International Symposium on Nonlinear Theory and its Applications
Xi'an, PRC, October 7-11, 2002

Serial Acquisition using the Estimated Channel Gain in CDMA Mobile Communication

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Abstract; In this paper, we propose a new serial acquisition scheme for code division multiple access (CDMA) mobile communications and analyze the effect of multiple-access interference (MAI). To reduce the fading effect, the proposed acquisition scheme utilizes the estimated channel gain in Rayleigh fading channel. The channel gain is estimated prior to PN code correlation at the channel gain estimator and is used to compensate the fluctuation of the received signal due to the fading effect. From the simulation results, it is shown that the proposed acquisition system provides a significant performance improvement because of the compensation of the amplitude fluctuation of received signal using the estimated channel gain and that the improvement is obtained when the MAI provides the severe acquisition performance degradation. These results depend on the assumption that the fading channel is so slow that we can estimate the channel gain in CDMA mobile communication environment.

1. Introduction

Owing to its well-known capability to combat fading effect and allow multi-users to simultaneously communicate over the same channel, direct sequence code division multiple access (DS/CDMA) became more popular in the area of digital cellular and personal communication systems [1][2]. However, the advantages of DS/CDMA can be exploited only when the pseudo-noise (PN) code locally generated at the receiver and an incoming signal are well synchronized within a traction of a PN chip. Typically, the process of synchronization is performed in two steps, code acquisition (coarse alignment) and code tracking (fine alignment). In this paper, code acquisition of DS/CDMA in digital cellular system is mainly considered. In the forward link of the system, the pilot signal is employed for providing the mobile station with the carrier and code-phase reference used in demodulation. The pilot signal is unmodulated by information and uses the zero Walsh function (64 zeros). Thus, the pilot signal simply consists of the short PN code. By searching out the full length of the pilot PN code, the mobile station can obtain synchronization with the base station without prior information for the unique code-phase offset of the base station. Then, the spreading pilot PN code timing is determined before any phase measurement or tracking is attempted.

Most of code acquisition schemes have been suggested for minimizing the mean acquisition time. These acquisition schemes can be classified into either serial search or parallel search. In a serial search, cells in an uncertainly region are consecutively tested. This class of scheme is widely employed for simple implementation. In a parallel search, cells are simultaneously tested, and the use of parallel search is desirable in applications where faster acquisition is required at the cost of complexity. In [3], a serial search scheme has been discussed and the mean acquisition time has been analyzed in a static (or nonfading) channel. The analysis has been extended to multipath Rayleigh fading channel in [4]. The performance of the parallel search is extensively analyzed in static and fading channels [5]-[7]. Thus, whether serial search or parallel search should be used for code acquisition depends on system design criteria (tradeoff between mean acquisition time and hardware cost). The results of these papers [4]-[7] show that the fading effect interferes seriously the acquisition process increasing the mean acquisition time. In [8], code acquisition systems have been analyzed the effect of multiple-access interference (MAI) in an AWGN channel. This paper [8] quantifies the severe performance degradation of code acquisition due to MAI, and demonstrates the dependence of the increase of mean acquisition time on the number of users in the CDMA system.

In this paper, we propose a new acquisition scheme with serial search for the purpose of alleviation of fading effect and analyze the effect of MAI. The proposed acquisition scheme utilizes the estimated channel gain in Rayleigh fading channel. The cannel gain is estimated prior to PN code correlation and is used to compensate the fluctuation of the received signal due to fading effect.

The organization of this paper as follows; Section 2 describes the conventional acquisition system model. The proposed acquisition scheme is introduced in Section 3. In Section 4, the simulation results for the mean acquisition time are presented and compared to that of the conventional acquisition. Finally, conclusions are drawn in Section 5.

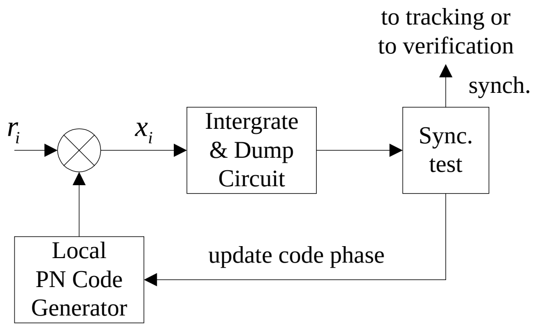

Fig.1 Structure of the conventional serial acquisition system

2. System Model

In this paper, we consider the case of Rayleigh fading channel. The power spectral density of the fading process is given by the classical Doppler spectrum formula. The normalized autocorrelation function $R_x(\rho)$ and $R_y(\rho)$ of the in-phase and quadrature components, $x(t)$ and $y(t)$ respectively, are given as

$$R_x(\rho) = R_y(\rho) = J_0(2\pi\ f_d\rho) \qquad (1)$$

where ρ is the time offset, $J_0(\cdot)$ is zeroth-order Bessel function, $f_d = f_c v/c$ is the maximum Doppler frequency shift, f_c is the carrier frequency, v is vehicle speed, and c is speed of light [9]. From (1), the amplitude and phase of the received signal can be assumed to be time-invariant over successive PN chips. Thus, we assume that the Rayleigh fading considered in this paper is slow enough that the amplitude and the phase of the received signal remain constant over N_I PN chip times but fast enough that successive outputs of a correlator are independent, where N_I is the number of PN chips for the integration length. This assumption is valid unless the Doppler spread is very large [5][6].

The structure of the conventional serial acquisition system for DS/SS system is shown in Fig. 1. The baseband equivalent of the received signal without MAI can be expressed as

$$r(t) = \alpha e^{j\theta} g(t + iT_c) + n(t) \qquad (2)$$

where $g(t)$ is the PN code on values of 1 and –1, i is the unknown phase of the PN code T_c is the chip duration, $n(t)$ is additive white Gaussian noise (AWGN) with one-sided power spectral density N_0, and $\alpha e^{j\theta}$ is a Gaussian random variable with α having Rayleigh probability distribution function (pdf) and unit second moment, i.e., $E[\alpha^2]$ = 1. If we can assume that the fading channel is so slow that we can estimate the phase shift θ with sufficient accuracy, and hence compensate for it, then coherent detection is feasible. Thus, equation (2) can be further simplified to

$$r(t) = \alpha g(t + iT_c) + n(t). \qquad (3)$$

From equation (3), it should be immediately apparent that with this simple model of the fading channel the only difference with respect to an AWGN channel resides in the fact that α, instead of being a constant attenuation, is now a random variable whose value affects the amplitude of the received signal.

The received signal is sampled at time $t = iT_c$ to form the input samples r_i given as

$$r_i = \alpha_i g(i - l) + n_i \qquad (4)$$

where l is the phase of the received PN code.

This sampled signal is correlated with a locally generated PN code in the correlator. The correlated value x_i is written as

$$\begin{aligned} x_i &= r_i \cdot g(i-k) \\ &= \alpha_i[g(i-l)g(i-k)] + n_i g(i-k) \\ &= \alpha_i\theta_i + \eta_i \end{aligned} \qquad (5)$$

where k is the phase of the local PN code, $\theta_i = g(i-l)g(i-k)$, and $\eta_i = n_i g(i-k)$, respectively. Because $g(i-l)$ and n_i are i.i.d random variables, the mean of η_i is zero and the variance is $\sigma_\eta^2 = \sigma_n^2$.

3. The Proposed Acquisition Scheme

3.1 Channel Gain Estimator

In fading channel, the channel estimation for the acquisition system is required to improve the acquisition performance, because the amplitude of the received signal fluctuates by the fading effect causing the mean acquisition time be increased. We assume that the fading channel is sufficiently slow and the amplitude of AWGN is known at the receiver that the channel gain can be estimated from the received signal without error.

In (4), $g(i-l)$, n_i are independent and identically distributed (i.i.d) random variables according to $E[n_i \cdot g(i-l)]$= 0. Also, if we let $s_i = r_i^2$, $\sigma_n^2 = E[n_i^2]$, the average power of the received signal is written as

$$E[s_i] = \alpha_i^2 E[g^2(i-l)] + E[n_i^2] + 2\alpha_i E[n_i \cdot g(i-l)]$$
$$= \alpha_i^2 + \sigma_n^2. \qquad (6)$$

Thus, the estimated channel gain is written as

$$\hat{\alpha}_i = \sqrt{E[s_i] - \sigma_n^2} \qquad (7)$$

where $\hat{\alpha}_i$ is approximated the gaussian distribution.

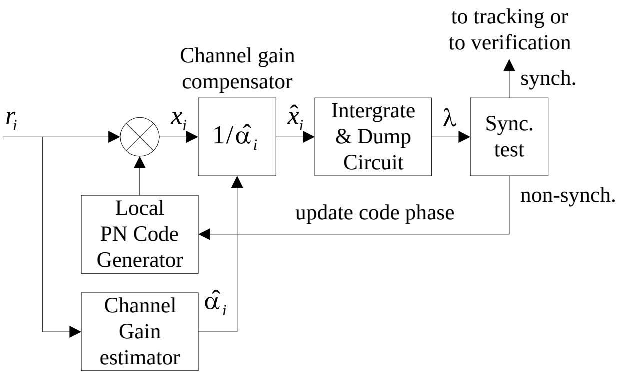

Fig. 2 Structure of proposed acquisition system

3.2 Channel Gain Compensator

For the purpose of alleviation of fading effect, the estimated channel gain is used to compensate the fluctuation of the received signal caused by the fading effect. The compensated value $\hat{x}_i$ from the channel gain compensator is written as

$$\hat{x}_i = \frac{1}{\hat{\alpha}_i} x_i = \frac{1}{\hat{\alpha}_i}(\alpha_i \theta_i + \eta_i). \qquad (8)$$

This sequence $\{\hat{x}_i\}$ is linearly accumulated and tested whether the phase of the local PN code is synchronized with that of the received PN code. If they are not synchronized, the phase of the local PN code is shifted by ΔT_c until it is aligned, where Δ is usually 1, 1/2, or some other fractional value, depending on the pull-in range of the tracking circuit and on whether or not the chip timing is known. Since we assume that the chip timing is known, it suffices to use $\Delta = 1$.

To test the synchronization of two codes, let the null hypothesis H_0 be the case when the phases of the two codes are unsynchronized, and the alternative hypothesis H_1 be the case when the phases of the two codes are synchronized. The synchronization test performs by comparing the correlation value with the threshold to decide between H_0 and H_1. If a correct phase is handed, to the tracking system, the acquisition process is finished. But, if a false phase is handed it cannot be absorbed and the system will go back to acquisition after the penalty time.

The test statistic λ is given as

$$\lambda = \frac{1}{N_c} \sum_{i=1}^{N_c} \hat{x}_i \qquad (9)$$

where N_c is the number of chip samples. λ is compared with the threshold to decide between H_0 and H_1.

4. Simulation Results

In order to evaluate the performance, the mean acquisition time of the proposed acquisition system is obtained by computer simulation and compared with that of the conventional one. In the simulation, we used the following parameters. The PN code period L (or PN code length) is set to 1024chips, the correlation length (256) is considered in search mode, the correlation interval in the verification mode is set twice as much as that in the search mode, and the penalty factor is set to be $25000T_c$. The threshold is determined numerically to minimize the mean acquisition time for each value of SNR/chip. The simulation was run for Rayleigh fading channel by Jakes model [9]. The carrier frequency sets f_c = 900MHz and the Doppler frequency sets f_d = 20Hz. For the results shown, the mean acquisition time has been normalized by LT_c, and denoted by $E\{T_{ACQ}\}/LT_c$ [3].

Fig. 3 shows the mean acquisition time of the proposed acquisition system without MAI compared with that of the conventional one. From fig. 3, we can see that the mean acquisition time in slow fading channel increases about 3.3 dB compared with an AWGN channel due to fading effect. At low SNR/chip regions, it is shown that the mean acquisition time of the proposed acquisition system is reduced than that of the conventional one. Specially, it saves about 2.4 dB at SNR/chip = –15dB. Thus, it is shown that the channel gain can be correctly estimated at the receiver and the amplitude fluctuation of received signal is compensated using this estimated channel gain, then the acquisition performance of the proposed acquisition scheme can be improved than that of conventional one.

In multiuser environment, the acquisition has to be achieved in the presence of the MAI due to other user signal. Thus, we analyze the effect of MAI on acquisition performance for the fading channel. In Fig. 4, we compare the mean acquisition time as a function of the number of users in conventional acquisition system. We consider the case of perfect power control and the parameter SNR/chip is chosen to be 0dB, -5dB, and -10dB, respectively. From Fig.4, the mean acquisition time increases significantly as the MAI increases. Thus, the increase of the mean acquisition time due to MAI depends on the number of users in the system. Fig. 5 shows the mean acquisition time of the proposed acquisition system with MAI compared with that of the conventional one when the SNR/chip is –10dB. From Fig. 5, the mean acquisition time of two systems increases significantly as the MAI increases and the proposed acquisition system performs considerably better than the conventional one. Specially, it saves about 1.3 dB at the number of users = 20.

5. Conclusions

In this paper, we proposed a new acquisition scheme for the purpose of alleviation of fading effect in DS/SS communication system and analyze the effect of MAI. The proposed acquisition scheme utilizes the estimated channel gain to compensate the fluctuation of the received signal caused by a fading channel. From the computer simulation results, it is shown that the proposed acquisition scheme provides a significant performance improvement because of the compensation of the amplitude fluctuation of received signal using the estimated channel gain and that the improvement is obtained when the MAI provides the severe acquisition performance degradation. These results depend on the assumption that the fading channel is so slow that we can estimate the channel gain in CDMA mobile communication environment.

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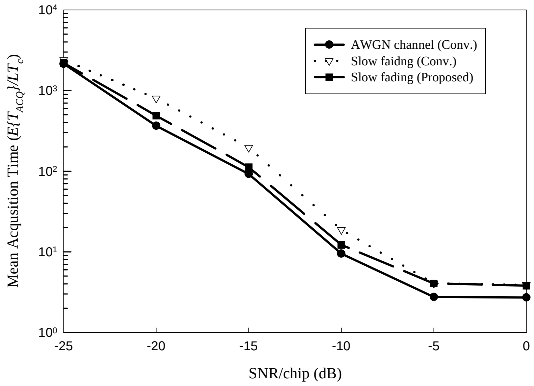

Fig. 3 Mean acquisition time versus SNR/chip (dB) in AWGN, slow fading channel

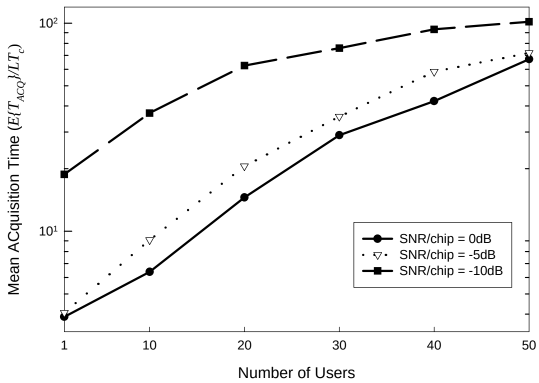

Fig. 4 Mean Acquisition time versus number of users in conventional acquisition system

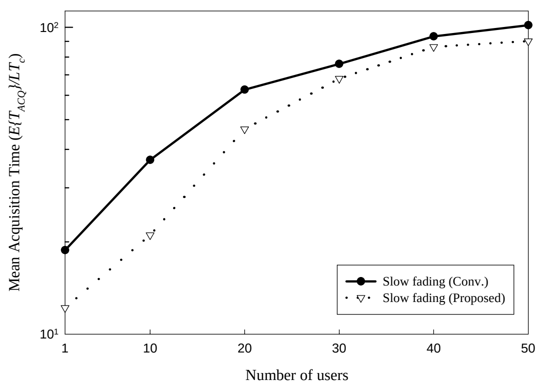

Fig. 5 Mean Acquisition time versus number of users