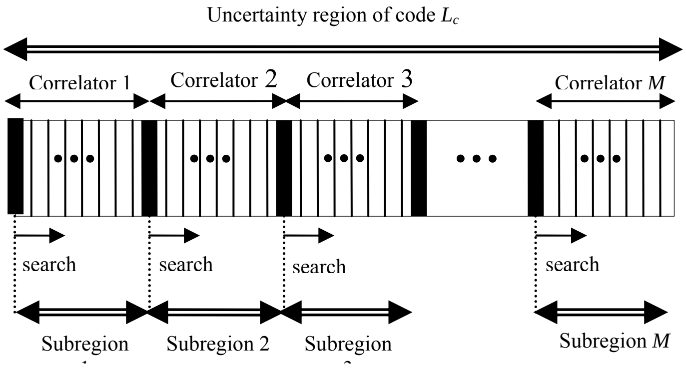

Figure 3. I-Q noncoherent matched filter.

The code phase uncertainty region of each subcode is discretized with a step size of Δ, which is normalized to the chip interval T_c. That is each subcode contains N_j/Δ discrete PN code phases. Normally, $\Delta = 2^{-n}$, with a nonnegative integer n. In this paper, Δ is sent to 1. In the partial noncoherent correlation at each correlator, the number of taps on the delay line is N_j with a ΔT_c delay between successive taps. The incoming code phase uncertainty region is searched in discrete steps. Over each noncoherent correlation period, $T_{d_j} (= N_j T_c)$, there are $N_j T_c$ input data samples. Each input data sample is correlated with the M subcodes loaded in the M parallel correlator simultaneously. The process repeats N times, each time with a unique code phase offset between the incoming PN code and the subcode loaded in any correlator, until all the possible PN code phases corresponding to the M subcodes are tested once. In the next period of duration $T_{d_j} (= N_j T_c)$, the M noncoherent correlators are loaded with a new group of PN subcodes, and the correlation process continues until a coarse code phase alignment is sensed. In this way, over a period of $P_I T_{d_j}$, the M parallel noncoherent correlators generate L_c decisions corresponding to all possible discrete PN code phase of the input signal.

The above hybrid parallel acquisition scheme combines the parallel acquisition with serial acquisition. The parameter M and P_I can be selected to achieve balance between the acquisition speed and system complexity. In the following, the acquisition performance of adaptive hybrid double-dwell scheme is analyzed theoretically in order to give a quantitative description of the mean acquisition time as function of M and P_I, so that the design parameters can be optimized according to system design criteria and channel characteristics.

For the adaptive operation of the decision processor, the order statistic constant false alarm rate (OS-CFAR) is used from among several CFAR algorithms due to its low hardware complexity and high interferences resistance. The threshold values of the comparators in the adaptive detectors are adapted in accordance with the magnitude of the incoming signals. Accordingly, the outputs of each correlator are sent serially into the two shift registers each of length M. The following $2M$ registers, denoted by $z_{i,j}$, $i = 1, 2, \ldots, M$ and $j = 1,2$, are ranked, to obtain the variables $X_j(i)$, $i = 1, 2, \ldots, M$ and $j = 1,2$. The variables X_j, $j = 1,2$, are the k^{th} samples of the values in each window. Using the variable X_j, $j = 1,2$, the system estimates the background noise power level of the incoming signals by scaling X_j ($=X_j(k)$, $k \leq M-1$) by T_j, where T_j is set accordingly to the desired false alarm rate from the OS-CFAR algorithm. Therefore, the adaptive threshold values of the adaptive detectors are T_jX_j, $j = 1,2$.

The decision variables Y_j, $j = 1,2$, are chosen to be the sum of the maximum correlation results of all correlators, thus

$$Y_j = X_j(M), \quad j = 1,2 \tag{1}$$

The Acquisition of the PN code is achieved by hypothesis testing involving the null hypothesis H_0 and the alternative hypothesis H_1. If the decision variable Y_j, $j = 1,2$, exceed the adaptive thresholds T_jX_j, $j = 1,2$, the proposed system declares that the code phase corresponding to the largest variables Y_j, $j = 1,2$, are the correct phase (H_1 cell). Otherwise, the correlators update their code phase by MTc, and the next M cells are tested with the same manner.

III. Analysis of System

In the derivation of the detection probability and false alarm probability for a typical Rayleigh fading channel, the following assumptions are made [3-9]: 1)There is one sample corresponding to the correct phase (one H_1 cells), 2)All samples are independent, 3)The correlation tap sizes N_j>>1 are selected that the correlation of the received sequence and the local code is about zero when they are not in phase (H_0 cell), and 4)The uncertainty region is the full code length L_c.

Referring to Figure2, it can be shown that the probability density function (pdf) of the H_1 sample can be expressed as [2],

$$f_{Y1}(y_1 \mid H_1) = \frac{1}{1+\mu}\exp\left(-\frac{y_1}{1+\mu}\right) \tag{2}$$

The pdf of the H_0 samples can expressed as

$$f_{Y1}(y_1 \mid H_0) = \exp(-y_1) \tag{3}$$

Since the reference signals in the window cells can be assumed to be noise signals, the pdf of values $Z_{j,i}$ in the window cells is the same as the H_0 distribution

$$f_{z_{j,i}}(z) = G(1,1) = \exp(-z) \tag{4}$$

After ranking, the pdf of H_1 cells can be expressed as

$$f_{X_j(k)}(x_j / H_1) = \frac{k}{1+\mu}\binom{M}{k}\left[1 - e^{-\frac{x_j}{1+\mu}}\right]^{k-1} e^{-(M-k+1)\frac{x_j}{1+\mu}} \tag{5}$$

and under H_0 is

$$f_{X_j(k)}(x / H_0) = k\binom{M}{k}\left[1 - e^{-x_j}\right]^{k-1} e^{-(M-k+1)x_j} \tag{6}$$

The pdf of noise estimate $f(z)$ is

$$f(z) = k\binom{M}{k}\left[1 - e^{-z}\right]^{k-1} e^{-(M-k+1)z} \tag{7}$$

a) Probabilities calculation:

The detection probability, $P_{d\,j}$, $j = 1,2$, is

$$P_{d_j} = \left[\int_0^\infty f(z)\int_{T_jz}^\infty f_{X_j(M)}(x_j|H_1)dx_j dz\right] \left[\int_0^\infty f(z)\int_0^{T_jz} f_{X_j(M)}(x_j/H_0)dx_j dz\right]^{M-1} \tag{8}$$

The probability of missing can expressed as

$$P_{m_j} = \left[\int_0^\infty f(z)\int_0^{T_jz} f_{X_j(M)}(x_j|H_1)dx_j dz\right] \left[\int_0^\infty f(z)\int_0^{T_jz} f_{X_j(M)}(x_j/H_0)dx_j dz\right]^{M-1} \tag{9}$$

The event of false can occur in two different cases: $P_{F_j\,|H_0}$ and $P_{F_j\,|H_1}$, $j = 1,2$. The false alarm probability corresponding to an H_0 state is

$$P_{F_j/H_0} = \left[\int_0^\infty f(z)\int_{T_jz}^\infty f_{X_j(M)}(x_j|H_0)dx_j dz\right] \left[\int_0^\infty f(z)\int_0^{T_jz} f_{X_j(M)}(x_j/H_0)dx_j dz\right]^{M-1} \tag{10}$$

Since the correlator outputs of the first and second ADs are independent, the detection probability of the system is the product of each AD's detection probability. Hence, the probability of actually detecting the correct cell is

$$P_d = P_{d_1}.P_{d_2} \quad (11)$$

The probability of missing is

$$P_m = P_{m_1}.P_{m_2} \quad (12)$$

The probability of false under H_0 hypothesis is

$$P_{F/H_0} = P_{F_1/H_0}.P_{F_2/H_0} \quad (13)$$

and under H_1 is

$$P_{F/H_1} = 1 - P_d - P_m \quad (14)$$

As such, $P_{F|H_1}$, only occurs once in the L_c cases, while $P_{F|H_0}$ appears $(L_c - 1)$ times. Therefore, the false alarm rate of the system is

$$P_F = \frac{1}{L_c} P_{F|H_1} + \frac{L_c - 1}{L_c} P_{F|H_0} \quad (15)$$

b) Mean acquisition time:

The mean acquisition time of the proposed system is derived using the state diagram given in Figure 4 which shows the search procedure for the hybrid double-dwell system. There are L_p acquisition states corresponding to L_p search iterations for all possible code phases. Only acquisition state one "state 1" contains the correct code phase, H_1, while all the other $(L_p - 1)$ acquisition states correspond to the H_0 state.

The following conditions are used to derive the mean acquisition time:

1. With a uniform distribution of the incoming PN code phase, the probability of starting at each node is equal.
2. A start at the correct phase node, 'state 1', is excluded.

In figue 4, the branch gains in the transform domain are as follows:

$$H_D(z) = P_{d_1} P_{d_2} z^{(N_1+N_2)T_c} \quad (16)$$

$$H_{F_1}(z) = P_{F_1|H_1} P_{F_2/H_1} z^{(N_1+N_2)T_c} \quad (17)$$

$$H_{F_0}(z) = P_{F_1|H_0} P_{F_2|H_0} z^{(N_1+N_2)T_c} \quad (18)$$

$$H_M(z)=P_{m_1} z^{N_1T_c}+P_1(1-P_2)Z^{(N_1+N_2)T_c}+P_{1/H_1}(1-P_{2/H_1})Z^{(N_1+N_2)T_c} \quad (19)$$

$$H_P(z) = z^{K(N_1+N_2)T_c} \quad (20)$$

$$H_{NF}(z) = \left[(1-P_{F_1|H_0}) + P_{F_1/H_0}(1-P_{F_2/H_0})Z^{N_2T_c}\right]Z^{N_1T_c} \quad (21)$$

$$H_T(z) = H_{NF}(z) + H_{F0}(z) + H_P(z) \quad (22)$$

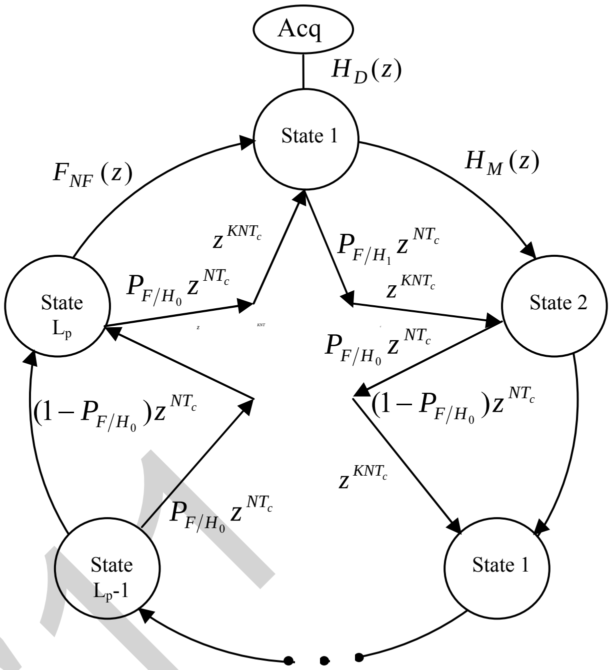

Figure 4. State diagram of hybrid search.

Meanwhile, an additional time, KT_c, where K means the penalty time constant, is required to re-enter the next acquisition state when the system recognizes a false alarm in the tracking stage.

Using the follow graph techniques, the transfer function, $H(z)$, is given as

$$H(z)=H_D(z)\left[1-\{H_M(z)+H_{F1}(z)H_P(z)\}H_T(z)^{P_I-1}\right]^{-1} \times \sum_{i=1}^{P_I} \frac{1}{P_I}\{H_T(z)\}^{P_I-i} \quad (23)$$

From the transfer function (23) and branch gains in (16)-(22), the mean acquisition time of the proposed system given by $\bar{T}_{acq}$, can be calculated as

$$\bar{T}_{acq} = \left.\frac{dH(z)}{dz}\right|_{z=1} \quad (24)$$

Finally, we obtain

$$\bar{T}_{acq}=\frac{(N_1+N_2)T_c}{P_d}\left[KP_{F/H_1}+P_{F_1/H_0}(P_I-1)(1+KP_{F_2/H_0})\left(\frac{3}{2}-P_d\right)\right]+ \frac{N_1T_c}{P_d}\left[1+(P_I-1)(1+KP_{F_1/H_0})\left(\frac{3}{2}-P_d\right)\right]+\frac{N_1T_c}{P_d}\left[P_{d_1}+P_{F_1/H_1}\right] \quad (25)$$

IV. Numerical and Simulaion Results

To verify the performance of the proposed adaptive hybrid double-dwell system, its detection probability, and mean acquisition time were determined using various system parameters. The system performance was analysed and compared with a serial system, a conventional hybrid-parallel system and a hybrid double-dwell system that using CA-CFAR algorithm. For the analysis, the false alarm rate was set at 0.0001 and the length of the PN code, *L*, was 2048. The chip time T_c , and the penalty time constant, *K*, were set at 10^{-6}s and 1000, respectively.

We start by a short comparison between serial and hybrid systems in figure 5 and 6 (For proving the interest of using the hybrid parallel system). We observe that the probability of detection is nearly the same for both systems which means that, we don't loss in detection if we use the hybrid parallel system. But, the mean acquisition time of hybrid parallel system is more less then that of serial one as shown in figure 6 (which shows the interest of using the hybrid parallel system). These two figures demonstrate also that, the increasing of correlation tap size *N* increases the detection probability and the mean acquisition time.

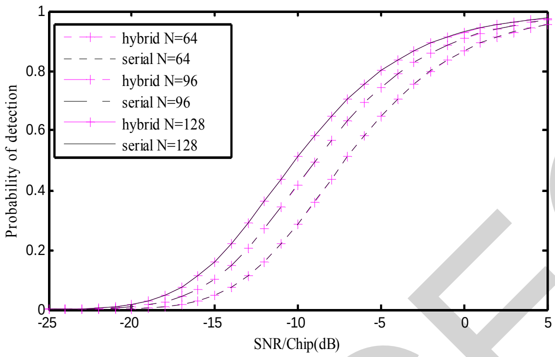

Figure 5. Comparison between probabilities of detection of serial and hybrid systems for *M*=16 and $P_{fa}=10^{-4}$.

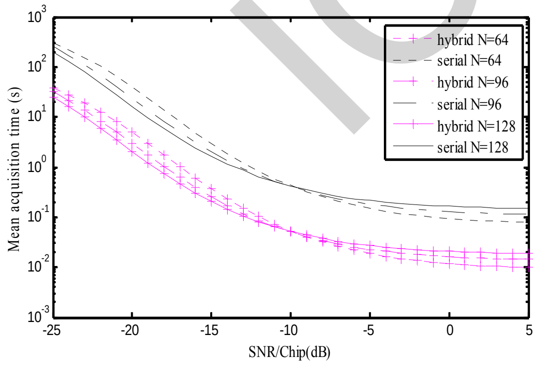

Figure 6. Comparison between the mean acquisition times of serial and hybrid systems for *M*=16, and $P_{fa}=10^{-4}$.

In Figures 7 and 8, we present the comparison between the adaptive system with the CA-CFAR detector and the conventional one. The conventional system uses a sub-optimum threshold value for an SNR/chip = 5 dB. We observe that the detection probability of the proposed system is superior to that of the conventional one all over SNR per chip ranges. We observe also that, the mean acquisition time of the proposed system is less then that of the conventional one all over the SNR per chip ranges. Hence, we can conclude that, the adaptive system outperforms the conventional one (using fixed threshold) by increasing the probability of detection, and decreasing the mean acquisition time. It can also, maintain the false alarm probability constant (which is the interest of using CFAR).

The performances of proposed system increase when the number of parallel correlators increases (figures 9 and 10).

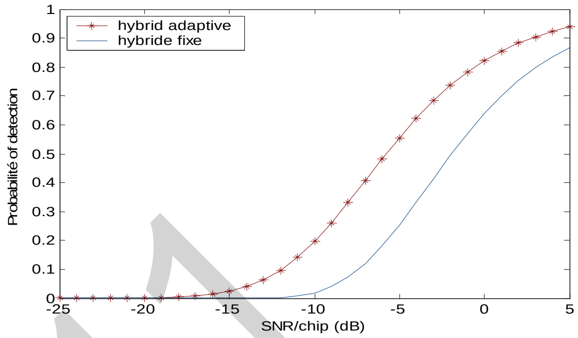

Figure 7. Comparison between the detection probabilities of adaptive and fixed hybrid systems for *M*=16, *N*=64 and $P_{fa}=10^{-4}$.

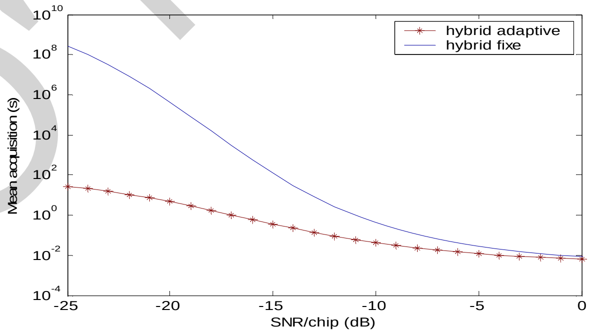

Figure 8. Comparison between the mean acquisition times of adaptive and fixed hybrid systems for *M*=16, *N*=64 and $P_{fa}=10^{-4}$.

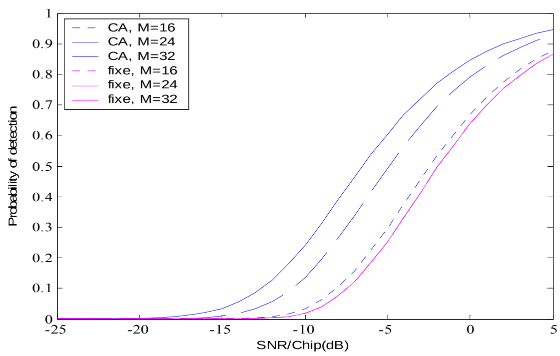

Figure 9. Comparison of detection probabilities for fixe and adaptive hybrid systems with *N*=64 and $P_{fa}=10^{-4}$ for different values of *M*.

Figure 11, compare the detection probabilities for both single and double-dwell hybrid systems using OS-CFAR algorithms in homogenous background, we observe that the probability of detection of the double-dwell hybrid system is less then that of the single dwell one if we give the same correlation tap size for both systems. But if we increase the correlation tap size of the second dwell in the second system, the probability of detection for the double-dwell hybrid system increased and they will be the same if $N_2 = 512$.

Figure 12, presents comparison between single-dwell and double-dwell adaptive hybrid systems. This figure show that the mean acquisition time of the adaptive double-dwell hybrid system is more less then that of single dwell one.

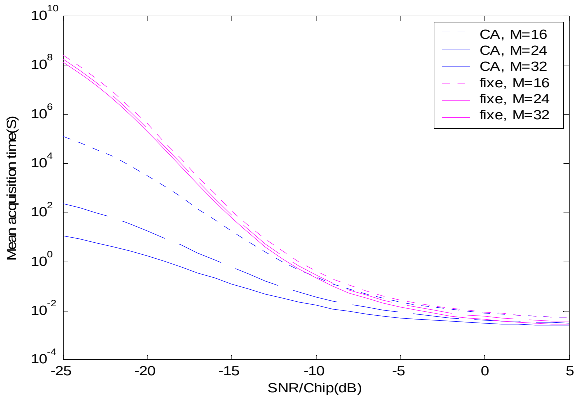

Figure 10. Comparison of mean acquisition time for fixe and adaptive hybrid systems with N=64 and $P_{fa}=10^{-4}$ for different values of M.

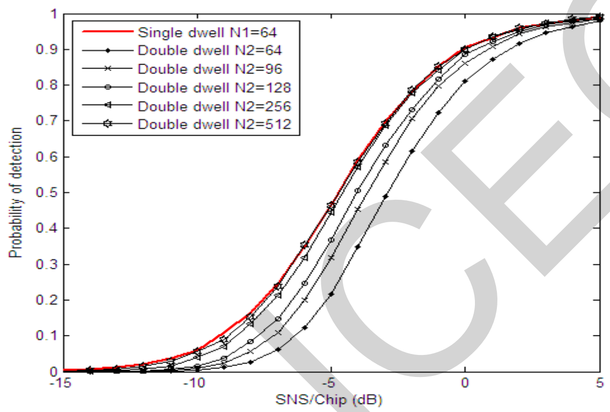

Figure 11. Comparison of detection probabilities for single and double-dwell hybrid system using OS-CFAR algorithm for different values of N_2 with M=16, N_1=64 and $P_{fa}=10^{-4}$.

V. Conclusion

This paper derived formulas for an adaptive double-dwell hybrid acquisition system in Rayleigh fading channel and used the resulting detection probabilities, false alarm rates and mean acquisition times to compare the performance of proposed system with a fixed threshold value system, single-dwell system and the adaptive with serial search one. Using the formulas derived for determining the detection probability, false alarm rate and mean acquisition time, the proposed system was analyzed relative to correlation tap sizes, window tap sizes and false alarm rate.

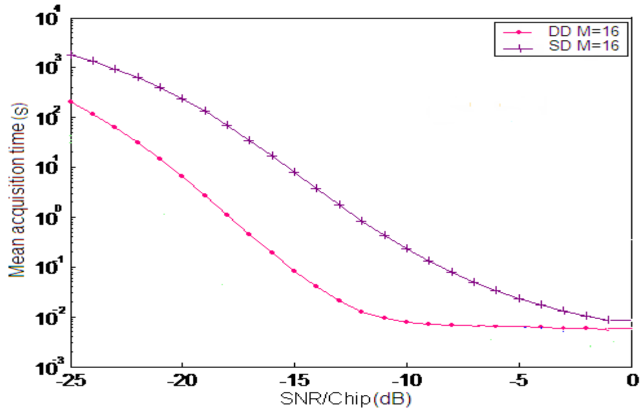

Figure 12. Comparison of mean acquisition time for single-dwell and double-dwell adaptive hybrid systems with N_1=64, N_2=256 and $P_{fa}=10^{-4}$.

The detection probability of the proposed system increased with the increasing of window cell sizes, correlation tap sizes the false alarm rates. By adopting the OS-CFAR algorithm to the acquisition system, the threshold value is update according to the magnitude of the incoming signals, thereby improving the system performances.

Form the results, we can conclude that the proposed system gives better performance and outperforms the conventional system with fixed threshold, the adaptive hybrid single-dwell system and the adaptive hybrid system with CA-CFAR algorithm and the adaptive serial one. If the first step of synchronization is successfully obtained, the tracking loop is activated to demodulate data.

References

[1] Plydoros and C. L. Weber, "A unified approach to serial search spread-spectrum code acquisition-Part I: general theory", IEEE Transactions in communications, Volume COM-32, No 5, pp. 542-549, May 1984.

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

[3] W. Zhuang, " Non coherent Hybrid Parallel PN Code Acquisition for CDMA Mobile Communications", IEEE Transactions on vehicular technology, Vol.VT-45, N°.4, November 1996.

[4] J. H. L. Linatti, "On the Threshold Setting Principles in Code Acquisition of DS-SS Signals", IEEE. Journal on Selected Areas in Communications, Volume 18, No. 1, January 2000.

[5] H.-S. Oh and D.-S. Han, "An Adaptive Doubel-Dwell PN Code Acquisition System in DS-CDMA Communications", Elsevier, Signal Processing, N0. 85, PP. 2327-2337, May 2005.

[6] S. Benkrinah, and M. Barkat, " An Adaptive Code Acquisition Using Order Statistic CFAR in DS/CDMA Double-Dwell for a Multipath Rayleigh Fading Channel," Colloque National sur le Traitement du Signal et ses Application, CNTSA'05, Guelma, Alger, septembre 2005.

[7] S. Benkrinah, and M. Barkat, "An Adaptive Code Acquisition Using Order Statistic CFAR in DS/CDMA Serial Search for a Multipath Rayleigh Fading Channel," Proceeding of IEEE International Conference on Systems, Signals and Devices, Sousse, Tunisia, March 2005.

[8] M. Barkat, Signal Detection and estimation, Second Edition, Artech House, boston, 2005.

[9] Viterbi, A. J., CDMA: Principals of Spread Spectrum Communication, Reading MA: Addison-Wesley, 1995.