An adaptative method for determination of WDS in a DS/CDMA system

Y. Jabrane, R. Iqdour, B. Ait Es said and N. Naja

***Abstract*—** The steeping chip weighting waveforms are used in Multiple Access Interference (MAI) cancellation by emphasizing the received spreading signal, therefore, that allows to solve the problem of orthogonality for the chip waveforms. Our paper presents a useful method based on fuzzy systems to determine the despreading sequences weighted by the steeping chip weighting waveforms for Direct Sequence Code Division Multiple Access (DS/CDMA). The validity of our proposed method has been tested by numerical examples for an Additive White Gaussian Noise channel. We show that the parameter values of the chip weighting waveforms are good and the Bit Error Rate performance of the system does not undergone any degradation.

***Keywords*—** DS/CDMA, MAI, Weighted Despreading Sequences (WDS), Fuzzy Systems.

I. INTRODUCTION :

THE continuous growth of traffic volume and emergence of new services [1] have begun to change the structure of wireless networks. The high capacity required to support these characteristics can be obtained by using the spectrum as efficiently as possible and by flexibility in radio resource management [5]. A spread spectrum Code Division Multiple Access (CDMA) approaches have been proposed for a variety of digital cellular mobile and wireless personal communications systems [6].

In a DS/CDMA system, the biggest problem limiting its performances and capacity is due to interference produced by multiple access of several users in the channel (Multiple Access Interference MAI) [3]-[4]. The optimal multiuser detector proposed by [2] and [11] is a major theoritical study but is disavantaged by its computational complexity in the number of users and its requiring knowledge of delays, amplitudes, and modulation waveforms of the desired user and the interfering users.

Huang and Tung-Sang [7] have proposed a method to Weight Despreading Sequences (WDS) by stepping chip weighting waveforms with the purpose to the MAI cancellation. The despreading sequences were expressed according to one parameter [12]. This parameter has been adjusted in order to maximize the signal to interference plus noise ratio (SINR). Nevertheless, for each spreading code the calculation of optimal values of this parameter which maximize SINR while varying the signal to noise ratio (SNR) is not so easy.

In this paper we propose a new method based on fuzzy systems to determine the WDS for a DS/CDMA system. Our goal is to reduce the complexity calculation of the optimal values of the parameter for each SNR by using the learning ability and the high-speed computational capacity features of fuzzy systems.

The paper is organized as follows : In section II, we introduce the system model, also System performance evaluations are presented. Review of fuzzy systems techniques used is provided in section III. Numerical results and discussions are provided in section IV. Conclusions are drawn in section V.

II. MODEL STATEMENT :

We consider the system proposed by Huang and Tung-sang [7] described in figure 1 for binary phase-shift keying (BPSK) modulation, which suppose that there are K CDMA users accessing the channel. The receivers are equivalent to specific matched filters with impulse responses matched to the WDS's, $\zeta_k(\lambda)$ is the decision variable and $\hat{a}_k(t)$ is the WDS which will be described in detail below. User k transmits a binary data signal $b_k(t)$ and employs a spreading signal $a_k(t)$ to spread each data bit. the transmitted signal relative to the kth user is given by :

$$S_k(t) = \sqrt{2P} b_k(t) a_k(t) \cos(\omega_c t + \Theta_k) \qquad (1)$$

Where P and ω_c, common to all users, are the transmitted power and the carrier frequency, respectively ; Θ_k is a random phase. $b_k(t)$ is a binary data signal and $a_k(t)$ is the spreading code, which have respectively T_b and T_c as durations where $T_b = NT_c$ and N is the period of the spreading sequence, $a_k(t)$ and $b_k(t)$ are given by :

$$a_k(t) = \sum_{-\infty}^{\infty} a_j^{(k)} P_{T_c}(t - jT_c) \qquad (2)$$

$$b_k(t) = \sum_{-\infty}^{\infty} b_j^{(k)} P_{T_b}(t - jT_b) \qquad (3)$$

Thus, the received signal $r(t)$ at the base station is given

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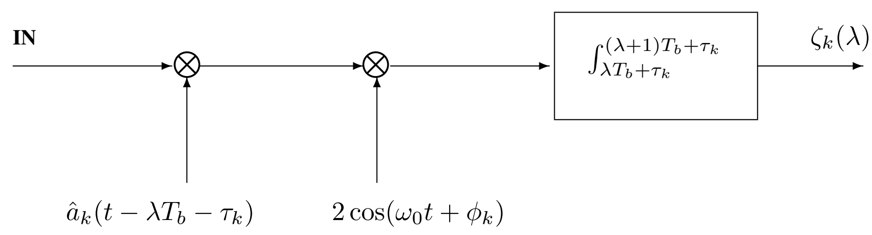

Fig. 1. The structure of a coherent receiver with a WDS for the k^{th} user

by :

$$r(t) = \sum_{k=1}^{K} S_k(t-\tau_k) + n(t)$$
$$= \sqrt{2P}\sum_{k=1}^{K} b_k(t-\tau_k)a_k(t-\tau_k)\cos(\omega_c t+\Phi_k) + n(t) \quad (4)$$

K is the total number of active users, τ_k and Φ_k are a random time delays and phases, respectively, which are related by : $\Phi_k = \Theta_k - \omega_c\tau_k$ for $1 \preceq k \preceq K$. n(t) is an AWGN with tow-sided power spectral density $\frac{N}{2}$. The weighted despreading sequence for the kth receiver is given by [7] :

$$\hat{a}_k(t) = \sum_{-\infty}^{+\infty} a_j^{(k)} w_j^{(k)}(t - jT_c/c_j^{(k)}, c_{j+1}^{(k)}) \quad (5)$$

Where $c_j^{(k)} = a_{j-1}^{(k)}a_j^{(k)}$and $w_j^{(k)}(t/c_j^{(k)}, c_{j+1}^{(k)})$ for $0 \le t \le T_c$, is the jth chip weighting waveforms for the kth receiver conditioned on the status of three consecutive chips : $\{c_j^{(k)}, c_{j+1}^{(k)}\} = \{a_{j-1}^{(k)}a_j^{(k)}, a_j^{(k)}a_{j+1}^{(k)}\}$ and $P_x(y) = 1$ for $0 < y < x$ and 0 otherwise. The jth chip conditional weighting waveforms for the kth receiver is defined by [7] as :

$$w_j^{(k)}(t/c_j^{(k)}, c_{j+1}^{(k)}) = \begin{cases} w_1, \text{ if } c_j^{(k)} = +1 \ and \ c_{j+1}^{(k)} = +1 \\ w_2, \text{ if } c_j^{(k)} = -1 \ and \ c_{j+1}^{(k)} = -1 \\ w_3, \text{ if } c_j^{(k)} = -1 \ and \ c_{j+1}^{(k)} = +1 \\ w_4, \text{ if } c_j^{(k)} = +1 \ and \ c_{j+1}^{(k)} = -1 \end{cases} \quad (6)$$

The elements of the chip weighting waveform vector $\{w_1(t), w_2(t), w_3(t), w_4(t)\}$ are given by :

$$\begin{cases} w_1(t) = L(\varepsilon)P_{T_c}(t) \\ w_2(t) = P_{T_c}(t) - [1-L(\varepsilon)]P_{T_c-2T_\Delta}(t-T_\Delta) \\ w_3(t) = P_{T_\Delta}(t) + L(\varepsilon)P_{T_c-T_\Delta}(t-T_\Delta) \\ w_4(t) = L(\varepsilon)P_{T_c-T_\Delta}(t) + P_{T_c}(t) - P_{T_c-T_\Delta}(t) \end{cases} \quad (7)$$

Where $T_\Delta \in [0, \frac{T_c}{2}]$, $\varepsilon = \frac{T_c}{T_\Delta} \in [2, \infty[$ is the parameter of the stepping chip weighting waveforms and $L(\varepsilon) \in [0,1]$ is a monotonically decreasing function with ε :
$L(\varepsilon) = [C(\frac{\varepsilon}{2}-1)+1]^{-1}$, where the constant C is chosen equal to 10 [7].We assume that$\tau_i = 0 \; and \; \Phi_i = 0$ for the i^{th} user, the $SINR_i$ conditioned on $c_j^{(k)}$ is given by equation (8), Where : $K_b = \frac{E_b}{N_0}$, $E_b = PT_b$, $\chi = \frac{\hat{N}_i}{N}$, N_j is a random variable which represents the number of occurrences of $c_j^i = -1$ for all $j \in [0, N-1]$ and the term $\Xi(\Gamma\{c_j^i\}, \varepsilon)$ is given by equation (9).

Where $\Gamma^{(i)}_{\{v_1,v_2,v_3\}}$ is the number of occurrences of $\{c_{j-1}^{(k)}, c_j^{(k)}, c_{j+1}^{(k)}\} = \{v_1, v_2, v_3\}$ for all $j \in [0, N-1]$ in the i^{th} WDS. Each element of $\{v_1, v_2, v_3\}$ takes values +1 or -1 with equal probabilities. It is obvious that $\sum_{\{v_1,v_2,v_3\}} \Gamma^{(i)}_{\{v_1,v_2,v_3\}} = N$.

In figure 2, SINR is plotted as function of ε for different values of $k_b = SNR$, when K=9. In the simulation, we took the following values :
$N = 63$, $\hat{N}_i = 34$, $\Gamma^{(i)}_{\{-1,-1,-1\}} = 6$, $\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}} = 20$, $\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}} = 6$,
$\Gamma^{(i)}_{\{-1,1,-1\}} = 20$, $\Gamma^{(i)}_{\{1,-1,1\}} = 6$, $\Gamma^{(i)}_{\{1,1,1\}} = 5$.

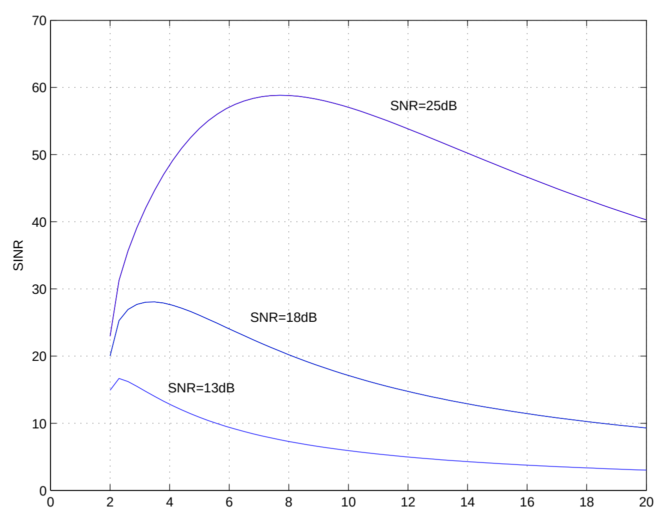

Fig. 2. SINR versus ε for various values $k_b = SNR$ when $K = 9$

As can be seen from the figure 2, the values of the parameter ε should be tuned to its optimal for different values of $k_b = SNR$, so the corresponding optimal values of ε to $SNR = 13dB$, $SNR = 18dB$ and $SNR = 25dB$ are respectively nearly equal to 2.25, 3.2 and 8.

That allows us to reduce the bit error rate in detection [8] given by (10) :

$$BER = erfc(\sqrt{max(SINR)}) \quad (10)$$

$$SINR_i = \left[\frac{\varepsilon[2\chi + (\varepsilon - 2\chi)L^2(\varepsilon)]}{2k_b[2\chi + (\varepsilon - 2\chi)L(\varepsilon)]^2} + \frac{(K-1)\Xi(\Gamma\{c_j^i\},\varepsilon)}{2\varepsilon N[2\chi + (\varepsilon - 2\chi)L(\varepsilon)]^2} \right]^{-1} \quad (8)$$

$$\begin{aligned} \Xi(\Gamma\{c_j^i\},\varepsilon) \;=\; & \frac{1}{N}\{\Gamma^{(i)}_{\{-1,-1,-1\}} \left[\frac{8}{3} + 4(\varepsilon-2)L(\varepsilon) + \frac{(\varepsilon-2)^2(4+\varepsilon)L^2(\varepsilon)}{3} \right] + \\ & (\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}) \left[\frac{5}{3} + (3\varepsilon - \frac{16}{3})L(\varepsilon)(\frac{\varepsilon^3}{3} - 3\varepsilon + \frac{11}{3})L^2(3) \right] + \\ & (\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}) \left[\frac{1}{3} + (\varepsilon - \frac{2}{3})L(\varepsilon) + (\varepsilon^3 - \varepsilon + \frac{1}{3})L^2(\varepsilon) \right] + \\ & \Gamma^{(i)}_{\{-1,1,-1\}} \left[\frac{2}{3} + 2(\varepsilon - \frac{2}{3})L(\varepsilon) + (\varepsilon^3 - 2\varepsilon + \frac{2}{3})L^2(\varepsilon) \right] + \\ & \Gamma^{(i)}_{\{1,-1,1\}} \left[\frac{2}{3} + (2\varepsilon - \frac{8}{3})L(\varepsilon) + (\frac{\varepsilon^3}{3} - 2\varepsilon + 2)L^2(\varepsilon) \right] + \\ & \Gamma^{(i)}_{\{1,1,1\}}\varepsilon^3 L^2(\varepsilon)\} \end{aligned} \quad (9)$$

where :

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty \exp(-x^2)dx \quad (11)$$

Figure 3 illustrates ε_{opt} versus SNR, calculated by direct method using equations (8) and (9).

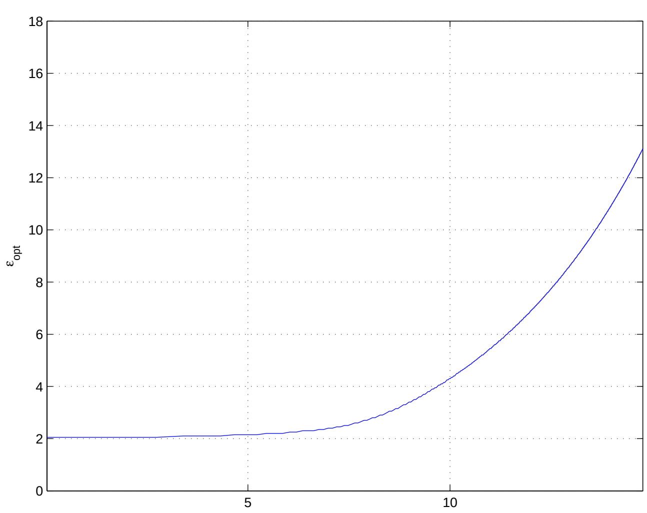

Fig. 3. ε versus SNR when $K = 9$ calculated by equation (8)

Figure 4 illustrates the bit error rate versus SNR, calculated by direct method using equations (8),(9) and (10).

It is remarkable from (8) and (9) that it is not easy to calculate the optimal values of ε for each code in a given code set.

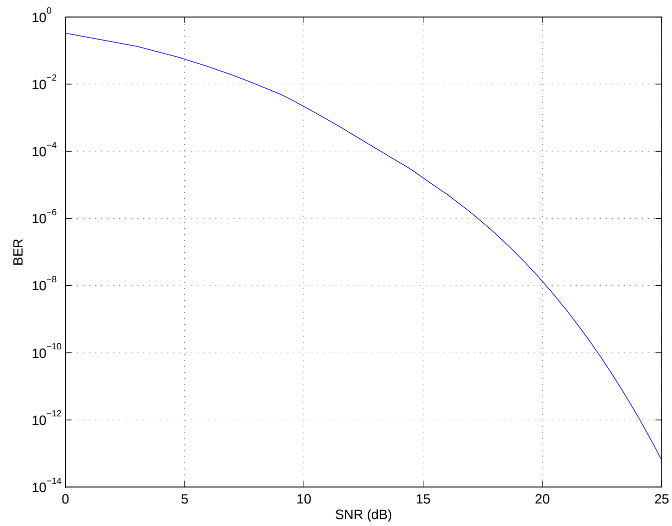

Fig. 4. BER versus snr when $K = 9$ calculated by equation (10)

To limit the complication of these calculations we introduce [9]-[10] fuzzy systems detailed in the following section.

III. FUZZY SYSTEMS BASED DETERMINATION :

Takagi-Sugeno (TS) fuzzy systems [13] is a very special class of fuzzy systems because the conclusion of each rule is crisp (not a fuzzy set). A typical single antecedent fuzzy rule in a Takagi-Sugeno model of order d has the form : R_k if x_t is A_k then :

$$\hat{y}_{t,k} = P_k^{(d)}(x_t) \quad (12)$$

for $k = 1, 2, ..., c$. Where x_t is the input variable ($x_t \in \Re^n$), A_k is a fuzzy set of R_k and $P_k^{(d)}(x_t)$ is a polynomial of order d of the components $x_{t,i}$ of x_t. In the sequel, we will suppose d=1.

For convenience, we will write the conclusion of rule R_k relatively to input x_t as :

$$\hat{y}_{t,k} = x_t^T \;\; \beta_k \quad (13)$$

Where

$$\beta_k = (\beta_1, \beta_2, ..., \beta_n)^T \tag{14}$$

An intercept is allowed in the conclusion $\hat{y}_{t,k}$ if we suppose that $x_{t,1} = 1$ (bias term).
Output $\hat{y}_t$ relative to input x_t obtained after aggregating a set of c TS rules can be written as a weighted sum of the individual conclusions :

$$\hat{y}_t = \sum_{k=1}^{c} \prod_k (x_t) \hat{y}_{t,k} \tag{15}$$

with :

$$\prod_k (x_t) = \frac{\mu_{A_k}(x_t)}{\sum_{j=1}^{c} \mu_{A_j}(x_t)} \tag{16}$$

Where μ_{A_k} is the membership function related to the fuzzy set A_k and is given by :

$$\mu_A(x) = \begin{cases} f(x) \ \ if \ \ x \in A \\ 0 \ \ if \ \ x \notin A \end{cases} \tag{17}$$

f(x) is a fuction which takes its values on [0,1].

The setting up of a TS fuzzy system requires two types of tuning [14]-[17] :
* Structural tuning : the number of the fuzzy rules c and the antecedent fuzzy sets $(A_k, k = 1, 2, ..., c)$ are identified. Many techniques are available in the literature [14]. In this study we used an exhaustive method, based on the use of the Gustafson-Kessel (GK) fuzzy clustering algorithm, which consists in initializing and adjusting the parameters for each selected structure, while starting with a system with two rules $(c = 2)$. The optimal number of the clusters c is that which gives a minimal value of the Root Mean Squares Error (RMSE) validity criterion.
* Parametric tuning : the model parameters (linear and non-linear) are estimated. The goal of the parameters optimisation is to find the "best" approximation $\hat{y}_t$ to the measured output y_t. The linear parameters β_k are identified using the Weighted Least Square (WLS) algorithm, where the Levenberg-Marquardt (LM) algorithm is used to estimate the non linear parameters (S_k and m_k).

The TS Fuzzy model employed has eight inputs and one output : Seven of the inputs are bound directly to the used code : $\Gamma^{(i)}_{\{-1,-1,-1\}}$, $\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}$, $\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}$, $\Gamma^{(i)}_{\{-1,1,-1\}}$, $\Gamma^{(i)}_{\{1,-1,1\}}$, $\Gamma^{(i)}_{\{1,1,1\}}$ $and\ \hat{N}_i$, the last input is k_b and the output of the TS fuzzy model is ε_{fs} . The k_b values of training data have been taken from the range of $[0, 25]dB$. This TS Fuzzy model used is illustred in figure 5.

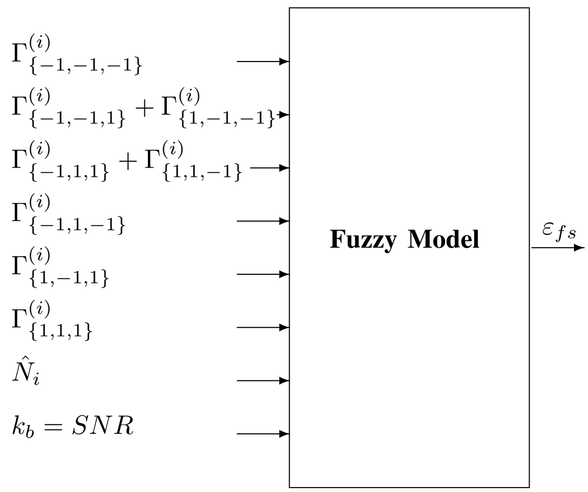

Fig. 5. The structure of the fuzzy model

IV. RESULTS :

In this section, we present the numerical results of our proposed method with $K = 9$ as number of users. The used codes in Table I are those of Gold having $N = 63$ for their good correlation properties [12]-[15]-[16]. The normalized cross-correlation matrix :

$$R = \rho_{mn} \tag{18}$$

with $m, n \in \{1, 2..., 9\}$, where :

$$\begin{aligned} \rho_{mn} &= \langle a_m, a_n \rangle \\ &= \int_0^T a_m(t) a_n(t) dt \end{aligned} \tag{19}$$

and :

$$\rho_{mn} = \begin{cases} \rho \ \ if \ \ m \neq n \\ 1 \ \ si \ \ m = n \end{cases} \tag{20}$$

Table II gives $\Gamma^{(i)}_{\{v_1,v_2,v_3\}}$ and $\hat{N}_i$ for each code and allow us to train our TS fuzzy model for different values of k_b.

After learning, the TS fuzzy model generalize the relation between the optimal values of $\varepsilon (= \varepsilon_{opt})$ and the spreading code while varying k_b values to maximize $SINR$, it was tested with unseen k_b values. The first code is used as reference in simulations.

In figure 6 we present the evolution of the ε_{opt} calculated directely by equations (8) and (9), and the ε_{fs} obtained using the TS fuzzy model (The number of the rules obtained is $c = 4$).

TABLE I

GOLD CODES OF $N = 63$

Code 1	010110110110110001100000011101010011010101101010100011010100110
Code 2	000111000101011100011100111110010111011100011111001000011000000
Code 3	010110010001111001111101010101111111010000000011000001111100000
Code 4	001110000110010110001011010010010111010100101011101011010011010
Code 5	000101001001101111101001100100010110101011110110010100100101001
Code 6	111011000000101011001111101101000011100100111001010111001000010
Code 7	100101110011011101100011100011101000101010000110010001100111001
Code 8	111111101111101101111110000111001110011110110000101001100001110
Code 9	001010010100110011001101110001100010010000011011100111011110110

TABLE II

NUMBER OF $\Gamma^{(i)}_{\{v_1,v_2,v_3\}}$ AND $\hat{N}_i$ CORRESPONDING TO EACH CODE

code	$\Gamma^{(i)}_{\{-1,-1,-1\}}$	$\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}$	$\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}$	$\Gamma^{(i)}_{\{-1,1,-1\}}$	$\Gamma^{(i)}_{\{1,-1,1\}}$	$\Gamma^{(i)}_{\{1,1,1\}}$	$\hat{N}_i$
1	16	16	8	12	8	3	40
2	4	8	24	4	12	11	24
3	8	8	16	4	8	19	24
4	14	20	12	10	6	1	40
5	12	24	8	12	4	3	40
6	8	16	16	8	8	7	32
7	6	12	20	10	14	1	32
8	2	12	20	6	10	13	24
9	4	16	16	12	12	3	32

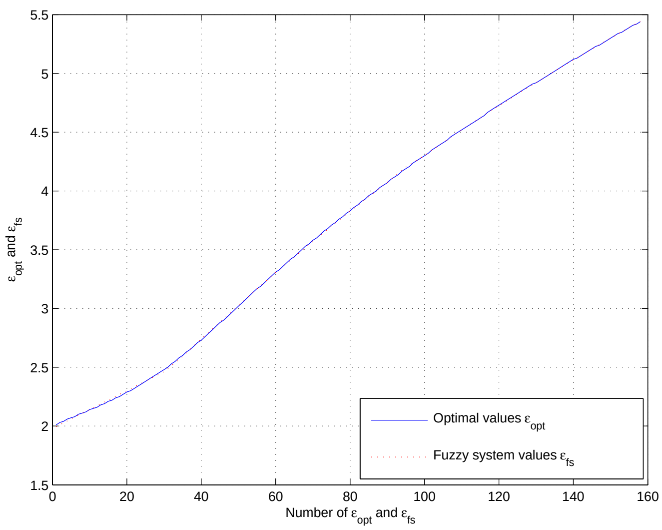

Fig. 6. The ε_{fs} and ε_{opt} for K=9

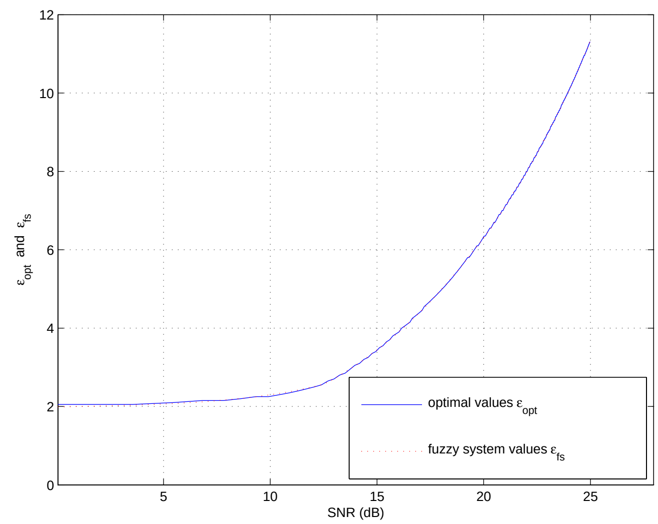

Fig. 7. The ε_{fs} and ε_{opt} versus k_b (K=9)

We note from figure 6 the good agreement between both parameters ε_{opt} and ε_{fs}.

Figure 7 illustrates, for different values of unseen k_b, the optimal values of the parameter ε_{opt} calculated directely by equations (8) and (9), and the results given by the TS fuzzy model ε_{fs}.

These results have been obtained using the first code given in Table 1 as reference, the same method can be done with the other codes from the given set.

According to this figure, we can conclude that the values obtained by the TS fuzzy model and the optimal values are identically near.

Figure 8 describe the bit error rate (BER) performances of the ith user's receiver versus k_b when the values given by the TS fuzzy model and the optimal values are used in the performance expression given by (10). We remark that the BER does not undergo any degradation . It remains to note that the same results are obtained for the other codes given in Table I.

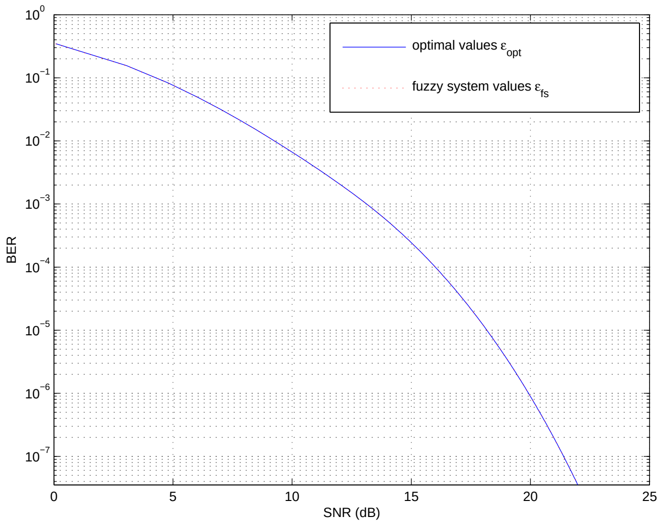

Fig. 8. BER versus k_b for the ith user's receiver when the ε_{fs} and ε_{opt} are used in the performance expression, $(K = 9)$

Another manner to prove the validity of our model consists to compute the RMSE (Root Mean Square Error) of both phases : training and test. The RMSE is given by :

$$RMSE = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(\varepsilon_{opt}(i) - \varepsilon_{fs}(i))^2} \qquad (21)$$

For 500 iterations, The RMSEs were 0.015 and 0.016 for the training and test (unseen k_b) phases, respectively. As we do not obtain a greater error, these results are in good agreement with those given on the figures.

V. Conclusion :

In this paper, a new method based on Takagi-Sugeno fuzzy systems permits us to determine easily the optimal values of ε while varying the SNR, and therefore the determination of the despreading sequences weighted by stepping chip weighting waveforms for a DS/CDMA system. It is worth concluding from the numerical evaluations that we get the nearly optimal values of $\varepsilon = (\varepsilon_{opt})$ quickly and easily by our method, and the bit error rate performance does not undergo any degradation while using the values obtained ε_{fs} instead of the optimal values.

The idea of our method can be successfully used for a DS/CDMA having different processing gain. It remains to note that the only inconvenience of our method is the constraint to train again our fuzzy systems when a new user is included in the system.

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