Performance of PN Code Acquisition with Nonlinear Power Amplifier based on DMF for CDMA Mobile Communications

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Abstract

In this paper, the DS/CDMA PN code acquisition system with nonlinear transmitter power amplifier based on digital matched filter (DMF) which has the rapid acquisition time is presented and the performance is evaluated in terms of mean acquisition time, detection probability, and signal to interference under multiuser environment. The performance is presented with respect to the output backoff of the nonlinear amplifier and the correlation window.

I. Introduction

In the future, not only voice service but high data rate services such as video and data transmission is required. But the CDMA technology based on IS-95 has some limits to accommodate the wireless multimedia service flexibly, because the system is optimized for voice and low rate data traffic services. To solve these problems, the technique of multi-carrier transmission has recently been receiving wide interest for high data rate applications. A critical aspect of a receiver in MC-CDMA as well as DS-CDMA system is data recovery by despreading the data through the synchronization of the incoming PN sequence and locally generated PN sequence. Meanwhile in particular to the RF section, spectral efficiency is achieved at the expense of requiring a linear transmit power amplifier. But the linear power amplifier cannot meet the low-power consumption requirements. To meet the requirements, as the efficiency increases so does the distortion (nonlinear characteristics), necessitating the use of compensation schemes. The nonlinear characteristics introduce the spectral spreading which cause the performance degradation in multiuser environment. Various kinds of researches for the CDMA system have been proposed and analyzed[1]-[3]. In theses researches, the effect of the nonlinearity of the power amplifier on the acquisition performance has rarely been evaluated. In this paper, the acquisition performance is analyzed with respect to the output backoff of the nonlinear amplifier in multiuser environment.

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II. System description

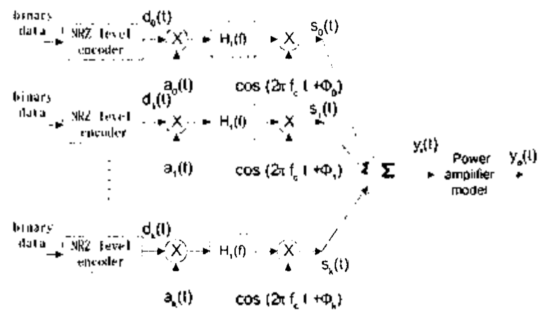

Figure 1. DS/SS transmitter block diagram.

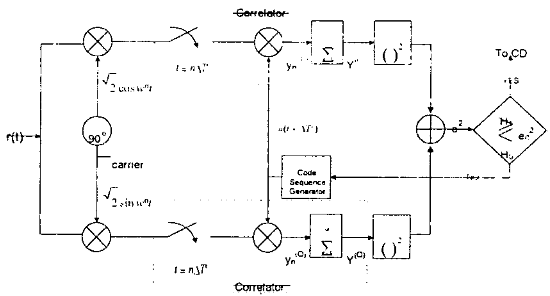

Figure 2. Digital Matched filter acquisition system.

The kth user's transmitted signal is given by

$$s_k(t) = \sqrt{E_c}\, a_k(t) \cos(2\pi f_c t + \Phi_k) \quad (1)$$

where E_c is chip energy, $a_k(t)$ is kth user's spreading sequence, f_c is carrier frequency, and Φ_k is carrier phase. A pilot signal is used for the purpose of acquisition, therefor the effect of data modulation is not considered here for acquisition. As a result, $d_k(t)$in the equation (1) has all 1's. And $H_1(f)$ is transfer function of the transmitter filter which is assumed constant. And the signal at the amplifier input is given by

$$y_i(t)=\sum_{k=1}^{K}s_k(t)=\sqrt{E_c}\sum_{k=1}^{K}a_k(t)\cos(2\pi f_c t+\Phi_k) \quad (2)$$

The characteristics of the power amplifier are presented by 3rd order power series, so the resultant output is given by[4]

$$y_o(t)=\sqrt{2P}[y_i(t)+A_3 y_i^3(t)] \quad (3)$$

The received signals are given by

$$r(t)=\sum_{k=1}^{K}\gamma_k\sqrt{2P}s_k(t+\Delta_k T_c)+A_3\sqrt{2P}[\sum_{k=1}^{K}s_k(t+\Delta_k T_c)]^3+n(t) \quad (4)$$

Where Δ_k is the propagation delay and γ_k is path loss. Theses two terms are assumed constant for the conveni-ence of analysis. At the receiver, partial correlation of the incoming and locally generated in-phase(I) and quadrature(Q) signals are performed with the correlation window ($T_p=MT_c$). Locally generated codes are represented as

$$I(t)=a_1(t+\hat{\Delta}T_c)\cos 2\pi f_c,\quad Q(t)=a_1(t+\hat{\Delta}T_c)\sin 2\pi f_c \quad (5)$$

Where $\hat{\Delta}T_c$ is the code phase offset of the receiver locally generated. The correlator outputs are given by

$$Y^{(I)}=\frac{1}{T_p}\int_0^{t_p}r(t)I(t)dt,\quad Y^{(Q)}=\frac{1}{T_p}\int_0^{t_p}r(t)Q(t)dt \quad (6)$$

The decision variables are represented as

$$Y^{(I)}=D+N+L_I+NL_I \quad (7)$$

Where D is the desired component of reference user(user1), N is AWGN component L_I is linear other user interference, and NL_I is nonlinear other user interference.

III. Performance analysis

In the linear region, the received signals are given by

$$r(t)=\sqrt{2P}\sum_{k=1}^{K}\gamma_k a_k(t+\Delta_k T_c)\cos(2\pi f_c t+\phi_k) \quad (8)$$

The desired component of the reference user is given

$$D=\frac{1}{T_p}\int_0^{T_p}\gamma_1\sqrt{2P}a_1(t+\Delta_1 T_c)\cos(2\pi f_c t+\phi_1)I(t)dt$$
$$=\gamma_1\sqrt{P/2}R_c(\delta_1)\cos\phi_1,\qquad \delta_1=|(\Delta_1-\hat{\Delta}_1)T_c| \quad (9)$$

$$R_c(\delta)=\frac{1}{T_p}\int_0^{T_p}a_1(t+\Delta_1 T_c)a_1(t+\hat{\Delta}_1 T_c)dt$$

where
$$=\begin{cases}1-\delta & \delta<1 \quad (H_1 state)\\ 0 & \delta>1 \quad (H_0 state)\end{cases} \quad (10)$$

linear other user interferences are represented as

$$L_I=\frac{1}{T_p}\int_0^{T_p}\sqrt{2P}\sum_{k=2}^{K}\gamma_k a_k(t+\Delta_k T_c)\cos(2\pi f_c t+\phi_k)I(t)dt$$
$$=\sqrt{P/2}\sum_{k=2}^{K}\gamma_k\cos\phi_k Z_k, \quad (11)$$

Where Z_k is partial correlation function between the desired signal and kth user, is given by [5]

$$Z_k=\frac{1}{M}\left[(1-\delta_k)\sum_{n=0}^{M-1}a_{1,n}a_{k,n-\eta_k}+\delta_k\sum_{n=0}^{M-1}a_{1,n-1}a_{k,n-\eta_k}\right] \quad (12)$$

where η_k is integer, $0\le\delta_k<1$

since $a_{1,n}$ and $a_{k,n}$ are independent random variables taking on +1 and -1 values with equal probability, based on the central limit theorem, Z_k has a Gaussian distribution when $M>>1$ with mean $E[Z_k]=0$ and variable $\sigma^2 zk=E[Z^2k]\approx\frac{2T_p}{3M}$. Due to the random phase $\varnothing_k$ uniformly distributed over $[0,2\pi]$, each terms L_I is independent of any other terms, therefore L_I is a Gaussian random variance with mean 0, and variance is given by

$$\sigma^2 L_I=E[L^2{}_I]=\frac{T^2_p P}{2}\sum_{k=2}^{K}\gamma_k\frac{1}{3M} \quad (13)$$

The nonlinear components which are generated by the term $y^3 i(t)$ in equation are represented as

$$\left\{ \sum_{k=1}^{K} s_k \right\}^3 = \sum_{k=1}^{K} s_k^{\,3} + 3s_1^{\,2} \sum_{k=1}^{K} s_k + 3s_1 \sum_{k=2}^{K} s_k^{\,2} + 3 \sum_{j=2}^{K} \sum_{k=2, j\neq k}^{K} s_j^{\,2} s_k + 3s_1 \sum_{j=2}^{K} \sum_{k=2, j\neq k}^{K} s_j s_k + \sum_{i=2}^{K} \sum_{j=2, j\neq i}^{K} \sum_{k=2, j\neq i, j}^{K} s_i s_j s_k \quad (13)$$

If the 3rd harmonic components are eliminated, the intermodulation distortion caused by equation (14) is represented by

$$y^3 i(t) = \frac{1}{4} \sum_{i=0}^{6} h_i(t) \quad (15)$$

where

$$h_1(t) = 3 \sum_{k=1}^{K} a_k(t + \triangle_k T_c) \cos(2\pi f_c t + \varnothing_k) \quad (16)$$

$$h_2(t) = 3 \sum_{k=2}^{K} a_k(t + \triangle_k T_c)[2\cos(2\pi f_c t + \varnothing_k) + \cos(2\pi f_c t - \varnothing_k)] \quad (17)$$

$$h_3(t) = 3 \sum_{k=2}^{K} a_1(t + \triangle_k T_c)[2\cos(2\pi f_c t) + \cos(2\pi f_c t + 2\varnothing_k)] \quad (18)$$

$$h_4(t) = 3 \sum_{j=2}^{K} \sum_{k=2, k\neq j}^{K} a_k(t + \triangle_k T_c)[2\cos(2\pi f_c t + \varnothing_k) + \cos(2\pi f_c t + 2\varnothing_j - \varnothing_k)] \quad (19)$$

$$h_5(t) = 3 \sum_{j=2}^{K} \sum_{k=2, k\neq j}^{K} a_1(t + \triangle_1 T_c) a_j(t + \triangle_j T_c) a_k(t + \triangle_k T_c) \cdot [\cos(2\pi f_c t + \varnothing_j + \varnothing_k) + \cos(2\pi f_c t + \varnothing_j - \varnothing_k) + \cos(2\pi f_c t + \varnothing_k - \varnothing_j)] \quad (20)$$

$$h_6(t) = \sum_{i=2}^{K} \sum_{j=2, j\neq i}^{K} \sum_{k=2, k\neq i,j}^{m} a_i(t + \triangle_i T_c) a_j(t + \triangle_j T_c) a_k(t + \triangle_k T_c) \cdot [\cos(2\pi f_c t + \varnothing_i + \varnothing_j - \varnothing_k) + \cos(2\pi f_c t + \varnothing_i - \varnothing_j + \varnothing_k) + \cos(2\pi f_c t - \varnothing_i + \varnothing_k + \varnothing_j)] \quad (21)$$

intermodulation distortion signal components at the correlator output are given by

$$NL_I = \sqrt{2P} \frac{A_3}{4T_b} \int_0^{T_b} \sum_{i=1}^{6} h_i(t) a_1(t + \widehat{\triangle}_1 T_c) \cos(2\pi f_c t) dt \quad (22)$$

And the variance are given by

$$\sigma^2_{NL_I} = E[NL_I^{\,2}] = \frac{A^2_3 P}{8} \sum_{m=1}^{6} \widetilde{N}L_{I_m} \quad (23)$$

where,

$$\widetilde{N}L_{I_1} = \sum_{k=2}^{K} \frac{3}{4} \frac{T_b^2}{M} \quad (24)$$

$$\widetilde{N}L_{I_2} = \sum_{k=2}^{K} \gamma_k \frac{27}{4} \frac{T_b^2}{M} \quad (25)$$

$$\widetilde{N}L_{I_3} = \sum_{k=2}^{K} \gamma_k \frac{27}{4} R(\rho, \delta) \quad (26)$$

$$\widetilde{N}L_{I_4} = \sum_{k=2}^{K} \gamma_k \frac{15}{4} \frac{KT_b^2}{M} \quad (27)$$

$$\widetilde{N}L_{I_5} = \sum_{j=2}^{K} \sum_{k=2, k\neq j}^{K} \frac{15}{2} R^2_{ajk} R(\rho, \delta) \quad (28)$$

$$\widetilde{N}L_{I_6} = \sum_{i=2}^{K} \sum_{j=2, j\neq i}^{K} \sum_{k=2, k\neq i,j}^{K} \frac{3}{20M^2} R^2_{aijk} \quad (29)$$

where,

$$R_{ajk} = \frac{1}{T} \int_0^{T_b} a_j(t + \triangle_j T_c) a_k(t + \triangle_k T_c) dt \quad (30)$$

$$R_{aijk} = \frac{1}{T} \int_0^{T_b} a_i(t + \triangle_i T_c) a_j(t + \triangle_j T_c) a_k(t + \triangle_k T_c) dt \quad (31)$$

$$R(\rho, \delta) = E[a_1(t) a_1(t - \rho) a_1(t + \delta T_c) a_1(t - \rho + \delta T_c)] \quad (32)$$

And the background noise is AWGN with mean 0 and variance $\frac{N_0}{4T_b}$

IV. Acquisition

The acquisition sprocess is modeled using state transition diagram shown [1]. For worst case code phase offset over code uncertainty region, mean acquisition time is obtained by

$$\overline{T}_{ACQ} = \left(\frac{P_{ACQ}}{P_{D1}} \right) \tau_d \{ (K+1) P_{D1} + \overline{T}_M P_{ACQ} + (\nu - 1) \overline{T}_0 [P_{D1} + P_{ACQ}(1 - P_{D1})] / (1 - P_{FA1}) \} \quad (33)$$

where $\overline{T}$ is mean time per H_0 normalized by τ_d, $\overline{T}_M$ is miss detection mean time. And each is represented by

$$\overline{T}_0 \equiv \tau_d^{\,-1} H_0(1) = (1 - P_{FA_0}) + (K+1) P_{FA_0}(1 - P_{FA_1}) \quad (34)$$

$$\overline{T}_M \equiv \tau_d^{\,-1} H_M(1) = (1 - P_{D_0}) + (K+1) P_{D_0}(1 - P_{D_1}) \quad (35)$$

And P_{D_0} is detection probability in verification mode at cell H_1 P_{D_1} is detection probability in search mode at cell H_1. P_{FA_0} is false alarm probability in search mode, and P_{FA_1} is false alarm probability in verification mode and is represented bys

$$P_{FA_0} = \int_0^\infty f_{H_0}(V)dV = \exp^{-\theta/2\sigma_1^2} \tag{36}$$

$$P_{d_0} = \int_0^\infty H_1(V)dV = \int_{\theta/2\sigma_1^2}^\infty e^{-(x+\lambda)} I_0(2\sqrt{\lambda x})\,dx \tag{37}$$

where I_0 is 0 order modified Bessel function and

$$x = \frac{V}{2\sigma_1^2}, \quad \lambda = \frac{E^2}{2\sigma_1^2} \tag{38}$$

And V, the detector input signal is defined by

$$V = Y^{(I)^2} + Y^{(Q)^2} \tag{39}$$

Its squared mean E is represented by

$$E^2 = \frac{MP}{2}\gamma_1^2 R^2 c(\delta_1) \tag{40}$$

and the variance of $Y^{(I)}$ is given by

$$\sigma^2_I = \sigma^2_{L_I} + \sigma^2_{NL_I} + \sigma^2_{N_I} = \frac{T_p^2 P}{2}\sum_{k=2}^{K}\gamma_k \frac{1}{3M} + \frac{A_3^2 P}{8}\sum_{m=1}^{6}\tilde{N}L_{I_m} + \frac{N_0}{4T_p} \tag{41}$$

$$P_{FA_1} = \sum_{n=B}^{A}\binom{A}{n} P^n_{FA_0}(1-P_{FA_0})^{A-n} \tag{42}$$

$$P_{D_1} = \sum_{n=B}^{A}\binom{A}{n} P^n_{D_0}(1-P_{D_0})^{A-n} \tag{43}$$

V. Results and conclusions

The mean acquisition time normalized to uncertainty time and detection probability is analyzed for a nonlinear amplifier on multiuser environment. The polynomial of the code sequence used is $X^{10}+X^3+1$. For the analysis, the following parameters are considered : the signal to interference(S/I), the number of correlation register(M), number of users(K), and amplifier output back off. In Fig3, the signal to interference ratios operated in the linear and nonlinear region (output backoff 2dB)are compared. From the results, the performance due to amplifier nonlinearity decreases rapidly as the number of users increases. In Fig4, detection probability versus number of users with correlation window M is presented. The results show that the correlation window is not critical in the performance when the users are rare. As other users increase, using a larger value of M reduces the performance degradation. And the curves show that the simulation results are very close to the analytical result. Fig.5 shows the acquisition time normalized to uncertainty time as a function of K which is the number of users. When there is a small other user interference, using M=256 gives the best performance. But the difference in the performance is not critical. As the users increase, the situation is changes. Using a larger value of M reduces the mean acquisition time. By this phenomenon we conclude as follow: In the case of small K, the correlation window M=256 is large enough to achieve a small variance of the decision variables so that code acquisition can be achieved correctly. As a result, using a smaller M value speed up the acquisition process. As the user increase, a longer correlation interval is necessary to ensure a high detection probability and, therefor, to keep a small value of the mean acquisition time. As a result, a larger M value results in better acquisition when the other user interference is severe. In this case, the interference results from the nonlinearity of the amplifier play a dominant role in the performance.

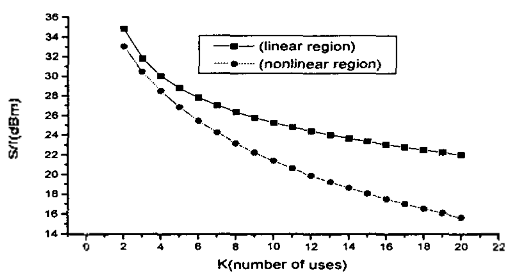

Figure 3. Signal to interference power ratio with the number of use.

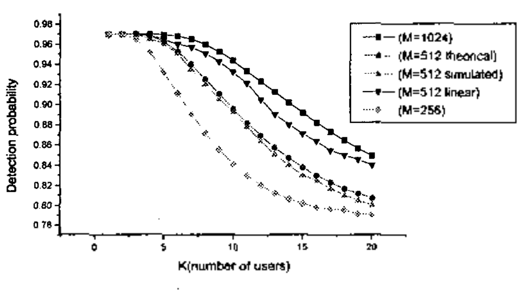

Figure 4. Detection probability with the number of user.

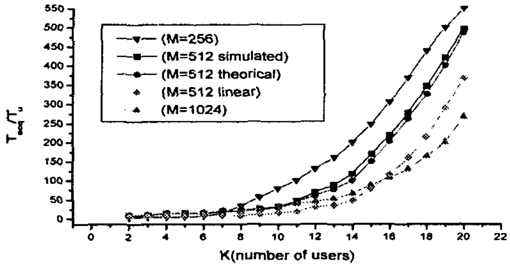

Figure 5. Acquisition time with the number of user

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