Simple PN Synchronization using the OS-CFAR Algorithm

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Abstract – The use of the cell averaging constant false-alarm rate (CA-CFAR) detector in the acquisition process for DS-CDMA (direct sequence-code division multiple access) presents serious performance degradation in nonhomogeneous environment caused by interferences. In this paper, we consider the analysis of the acquisition process using the ordered-statistic CFAR (OS-CFAR) algorithm as an alternative to the CA-CFAR.

I. INTRODUCTION

The potential demand for ubiquitous wireless communications combined with restricted availability of the radio frequency spectrum has motivated intense research into bandwidth-efficient multiple-access schemes.

In DS-SS systems, the synchronization between the received and the locally generated codes is required prior to data detection [1, 2]. The code synchronization problem has traditionally been seen as a two-step process: acquisition and tracking [3]. In this paper, the focus is mainly on the acquisition system of DS-SS signals. PN acquisition is a process by which the receiver attempts to align its local PN sequence's phase to the incoming signal within a fraction (usually one-half or less) of the chip duration. The receiver usually stores a threshold to determine whether the result of the correlation is the autocorrelation peak when the two sequences are in alignment.

The concept of adaptive thresholding CFAR in radar signal processing, which sets the threshold adaptively based on the local information of the total noise power, is considered for the acquisition of PN sequences. It has been shown that the DS/CDMA systems with cell averaging (CA) CFAR processor exhibit an excellent performance in homogeneous environment where the power of interference noise varies slowly as time changes, but in the nonhomogeneous case, this algorithm presents serious performance degradation. The good alternative is the ordered statistics schemes that have in general a better overall performance [5]. Thus, we consider the use of the order-statistic CFAR (OS-CFAR) detector for a Rayleigh fading channel in non-uniform noise background and multiple access interference environments to maintain the false alarm rate constant, and which can accommodate a variety of mobile communication environments. Non-coherent combining techniques are analysed because coherent diversity techniques, such as maximal ratio combining, cannot be employed prior to initial acquisition.

A description of the channel model is given in Section 2. Section 3 describes the proposed adaptive acquisition scheme. The performance analyses and the simulations results are presented. The conclusion is given in Section 4.

II. CHANNEL MODEL

The system under consideration is a single dwell serial search based on MF correlators is shown in Fig.1.

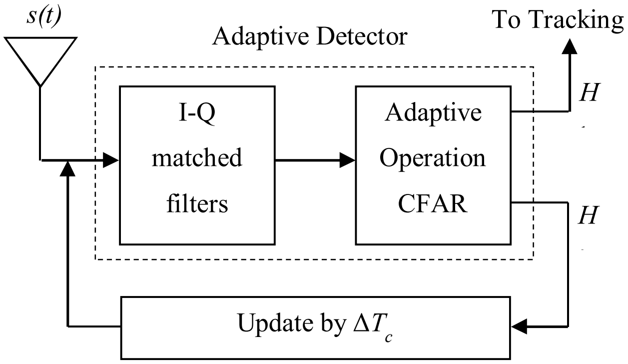

Fig. 1 Architecture of the detector

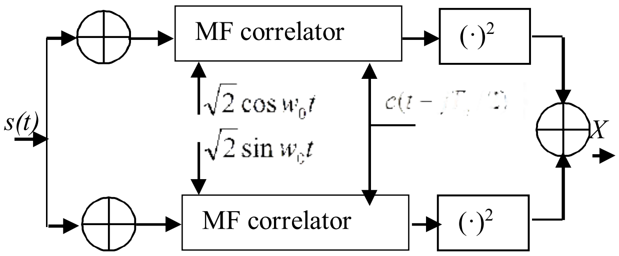

Fig. 2 I-Q MF detector

In Fig. 2, the statistic at the output of the I-Q MF is X=│XI│2+│XQ│2 Since XI and XQ follow noncentral Gaussians laws, the pdf of X is a chi-square distribution with two degrees of freedom given by [2, 5]

$$f_X(x \mid \alpha_{1p}, H_1) = \frac{1}{2\sigma_0^2}\exp\left(-\frac{m^2+x}{2\sigma_0^2}\right) I_0\left(\frac{m\sqrt{x}}{\sigma_0^2}\right), \quad \text{for } x \geq 0, \tag{1}$$

where I0(.) is the modified Bessel function of the first kind with zero order and m2 is the normalized noncentral metricThe variance σ02 is given by

$$\sigma_0^2 = \frac{(L-1)\alpha^2}{3N} + \frac{(D-1)L\rho\alpha^2}{3N} + \frac{1}{2N\bar{\gamma}_c} \tag{2}$$

wher $\rho = P_I / P_R$, $\alpha^2 = E[\alpha_{kl}^2] = 2\sigma^2$, and $\bar{\gamma}_c = P_R T_c / N_0$ is the SNR/chip.

Since

$$\begin{cases} H_0 : f_X(x/H_0) = \int_0^\infty f_x(x/\alpha_{1p}, H_0)\ f_{\alpha_{1p}}(\alpha_{1p})\ d\alpha \\ H_1 : f_X(x/H_1) = \int_0^\infty f_x(x/\alpha_{1p}, H_1)\ f_{\alpha_{1p}}(\alpha_{1p})\ d\alpha \end{cases} \tag{3}$$

then after some mathematical manipulations, we obtain

$$\begin{cases} H_0 : f_X(x/H_0) = \dfrac{1}{2\sigma_0^2}\exp\left[-\dfrac{x}{2\sigma_0^2}\right], \ \mathrm{x} \geq 0 \\ H_1 : f_X(x/H_1) = \dfrac{1}{2\sigma_0^2(1+\mu)}\exp\left[-\dfrac{x}{2\sigma_0^2(1+\mu)}\right], \ \mathrm{x} \geq 0 \end{cases} \tag{4}$$

where $\mu = 9\sigma^2 / 32\sigma_0^2$ is the average SNR.

III. ADAPTIVE ACQUISITION SCHEME

For the adaptive operation of the decision processor, we consider two CFAR detectors: CA-CFAR and OS-CFAR. The outputs of the I-Q MF correlator are sent serially into a shift register of length M as shown in Fig. 3. The first register, denoted as Y, stores the output of the multiplication of the power of the incoming signal with the value of the partial correlation between the locally and incoming PN sequences.

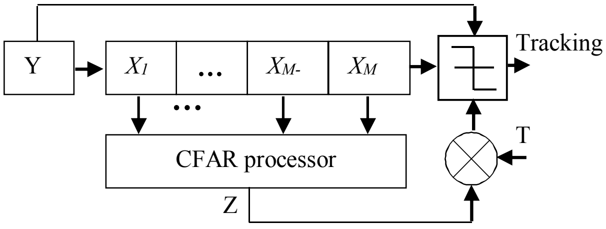

Fig. 3 Adaptive Operation CFAR

1. CA-CFAR DETECTOR

In CA-CFAR processing, the adaptive threshold is obtained from the arithmetic mean of the reference cells. Then, the CA-CFAR estimation of the threshold ZCA is given by [5, 8]

$$Z_{CA} = \sum_{i=1}^{r} X_{i_{2\sigma_0^2(1+I)}} + \sum_{i=r+1}^{M} X_{i_{2\sigma_0^2}} \tag{5}$$

Where I is the interference-to-total noise ratio (INR). The probabilities of detection Pd and false alarm Pfa, can then be obtained to be

$$P_{fa} = \frac{1}{\left(1+(1+I)T/\left(1+2\sigma_0^2\right)\right)^r} \cdot \frac{1}{\left(1+T/\left(1+2\sigma_0^2\right)\right)^{M-r}} \tag{6}$$

$$P_{fa} = \frac{1}{\left(1+(1+I)T\right)^r} \cdot \frac{1}{\left(1+T\right)^{M-r}} \tag{7}$$

The characteristics of the CA-CFAR processor will be compared later with those of the OS-CFAR processors to show the degradation of the performance of the CA-CFAR processor performances in the nonhomogeneous situation as expected.

2. OS-CFAR DETECTOR

In the OS-CFAR processor, the data in the window are sorted in an increasing order in terms of their magnitudes [9]. The order statistics acquisition processor (OSAP), denoted as OSAP(k), uses the kth value, k=3M/4 in the window as a power level estimate [3, 6]. Hence, the estimated total noise power *Z=X_k* from this set has a cumulative distribution function (cdf) given by [11].

$$F_{X_k}(X_k) = \sum_{i=k}^{M}\sum_{J=J_1}^{J_2}\binom{r}{i-j}\binom{M-r}{i-j}\left[1-F_r(X_k)\right]^{r-i+j}\left[F_r(X_k)\right]^{i-j} \cdot \left[1-F_{M-r}(X_k)\right]^{M-r-j}\left[F_{M-r}(X_k)\right]^{j} \tag{8}$$

where, $J_1 = \max(0, i-M+r)$ and $\mathbf{J_2} = \min(i,r)$, while $F_r(X_k)$ represents the cdf of the cell that contains thermal noise only, and $F_{M-r}(X_k)$ denotes the pdf of the interfering cell such that:

$$\begin{cases} F_{M-r}(x) = 1-\exp\left(\dfrac{-x}{2\sigma_0^2}\right) \\ F_r(x) = 1-\exp\left(\dfrac{-x}{2\sigma_0^2(1+\mu)}\right) \end{cases} \tag{9}$$

The detection probability is then given by

$$P_d = \frac{T}{2\sigma_0^2(1+\mu)} \sum_{i=k}^{M} \sum_{J=J_1}^{J_2} \binom{r}{i-j} \binom{M-r}{i-j} \sum_{s_1=0}^{j} \sum_{s_2=0}^{i-j} (-1)^{s_1+s_2} \binom{j}{s_1} \binom{i-j}{s_2} \cdot \frac{2\sigma_0^2(1+I)(1+\mu)}{((M-r-j+s_1)(1+I)(1+\mu)+(r-i+j+s_2)(1+\mu)+T(1+I))} \tag{10}$$

The probability of false alarm is

$$P_{fa} = \frac{T}{2\sigma_0^2} \sum_{i=k}^{M} \sum_{J=J_1}^{J_2} \binom{r}{i-j} \binom{M-r}{i-j} \sum_{s_1=0}^{j} \sum_{s_2=0}^{i-j} (-1)^{s_1+s_2} \binom{j}{s_1} \binom{i-j}{s_2} \cdot \frac{2\sigma_0^2(1+I)}{((M-r-j+s_1)(1+I)+(r-i+j+s_2)+T(1+I))} \tag{11}$$

III. RESULTS

Fig.4 shows the comparison of the performances in nonhomogeneous environment of the CA-CFAR processor against the OS-CFAR processor for a single antenna system in terms of the number of reference cells M in a window. We observe that the OS-CFAR detector is robust in presence of interfering targets.

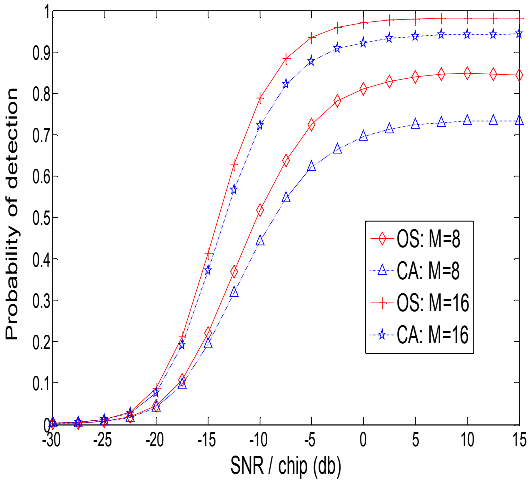

Fig 4 Detection performances comparison for CA--CFAR and OS-CFAR processing in nonhomogeneous environment

The mean acquisition time is plotted in Fig.5 for both algorithms using different values of M. It is clear that the OS-CFAR has the best performance.

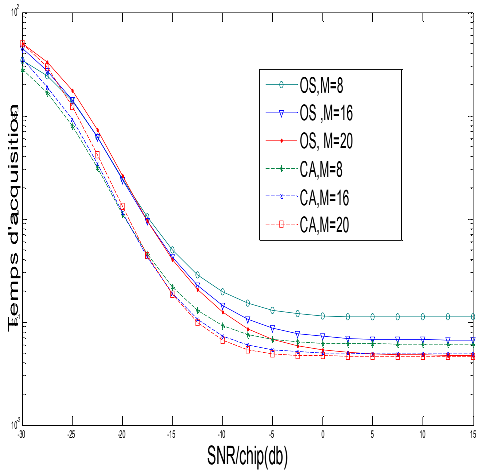

Fig. 5 Comparison between the time acquisition for CA and OS in homogeneous environment

VI. CONCLUSION

In this paper, we have presented a comparison between the CA-CFAR and OS-CFAR detectors in adaptive acquisition scheme for PN sequences. This comparison demonstrates the superiority of the CA-CFAR processor performance in homogeneous environment (absence of interferences). Nonetheless, it is inferior behavior in the non-homogeneous situation. In this case the OS-CFAR proves to be more robust as expected.

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