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# A NOVEL ACQUISITION TECHNIQUE OF SPREAD SPECTRUM SIGNALS USING TWO CORRECT CELLS JOINTLY

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## ABSTRACT

*In this paper, a new pseudo noise (PN) code acquisition scheme for direct sequence spread spectrum (DS/SS) signals is proposed based on a joint decision rule of two correct cells ($H_1$ cells) at which the code phase offset between the locally generated and received PN codes is within a desired small value. To derive the joint decision rule, the acquisition problem is modeled as a hypothesis testing problem and then the locally optimum (LO) test statistic is used for the problem. Finally, a novel acquisition technique is proposed based on the joint decision rule. The detection and mean acquisition time performances of the proposed acquisition scheme are analyzed and compared with those of a conventional acquisition scheme in which $H_1$ cells are individually used for detection. The numerical results show that the proposed scheme not only has better performance but also is more robust to the residual code phase offset variation than the conventional scheme.*

## I. INTRODUCTION

In direct-sequence spread-spectrum (DS/SS) systems, the pseudo noise (PN) code in the received signal should first be synchronized with a locally generated one to demodulate the received signal. The synchronization process is usually achieved in two steps; acquisition (coarse alignment) and tracking (fine alignment), of which the former is dealt with in this paper.

In the code acquisition process, a correct ($H_1$) cell is defined as the cell at which the code phase offset between the locally generated and received PN codes is within a desired small value: otherwise, the cell is called an $H_0$ cell. In addition, the desired offset range and outside of this range are defined as the $H_1$ and $H_0$ *regions*, respectively, in this paper. In practical systems, the $H_1$ region is typically $(-\Delta T_c, \Delta T_c)$ [1], where $\Delta$ is the search step size and $T_c$ is the chip duration of the PN code. Then there exist two $H_1$ cells in the range. [1] (Each $H_1$ cell's energy for detection is smaller than that of the only $H_1$ cell in perfect alignment).

So far, however, most of the techniques [2][3] proposed for (rapid) code acquisition have been discussed under the assumption that there exists only one $H_1$ cell in the $H_1$ region (the perfect alignment assumption). Although the fact that there exist two $H_1$ cells in the $H_1$ region has been mentioned in [4], the two $H_1$ cells are used only one by one, but not jointly, for detection in [4].

In this work, our aim is to improve the detection performance in the $H_1$ region (and consequently, to enhance the overall acquisition performance) via an efficient combination of two $H_1$ cells. In this paper, a single dwell serial search PN code acquisition with noncoherent in-phase/quadrature-phase ($I$-$Q$) correlator is considered in nonselective Rayleigh fading channels. To derive a joint decision rule of the two $H_1$ cells for enhancing the detection performance, we first model the acquisition problem as a hypothesis testing problem and then use the locally optimum (LO) test statistic for the problem. The motivation of using the LO test statistic is as follows: first, since the LO detector has the maximum slope of its power function when the signal-to-noise ratio (SNR) approaches zero [5], it is expected to have quite good performance when the SNR is low with a specified false-alarm probability. Second, the LO detector can always be obtained and is usually easier to implement than other detectors including uniformly most powerful and optimum detectors [6][7].

In this paper, a novel acquisition technique based on the joint decision rule is proposed. With the proposed acquisition scheme, a closed-form expression of the mean acquisition time is obtained with the state diagram and the probabilities of detection, missing, and false alarm are derived. The mean acquisition time performance of the proposed acquisition scheme is compared with that of a conventional

[1] Exceptionally, for perfect alignment, there is only one $H_1$ cell. However, such a case occurs with zero probability.

acquisition scheme in which the $H_1$ cells are individually used for detection. Finally, numerical results are given to show that the proposed scheme not only has better performance but also is more robust to the residual code phase offset variation than the conventional scheme.

## II. JOINT DETECTION OF TWO $H_1$ CELLS USING LOCALLY OPTIMUM TEST STATISTIC

### *A. Joint Decision Rule*

In a DS/SS system, when the data modulation is not concerned, the received signal in a nonselective Rayleigh fading channel can be expressed as [8]

$$r(t)=\sqrt{2P}c(t+\tau T_c)\left[x(t)\cos(\omega_c t)-y(t)\sin(\omega_c t)\right]+n(t). \quad (1)$$

Here, $P$ is the signal power; $c(t)=\sum_{i=-\infty}^{\infty} c_i p_{T_c}(t-iT_c)$, where $c_i \in \{-1,+1\}$ is the $i$-th chip of a PN code sequence of period $L$ and $p_{T_c}(t)$ is the PN code waveform defined as a unit rectangular pulse over $[0,T_c]$; $\tau$ is the time delay normalized to the chip duration $T_c$; $x(t)$ and $y(t)$ are the in-phase and quadrature-phase components of the fading channel, respectively; $\omega_c$ is the carrier angular frequency; and $n(t)$ represents the additive white Gaussian noise (AWGN) with one-sided power spectral density $N_0$ and is statistically independent of $x(t)$ and $y(t)$. For Rayleigh fading channels, $x(t)$ and $y(t)$ are uncorrelated zero-mean Gaussian processes with equal variance $\sigma_s^2$. The channel is assumed to be wide-sense stationary. Also, it is assumed that the fading processes of $x(t)$ and $y(t)$ are constants during one chip duration and, similarly as in [9], have autocorrelation $E[x(i)x(j)] = E[y(i)y(j)] = \rho_{|i-j|}\sigma_s^2$, where $\rho_{(\cdot)}$ is the correlation coefficient of the fading process.

In the noncoherent $I$-$Q$ correlator receiver, the operation is as follows: the received signal $r(t)$ is first down converted to the $I$ and $Q$ components. Then, the correlator performs correlation between the locally generated PN code and the $I$ and $Q$ signals over a dwell time $t_d = MT_c$, where $M$ is called the correlation length. Finally, the outputs of the $I$ and $Q$ branches are squared and summed to produce a test sample in the conventional receiver. In the proposed receiver, on the other hand, the outputs of the $I$ and $Q$ branches are combined with its immediate previous outputs by a joint decision rule (which will be derived later in this section).

Letting $\hat{\tau}^{(n)} = \hat{\tau}^{(0)} + n\Delta \in [0,L]$ be the time delay of the locally generated PN code at the $n$-th sampling instant ($\hat{\tau}^{(0)}$ is an initial time delay), we can write $\tau - \hat{\tau}^{(n)} = \Delta p_0 + \delta$, where $p_0$ is an integer and $\delta \in [0,\Delta)$ is the residual code phase offset. The ranges of $\tau - \hat{\tau}^{(n)}$ corresponding to the $H_1$ and $H_0$ regions are thus given as $H_1: |\tau - \hat{\tau}^{(n)}| < \Delta$ and $H_0: |\tau - \hat{\tau}^{(n)}| \geq \Delta$, respectively. Then, the $H_1$ region has two $H_1$ cells. For simplicity, in this paper, full chip spacing of $\Delta = 1$ is used.

From (1) and the operation of the noncoherent $I$-$Q$ correlator receiver described above, the $n$-th outputs of the $I$ and $Q$ branches of the correlator are given by $u_I[n] = F_I[n] + N_I[n]$ and $u_Q[n] = F_Q[n] + N_Q[n]$, respectively. Here, $F_I[n]$ and $F_Q[n]$ are the components due to the faded PN code and $N_I[n]$ and $N_Q[n]$ are zero-mean independent and identically distributed (i.i.d.) Gaussian random processes due to the AWGN with variance $\sigma_N^2 = N_0 M T_c/2$. It is straightforward to see that $F_I[n]$ and $F_Q[n]$ are given by, for $n = 0,1,2,\cdots$, $F_I[n] = \sqrt{P}\int_{(n-1)MT_c}^{nMT_c} c(t+\tau T_c)c(t+\hat{\tau}^{(n)}T_c)x(t)dt$ and $F_Q[n] = \sqrt{P}\int_{(n-1)MT_c}^{nMT_c} c(t+\tau T_c)c(t+\hat{\tau}^{(n)}T_c)y(t)dt$, respectively. Each chip in the sequence $c(t)$ is modeled as an independent random variable taking on $+1$ and $-1$ with equal probability. Furthermore, $c(t)$ is assumed to be independent of $x(t)$ and $y(t)$. This random modeling on $c(t)$ is reasonable when $L \gg M \gg 1$ [4]. It should be noted that $u_I[n]$ and $u_Q[n]$ are in general neither jointly Gaussian nor independent because of $F_I[n]$ and $F_Q[n]$ when $\delta$ is nonzero: yet, they are uncorrelated. In addition, with the modeling that $c(t)$, $x(t)$, and $y(t)$ are mutually independent and the assumption of fast fading, $F_I[n]$ and $F_Q[n]$ can be approximated as Gaussian for $M \gg 1$ by virtue of a central-limit-theorem type of argument. Therefore, we can approximate $u_I[n]$ and $u_Q[n]$ as independent Gaussian random variables with the distribution $G(0, \sigma_{F[n]}^2 + \sigma_N^2)$, where $G(m,\sigma^2)$ represents the Gaussian distribution with mean $m$ and variance $\sigma^2$, and $\sigma_{F[n]}^2$ is the common variance of $F_I[n]$ and $F_Q[n]$. In [10], it is shown that

$$\sigma_{F[n]}^2 = \begin{cases} \sigma_N^2\mu\left[\frac{W}{M}\delta^2 + (1-\delta)^2\right], & \text{if } -1 < \tau - \hat{\tau}^{(n)} < 0, \\ \sigma_N^2\mu\left[\frac{W}{M}(1-\delta)^2 + \delta^2\right], & \text{if } 0 \leq \tau - \hat{\tau}^{(n)} < 1, \\ \sigma_N^2\mu(1-2\delta+2\delta^2), & \text{otherwise,} \end{cases} \quad (2)$$

where $W = M + 2\sum_{j=1}^{M-1}(M-j)\rho_j$ and $\mu = 2\sigma_s^2 P T_c/N_0$ is the SNR/chip.

In addition, $u_I[n]$'s and $u_Q[n]$'s are both obtained from disjoint observations at every sampling instant and as the SNR/chip ($\mu$) decreases and fading rate increases (consequently, $\frac{W}{M}$ decreases), the effect of $F_I[n]$ and $F_Q[n]$ reduces with respect to the dominating noise components $N_I[n]$ and $N_Q[n]$. Then $u_I[n]$'s and $u_Q[n]$'s are both approximately uncorrelated. Coupling this result with the Gaussian approximation on $u_I[n]$'s and $u_Q[n]$'s, it then follows that $u_I[n]$'s and $u_Q[n]$'s are both approximated to be mutually independent Gaussian random variables. In Section IV, it is shown that simulation results confirm the validity of the Gaussian approximation.

Now, we formulate the detection problem as a hypothesis testing problem of choosing between a null hypothesis $\mathbf{H_0}$ and an alternative hypothesis $\mathbf{H_1}$ describing the joint probability density function (pdf) of the observation vector

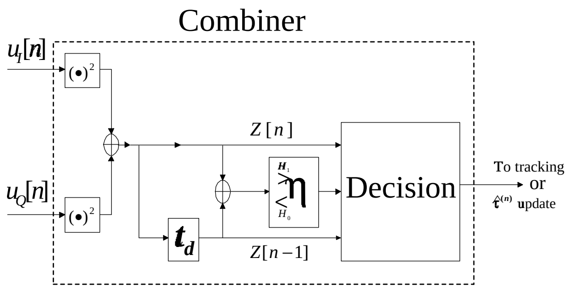


Fig. 1. The structure of the proposed combiner.

$\mathbf{U} = (u_I[n], u_Q[n], u_I[n-1], u_Q[n-1])$. From (2) and above discussions, we have

$$\mathbf{H_1}: \quad f_1(\mathbf{u}|\delta) = \prod_{i=1}^{2} \phi(u_i : 0, \frac{\sigma_2^2}{\sigma_3^2})\phi(u_{i+2} : 0, \frac{\sigma_1^2}{\sigma_3^2}), \quad (3a)$$

and

$$\mathbf{H_0}: \quad f_0(\mathbf{u}|\delta) = \prod_{i=1}^{4} \phi(u_i : 0, 1) \quad (3b)$$

after normalization by $\sigma_3$. Here, $\phi(x : m, \sigma^2)$ represents the Gaussian pdf with mean $m$ and variance $\sigma^2$, $\sigma_1^2 = \sigma_N^2(1 + \mu(\frac{W}{M}\delta^2 + (1-\delta)^2))$, $\sigma_2^2 = \sigma_N^2(1 + \mu(\frac{W}{M}(1-\delta)^2 + \delta^2))$, $\sigma_3^2 = \sigma_N^2(1 + \mu(1 - 2\delta + 2\delta^2))$, and $\mathbf{u} = (u_1, u_2, u_3, u_4)$ is a realization of $\mathbf{U}$. Note that $\sigma_1^2 \geq \sigma_3^2$ and $\sigma_2^2 \geq \sigma_3^2$.

Now, we derive a decision rule for the joint detection of the two $H_1$ cells in the $H_1$ region using the LO test statistic. From the generalized Neyman-Pearson lemma [5], the LO test statistic can be obtained as

$$\Lambda_{LO}(\mathbf{u}|\delta) = \left.\frac{d^\nu f_1(\mathbf{u}|\delta)}{d\mu^\nu}\right|_{\mu=0} / f_0(\mathbf{u}|\delta), \quad (4)$$

where $\nu$ is the order of the first nonzero derivative of $f_1$ at $\mu = 0$. By averaging over $\delta$, it can be shown [10] that (4) yields

$$\Lambda_{LO}(\mathbf{U}) = Z[n] + Z[n-1], \quad (5)$$

where $Z[n] = u_I^2[n] + u_Q^2[n]$. Note that $Z[n] + Z[n-1] = u_I^2[n] + u_Q^2[n] + u_I^2[n-1] + u_Q^2[n-1]$ can be considered as the sum of signal energy in the present and immediate previous cells. The class of energy detectors are frequently used for random signals in classical signal detection problems [5][6].

### B. System Description

The structure of the combiner based on the decision rule obtained in the previous subsection is shown in Fig. 1. The threshold $\eta$ is determined by the specified false alarm probability as in the usual detection schemes. In the combiner, the outputs of the two branches of the correlator are squared and summed to produce $Z[n]$. Then with one delay unit and an adder, we can obtain $Z[n] + Z[n-1]$. If $Z[n] + Z[n-1]$ is smaller than the threshold $\eta$, we take the next sample to continue. If $Z[n] + Z[n-1]$ is larger than the threshold, we choose the code corresponding to $\max(Z[n], Z[n-1])$, not the code corresponding to just either $Z[n]$ or $Z[n-1]$. That is, the result of the code acquisition is $c(t + \hat{\tau}^{(d)}T_c)$, where $\hat{\tau}^{(d)} = \hat{\tau}^{(0)} + \arg\{\max(Z[n], Z[n-1])\}$. Since the decision rule uses two samples, $Z[n]$ and $Z[n-1]$, the composition of the cells is one of $\{H_0, H_0\}$, $\{H_0, H_1\}$, $\{H_1, H_1\}$, and $\{H_1, H_0\}$. Therefore, even if $Z[n] + Z[n-1]$ exceeds the threshold $\eta$, only one cell of the two cells may be correct. Thus, when it is decided that we are under the $H_1$ region (that is, when $Z[n] + Z[n-1] > \eta$), we would have more chance of correct detection if we chose $\max(Z[n], Z[n-1])$ as our estimate than if we chose just $Z[n]$ or $Z[n-1]$.

## III. PERFORMANCE ANALYSIS

In Fig. 2, State $S$ is the state from which a transition to the acquisition state ($ACQ$) can occur, States $F_1, F_2, \cdots, F_{v-1}$ correspond to the cells under $H_0$. (For active correlation, as in this paper, a state diagram approach based on a Markov chain modeling is approximately valid for fading channels [11]). Since we use two successive samples for the acquisition process, $S$ has four substates, as shown in Fig. 2. In Fig. 2, State $T_1$ ($T_2$) occurs when the current cell is under $H_1$ ($H_0$) and the immediate previous cell is under $H_0$ ($H_1$). In $T_1$ ($T_2$), if the $H_1$ cell is selected, acquisition is achieved; if the $H_0$ cell is selected, false alarm occurs; and if no decision is made (that is, if the test variable $Z[n] + Z[n-1]$ is less than the threshold), a transition to $V$ ($F_{v-1}$) occurs. From this discussion, we call $T_1$ and $T_2$ the transition states. In $V$, either an acquisition or a 'missing' can occur, since the two cells under test are both under $H_1$: if a decision is made anyway, then the acquisition is achieved; otherwise, a 'missing' occurs and the state changes to $T_2$. State $U$ is the false alarm state which is an intermediate state at which a transition from $T_1$ to $V$ or from $T_2$ to $F_{v-1}$ may occur. After some algebra,

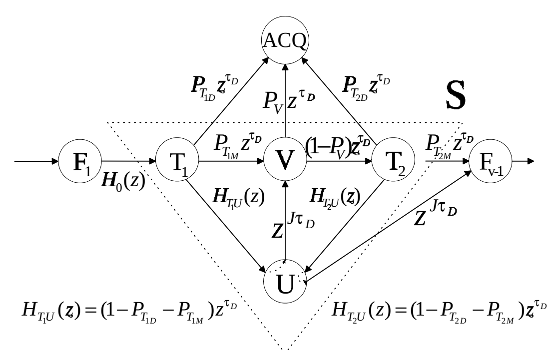


Fig. 2. The details of State $S$.

the mean acquisition time $T_A = E\{T_{acq}\}$ can be obtained as $T_A = \frac{1}{H_D(1)}\Big[H'_D(1)+H'_M(1)+(v-1)H'_0(1)\Big\{1-\frac{H_D(1)}{2}\Big\}\Big]$. Here, $H_D(1)=P_{T_{1D}}+(1-P_{T_{1D}})P_V+(1-P_{T_{1D}})(1-P_V)P_{T_{2D}}$, $H'_D(1)=\tau_D[P_{T_{1D}}+\{2+J(1-P_{T_{1M}})-(J+2)P_{T_{1D}}\}P_V+\{3+J(1-P_{T_1M})-(J+3)P_{T_{1D}}\}(1-P_V)P_{T_{2D}}]$, $H'_0(1)=\tau_D[1+JP_F]$, $H'_M(1)=\tau_D[(1-P_V)[\{3+J(1-P_{T_{1M}})-(J+3)P_{T_{1D}}\}P_{T_{2M}})+\{J+3+J(1-P_{T_{1M}})-(2J+3)P_{T_{1D}}\}(1-P_{T_{2M}}-P_{T_{2D}})]]$, $\tau_D$ is the dwell time (which is equal to $t_d$), $J$ is the penalty time due to false alarm, $P_{T_{iD}}$ and $P_{T_{iM}}$ are the probabilities of detection and missing in $T_i$, respectively, $P_V$ is the probability of detection in $V$, and $P_F$ is the false alarm probability in $F_i$. Then, as shown in [10], the probabilities are given as follows: $P_V=K_{21}\exp(\frac{-\gamma}{2}G_{21}H_{21})\Big(\frac{K_{21}+1}{K_{21}}-\exp(\frac{-\gamma}{2}L_{21})\Big)$, $P_{T_{1D}}=-G_{13}\exp(\frac{-\gamma}{4}H_{13})+K_{13}\exp(\frac{-\gamma}{2}G_{13}H_{13})\Big(\frac{K_{13}+1}{K_{13}}-\exp(\frac{-\gamma}{4}L_{13})\Big)$, $P_{T_{2D}} = -A_{32}\exp(\frac{-\gamma}{4}H_{32}) + B_{32}\exp\Big(\frac{-\gamma}{4}(H_{32}+L_{32})\Big)\Big(\frac{B_{32}+1}{B_{32}}-\exp(\frac{-\gamma}{4}L_{32})\Big)$, $P_{T_{1M}}=1-K_{13}\exp(\frac{-\gamma}{2}G_{13}H_{13})\Big(\frac{K_{13}+1}{K_{13}}-\exp(\frac{-\gamma}{2}L_{13})\Big)$, $P_{T_{2M}}=1-K_{32}\exp(\frac{-\gamma}{2}G_{32}H_{32})\Big(\frac{K_{32}+1}{K_{32}}-\exp(\frac{-\gamma}{2}L_{32})\Big)$, and $P_F = (1+\frac{\gamma}{2}G_{33}H_{33})\exp(\frac{-\gamma}{2}G_{33}H_{33})$. Here, $G_{ij}=\sigma_j^2/(\sigma_i^2+\sigma_j^2)$, $H_{ij}=\sigma_N^2(\sigma_i^2+\sigma_j^2)/\sigma_i^2\sigma_j^2$, $K_{ij}=\sigma_j^2/(\sigma_i^2-\sigma_j^2)$, $L_{ij}=\sigma_N^2(\sigma_i^2-\sigma_j^2)/\sigma_i^2\sigma_j^2$, $A_{ij}=(H_{ij}+L_{ij})/(H_{ij}+L_{ij}+2G_{ij}H_{ij})$, $B_{ij}=(H_{ij}+L_{ij})/(2G_{ij}H_{ij}-H_{ij}-L_{ij})$, and $\gamma=\eta/\sigma_N^2$.

In the next section, we compare the proposed system analyzed above with a conventional system via numerical methods, since a direct analytic comparison is not feasible.

## IV. NUMERICAL RESULTS AND DISCUSSION

In this section, we compare the mean acquisition time performance of the proposed system with that of the conventional system in which $H_1$ cells are individually used for detection. In evaluating the performance, we consider the following system parameters: PN code of $L$=32767 chips (which is generated from a primitive polynomial $z^{15}+z+1$), correlation length of $M$=1023 chips, and false alarm penalty time of $J = 10^4$ chips. For the comparison of the mean acquisition times of the proposed and conventional schemes, the threshold $\eta$ is selected numerically to minimize the mean acquisition time at each value of SNR/chip. Note that the SNR/chip is defined as $2\sigma_s^2 PT_c/N_0$ in Section II.A. The correlation coefficient of the fading process is taken as $\rho_i = J_0(2\pi f_d T_c i)$ [12], where $J_0(\cdot)$ is the zeroth-order Bessel function and $f_d$ is the maximum Doppler frequency shift. The product of maximum Doppler frequency shift and chip duration is assumed to be $10^{-3}$.

Fig. 3 shows the detection probabilities of the conventional and proposed schemes for $M = 1023$, $P_F = 10^{-2}$, and $\delta = 0.5$. In the simulation, the fading samples $x(i)$ and $y(i)$ were produced by Jakes model [12] and each point was obtained from $10^5$ runs. In this figure, the detection probability of the proposed scheme represents the probability $P_V$ given in State $V$. As expected, the detection performance of the proposed scheme is better than that of the conventional scheme. In this figure, a close agreement between the analysis results based on Gaussian approximation and the simulation results based on Monte Carlo runs can be observed, which implies the Gaussian approximation modeling on $u_I[n]$'s and $u_Q[n]$'s discussed in Section II.A is reasonable in these cases.

Fig. 4 shows the averaged mean acquisition time, normalized to $LT_c$ (i.e., $E_\delta\{T_A\}/LT_c$), of the conventional and proposed schemes. Here, $E_\delta$ denotes the expectation over $\delta$. From the figure, we can see that the proposed scheme yields an improvement of roughly 1-3 $dB$ over the conventional scheme. This can be explained as follows. In the conventional scheme, $H_1$ cells are individually used for detection: in the proposed scheme, on the other hand, two $H_1$ cells are used jointly for detection. Thus, the signal energy corresponding to each $H_1$ cell in the $H_1$ region are efficiently combined and then used for detection. That is, in the proposed scheme, during the detection process, we can obtain *more accurate* information on the signal from the *two reliable* cells. Therefore, the proposed scheme performs better than the conventional scheme: that is, the proposed scheme has smaller mean acquisition time.

Fig. 5 shows the mean acquisition time of the conventional and proposed schemes as the residual code phase offset $\delta$ changes. From the figure, it is clear that the difference of the mean acquisition time between the proposed and conventional schemes becomes larger, as $\delta$ approaches the worst case value $\delta = 0.5$: when $\delta = 0.5$, the average signal energy in the $H_1$ region is smallest as we can see from (2). This observation also allows us to see that the proposed scheme is more robust to the residual code phase offset variation than the conventional scheme. When $\delta$ is smaller, $Z[n]$ is larger and $Z[n-1]$ is smaller; when $\delta$ is larger, on the other hand, $Z[n]$ is smaller and $Z[n-1]$ is larger. Therefore, in the conventional scheme which individually uses $H_1$ cells for detection, the performance also experiences much variation as $\delta$ changes. In the proposed scheme, on the other hand, since the test statistic for detection is $Z[n]+Z[n-1]$, the test statistic can maintain relatively constant signal energy under the variation of $\delta$. This is why the proposed scheme is less sensitive to the variation of $\delta$ than the conventional scheme.

## V. CONCLUSION

In this paper, a new PN code acquisition scheme using joint detection of two $H_1$ cells in the $H_1$ region has been pro-



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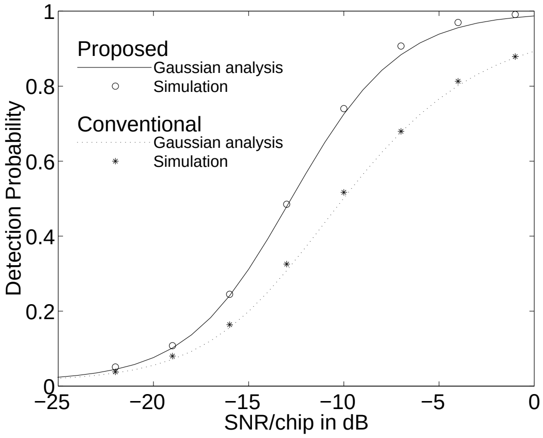


Fig. 3. The detection probabilities for the conventional and proposed schemes when $M = 1023$, $P_F = 10^{-2}$, and $\delta = 0.5$.

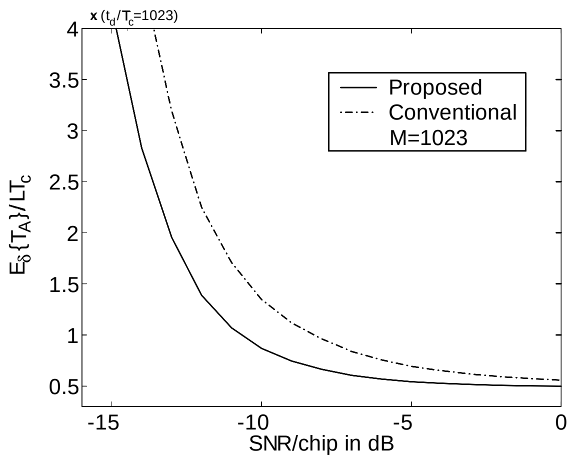


Fig. 4. Comparison of the averaged mean acquisition time normalized the PN code period between the conventional and proposed schemes.

posed and its performance has been evaluated in a Rayleigh fading channel. Using the locally optimum test statistic, a joint decision rule of the two $H_1$ cells has been derived and a new acquisition system has been proposed based on the joint decision rule. We have analyzed the performance of the proposed scheme: the closed-form of the mean acquisition time has been obtained and the detection, missing, and false alarm probabilities have been derived. The performance of the proposed scheme has been compared with that of the conventional scheme which individually uses $H_1$ cells for detection. From the results, it has been observed that the proposed scheme yields roughly 1-3 $dB$ improvement in SNR/chip over the conventional scheme. It has also been found that the proposed scheme is more robust to the residual code phase offset change than the conventional scheme.

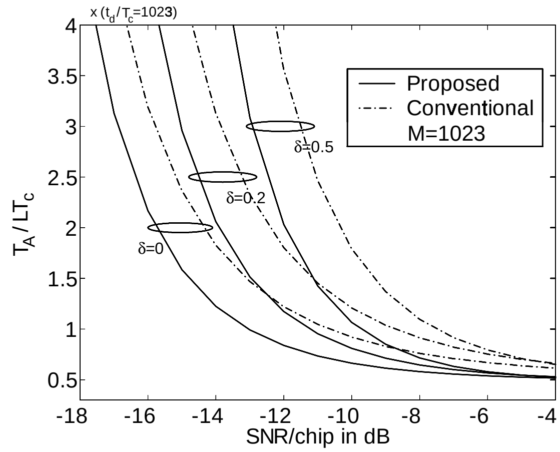


Fig. 5. Comparison of the mean acquisition time of the conventional and proposed schemes as the residual code phase offset ($\delta$) changes.


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