Blind Multiuser Identification in Multirate CDMA Transmissions: A New Approach

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Blind Multiuser Identification in Multirate CDMA Transmissions: A New Approach

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***Abstract*— A new blind sequences synchronization method in multiuser multirate CDMA context is proposed in this paper. Instead of the approach based on the FROBENIUS Square Norm Behaviour (FSNB) previously proposed in [1]–[3], we develop a new blind method based on the Maximum Eigenvalue Behaviour (MEVB) according to analysis window shifts. Theoretical analysis shows that the MEVB-based criterion provides a significant improvement of performances, and proves that it is a powerful tool for blind synchronization. We show that the improvement is mainly due to suppression of synchronisation peaks masking that occurred with the previous method. Simulation results confirm that, performing the synchronization process using this new criterion, allows one to achieve very good performances at the receiver side in term of chip error rate (CER) and bit error rate (BER), even at very low SNRs.**

I. INTRODUCTION

Spread spectrum signals have been used in the military domain for long time for secure communications [4]. Nowadays their field of application includes civilian transmissions, especially CDMA transmissions [5]. Thanks to the properties of the pseudo-random sequences used, the CDMA technique allows to solve the problem of the increasing number of users in a frequency band. Moreover, these signals are difficult to detect, especially in a non cooperative context (e.g. spectrum surveillance), because they are often below the noise level, due to low Signal-to-Noise Ratios (SNRs).

Several blind approaches (i.e. when the process of recovering data from multiple simultaneously transmitting users without access to training sequences) have been addressed in the literature [6]–[8]. In another way of research, many partially blind multiuser schemes, that exploit some known channel properties, have been proposed [9], [10]. But, all these methods are not blind in the sense used in our non cooperative context. Indeed, they require some prior knowledge about users parameters. This knowledge is not available in a non cooperative context.

Hence, this article is organized as follows: Section II will introduce the signal model and assumptions made. Section III will present the new approach. Section IV will deal with the theoretical analysis of the MEVB-based criterion and compare it with the FSNB-based one. The simulations results will be detailed in Section VI, and our conclusions will be drawn in Section VII.

II. SIGNAL MODELING AND ASSUMPTIONS

Let us consider the uplink multirate CDMA transmissions using the variable spreading length (VSL) technique (i.e. sequences have the same chip period, and data rates are tied to sequences length), the downlink can be viewed as a particular case of the uplink. Let us denote S, a set of available data rates $\mathcal{R}_0 < \mathcal{R}_1 < \cdots < \mathcal{R}_{S-1}$. By denoting N_u^i the number of active users transmitting at R_i and N_u the total number of users such that $\sum_{i=0}^{S-1} N_u^i = N_u$, the received signal can be expressed as:

$$y(t) = \sum_{i=0}^{S-1} \sum_{n=0}^{N_u^i-1} \sum_{k=-\infty}^{+\infty} a_{n,i}(k) h_{n,i}(t - kT_{s_i} - T_{d_{n,i}}) + b(t) \quad (1)$$

where $h_{n,i}(t) = \sum_{k=0}^{L_i-1} c_{n,i}(k) p_i(t - kT_c)$. In (1), the subscript $(\cdot)_{n,i}$ refers to the n^{th} user transmitting at $\mathcal{R}_i$, denoted throughout this article as the $(n,i)^{th}$ user. Accordingly:

- $a_{n,i}(k)$ are the baseband symbols of variance $\sigma^2_{a_{n,i}}$ for the $(n,i)^{th}$ user, whereas $p_i(t)$ is the convolution of the transmission filter, channel filter (which takes into account channel echoes, fading, multipaths and jammers) and receiver filter for each rate.
- The term $h_{n,i}(t)$, defined in $[0 \quad T_{s_i}[$, is a virtual filter corresponding to the convolution of all filters of the transmission chain with the spreading sequence $\{c_{n,i}(k)\}_{k=0 \cdots L_i-1}$, where L_i is the spreading factor for the $(n,i)^{th}$ user.
- Because of the VSL technique, the symbol period T_{s_i} for the users transmitting at the rate R_i is tied to the common chip period T_c: $T_{s_i} = L_i T_c$, and $s_{n,i}$ stands for the $(n,i)^{th}$ signal.
- The term $T_{d_{n,i}}$ is the corresponding transmission delay for the $(n,i)^{th}$ user; it is assumed to satisfy: $0 \leqslant T_{d_{n,i}} < T_{s_i}$ and to remain constant during the observation.
- $b(t)$ is a centered white Gaussian noise of variance σ_b^2.
- Signals are assumed to be independent, centered, noise-uncorrelated and received with the same power: $\sigma^2_{s_{n,i}} =$

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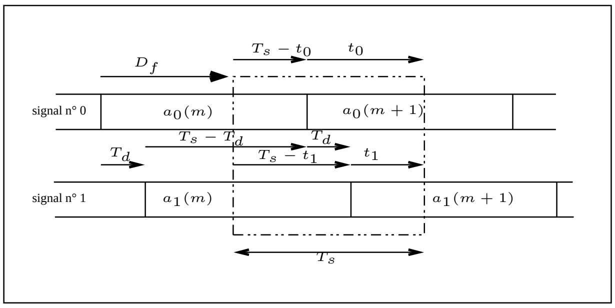

Figure 1. Relative position of two signals and an analysis window in uplink.

$\sigma^2_{s_{0,0}}$, for all (n,i), $n = 0,1,\cdots,N_u^i - 1$, $i = 0,1,\cdots,S-1$.

- Finally, the SNR (in dB) at the detector intput is negative (signal hidden in the noise).

III. Proposed Approach

The blind multiusers detection scheme proposed in [11] allowed us to estimate symbol periods T_{s_i}, thus data rates. Then, the synchronization process is performed within each group i of users transmitting at the same data rate. The received signal is sampled and divided into N non-overlapping temporal windows of duration $T_F = T_{s_i} = MT_e$, $M \in \mathbb{N}^\star$, where T_e is the sampling period, T_{s_i} is the symbol period estimated in [11], and denoted within a group T_s for more clearness.

Denoting $\mathbf{Y}$ the sampled received signal matrix which each column contains M signal $y(t)$ samples, leads us to get the following $(M \times N)$-matrix:

$$\mathbf{Y} = \begin{pmatrix} y(t) & \cdots & y(t+(N-1)T_s) \\ \vdots & \cdots & \vdots \\ y(t+T_s-T_e) & \cdots & y(t+NT_s-T_e) \end{pmatrix} \quad (2)$$

Thanks to theoretical analysis, (2) can be expressed as:

$$\mathbf{Y} = \sum_{n=0}^{N_u^i-1} \left(\mathbf{h}_n^0 + \mathbf{h}_n^{-1}\right) \mathbf{a}_n^T \quad (3)$$

where the vector $\mathbf{a}_n^T = [\cdots, a_n(m)\cdots]$ contains all the symbols of the n^{th} user. Since filters $h_n(t)$ are defined in $[0 \quad T_s[$ vectors $\mathbf{h}_0^n$ and $\mathbf{h}_n^{-1}$ are defined, for each interfering user whithin the group, as follows :

- the vector $\mathbf{h}_n^{-1}$ contains the end of the corresponding spreading waveform during $T_s - t_n$, followed by zeros during t_n;
- the vector $\mathbf{h}_n^0$ contains zeros during t_n, followed by the beginning of the corresponding spreading waveform during $T_s - t_n$.

where t_n, $n = 0,1,\cdots,N_u^i - 1$, represents the temporal shift between an analysis window and the beginning of a whole symbol of each corresponding signal, as illustrated on Fig. 1 for two users, T_d represents the transmission delay of the second signal, and D_f the analysis window translation.

Vectors $\mathbf{h}_n^0$ and $\mathbf{h}_n^{-1}$ allow one to take into account the temporal shifts t_n between an analysis window and the beginning of a whole symbol of the n^{th} interfering signal in the correlation matrix defined as: $\mathbf{R} = \mathbf{Y}\mathbf{Y}^*$, where $(\cdot)^*$ stands for the transpose conjugate of $(\cdot)$. Then, like in [1]–[3], and under the assumptions of independent, centered and noise-uncorrelated signals, and since the signals are assumed to be received with the same power, the correlation matrix $\mathbf{R}$ can be written as:

$$\mathbf{R} = \sigma_b^2 \left\{ \rho \frac{T_s}{T_e} \sum_{n=0}^{N_u^i-1} \left\{ (1 - \frac{t_n}{T_s}) \mathbf{v}_n^0 (\mathbf{v}_n^0)^* + \frac{t_n}{T_s} \mathbf{v}_n^{-1} (\mathbf{v}_n^{-1})^* \right\} + \mathbf{I} \right\} \quad (4)$$

where ρ is the signal to noise and interference ratio (SNIR) compared to one of the other users, $\mathbf{I}$ is the identity matrix, and vectors $\mathbf{v}_n^0$ and $\mathbf{v}_n^{-1}$ are normalized versions of $\mathbf{h}_n^0$ and $\mathbf{h}_n^{-1}$. Then, we set:

$$\begin{cases} \beta = \rho \frac{T_s}{T_e}, \; d_f = \frac{D_f}{T_s} \\ \alpha_n = \frac{t_n}{T_s}, \; \tau_n = \frac{T_{d_n}}{T_s} \end{cases} \quad (5)$$

Thus, $\alpha_n, \; \tau_n, \; d_f \in \; [0 \; 1[$. The $(M \times M)$ correlation matrix $\mathbf{R}$ can be rewritten as:

$$\mathbf{R} = \sigma_b^2 \left(\beta \sum_{n=0}^{N_u^i-1} \left\{ (1-\alpha_n) \mathbf{v}_n^0 (\mathbf{v}_n^0)^* + \alpha_n \mathbf{v}_n^{-1} (\mathbf{v}_n^{-1})^* \right\} + \mathbf{I} \right) \quad (6)$$

Since sequences are assumed to be slightly correlated, the matrix $\mathbf{R}$ eigenvalues in an unspecified order can be expressed as:

$$\begin{cases} \lambda_n^0 = \sigma_b^2 \left\{ \beta \left(1 - \alpha_n\right) + 1 \right\}, \quad n = 0,\cdots,N_u^i - 1 \\ \lambda_n^{-1} = \sigma_b^2 \left\{ \beta \alpha_n + 1 \right\}, \quad n = 0,\cdots,N_u^i - 1 \\ \lambda_n = \sigma_b^2, \quad n = 2N_u^i,\cdots,M-1 \end{cases} \quad (7)$$

Equations (6) and (7) highlight $2N_u^i$ eigenvalues associated to the signal space and the $M - 2N_u^i$ ones associated to the noise space (all are assumed to be equal on average to the noise power). Fig.1 and (7) evidence that each value α_n will change according to the normalized analysis windows shifts d_f in cyclic fashion. Thus, to take it into account, we set:

$$\begin{cases} \alpha = \langle d_f - \tau_n \rangle, n = 0,\cdots,N_u^i - 1 \\ \langle x \rangle \equiv \; x \; modulo \; 1, x \in \mathbb{R} \end{cases} \quad (8)$$

Then, using (6), (7) and (8) led us to derive a blind synchronization criterion based on the Frobenius Square Norm behaviour (FSNB) of (6) according to analysis windows shifts [1]–[3]. Nevertheless, theoretical analysis of the extended FSNB-based criterion to the multiuser case, evidence

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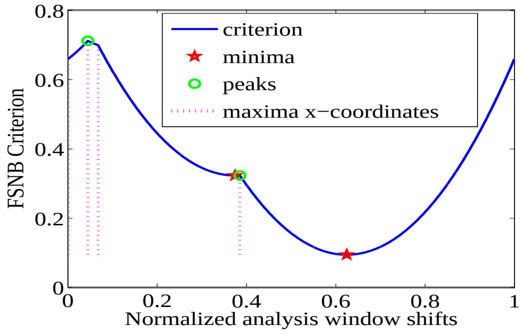

Figure 2. FSNB Criterion: case of the masking of synchronization peaks, $N_u^i = 4$

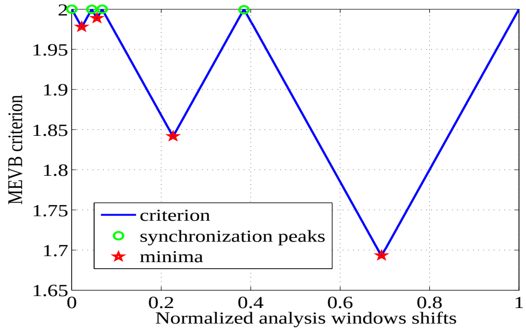

Figure 3. MEVB Criterion in uplink, $N_u^i = 4$

the performances degradation further to any increase in the number of users and/or decrease of SNRs.

Consequently, we developed a new blind synchronization scheme based no longer on the study of the FROBENIUS square norm behaviour, but rather on each maximum eigennvalue behaviour (MEVB) with analysis window shifts, as detailed in section below.

IV. THEORETICAL ANALYSIS

The FROBENIUS Square Norm of (6), denoted $\|\mathbf{R}\|_F^2$ is defined as:

$$\|\mathbf{R}\|_F^2 = \sum_{n=0}^{N_u^i-1} \left\{(\lambda_n^0)^2 + (\lambda_n^{-1})^2\right\} + (M - N_u^i)\sigma_b^2 \quad (9)$$

Using (8) in (9), and only keeping the variable part of the result, allowed us to express the extended FSNB-based criterion previously proposed in [1], and denoted here F:

$$F(d_f) = 1 + \sum_{n=0}^{N_u^i-1} \left\{\langle d_f - \tau_n\rangle^2 - \langle d_f - \tau_n\rangle\right\} \quad (10)$$

Equation (10) is quadratic convex function in each interval $[\tau_n \quad \tau_{n+1}[$. The extended FSNB-based synchronization scheme consists in maximizing (9), which is equivalent to find the criterion (10) maxima (synchronization peaks). Let us recall that a peak is a curve point from which while moving by lower or higher values, the curve is always decreasing. From (7) and (8), synchronization peaks may be at points $d_f = \tau_n$. However, we proved that according to the choice of τ_n, e.g. when two consecutive τ_n and τ_{n+1} are very close, points at $d_f = \tau_n$ are not synchronization peaks, as illustrated on Fig. 2, where: $\tau_0 = 0$, $\tau_1 = 0.0448$, $\tau_2 = 0.068$, $\tau_3 = 0.3853$.

Hence, this considerations led us to propose, as detailed here after, a new blind synchronization method based on the maximum largest eigenvalue behaviour according to analysis window shifts (MEVB).

Without loss of generality, let us set: $\sigma_b^2 = \beta = 1$, and introduce (8) in (7). Thus, the consecutive largest eigenvalues of (6) can be rewritten as:

$$\text{(a)} \begin{cases} \lambda_n^0 = 2 - \langle d_f - \tilde{\tau}_n\rangle \\ \lambda_n^{-1} = 1 + \langle d_f - \tilde{\tau}_n\rangle \end{cases} \qquad \text{(b)} \begin{cases} \lambda_{n+1}^0 = 2 - \langle d_f - \tilde{\tau}_{n+1}\rangle \\ \lambda_{n+1}^{-1} = 1 + \langle d_f - \tilde{\tau}_{n+1}\rangle \end{cases} \quad (11)$$

For any analysis window shift d_f such that $\tau_n \leq d_f < \tau_{n+1}$ and for any user n, (11) (a) shows that λ_n^0 decreases while λ_n^{-1} increases, and conversly. Moreover, (11) (a) and (b) also show that the n^{th} user eigenvalue decreases starting from its maximum value (synchronization peak) in $d_f = \tau_n$, while that of the $(n+1)^{th}$ increases, and the values for which they are equal are local minima. Hence, the MEVB-based criterion is defined as the maximum value between two consecutive largest eigenvalues. Consequently, the MEVB-based criterion is equivalent to the function $C(d_f)$ defined as:

$$C(d_f) = \max_{\tau_n \leq d_f < \tau_{n+1}} \left(\lambda_n^0, \lambda_{n+1}^{-1}\right), \ n = 0, \cdots, N_u^i - 1 \quad (12)$$

Since eigenvalues are linear functions of d_f, the MEVB-based criterion (12) always presents maxima, thus synchronization peaks in $d_f = \tilde{\tau}_n$, contrary to the extended FSNB-based one, as shown on Fig. 3, with the same parameters that those on Fig. 2. Let us note that the MEVB-based criterion can easily be derived for downlink transmissions by setting $\tau_n = 0$, $n = 0, \cdots, N_u^i - 1$ in all equations above.

Hence, the discussion above highlights that, after synchronizing using the criterion (12) performances will be better than those that will be obtained after synchronizing using the criterion (10), due to the lack of synchronization peaks masking as it will be shown in section VI. Once the synchronization process has been performed, sequences can be identified and the numbers of interfering users within the group detreminated as detailed in the following section.

V. SEQUENCES IDENTIFICATION AND NUMBER OF USERS DETERMINATION

Since it was set $\sigma_b^2 = \beta = 1$, once one of the interfering users is synchronised, e.g. $d_f = \tau_0$, which corresponds to set $\alpha_0 = 0$, the correlation matrix becomes:

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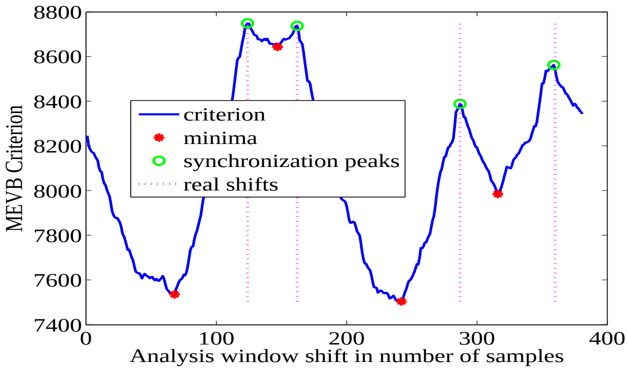

Figure 4. Experimental MEVB-based criterion, SNR $=-5\ dB$, $N_u^i = 4$

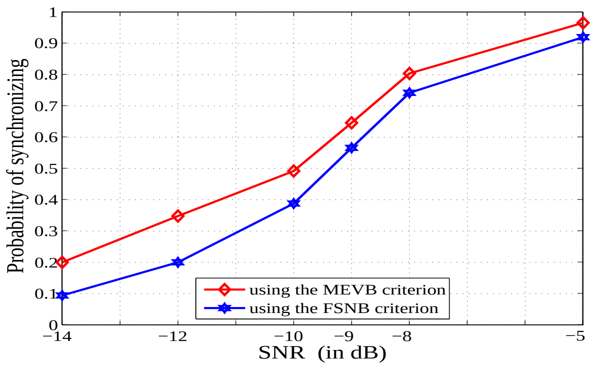

Figure 5. Probability of synchronizing at least one user, $N_u^i = 4$

$$\mathbf{R} = \mathbf{v}_0\mathbf{v}_0^* + \sum_{n=1}^{N_u^i-1} \{(1-\alpha_n)\mathbf{v}_n^0(\mathbf{v}_n^0)^* + \alpha_n\mathbf{v}_n^{-1}(\mathbf{v}_n^{-1})^*\} + \mathbf{I} \tag{13}$$

Hence, still under the assumptions of almost uncorrelated sequences, (13) highlights a maximum eigenvalue which associated vector contains the corresponding spreading sequence (apart from the effects the global transmission filter), $2(N_u^i-1)$ eigenvalues generated by the other users, and $M-2N_u^i+1$ eigenvalues equal, on average, to the noise power. Then this process is performed in an iterative way so as to get the N_u^i largest eigenvalues, which the N_u^i associated vectors contain the corresponding spreading sequences.

Moreover, the number of interfering users N_u^i within a group is directly equal to the number of synchronization peaks. In addition, in the particular case of downlink, i.e. $\tau_n = 0,\ \alpha_n = \alpha,\ n = 0, 1, \cdots, N_u^i - 1$, when users are synchronized, i.e. $\alpha = 0$, the correlation matrix becomes:

$$\mathbf{R} = \sum_{n=0}^{N_u^i-1} \mathbf{v}_n\mathbf{v}_n^* + \mathbf{I} \tag{14}$$

Hence, the correlation matrix (14) has N_u^i largest eigenvalues and $M - N_u^i$ eigenvalues equal which associated vector contains the corresponding spreading sequence (apart from the effects the total transmission filter), and the others are on average equal to the noise power. In this case, the number of interfering users is equal to the number of the largest eigenvalues.

At last, linear algebra techniques described in [1]–[3] and applied to the estimated eigenvectors, allow one to identify sequences used at the transmiter side and to recover transmitted symbols. It is obvious that the synchronization process errors will be propagated to the sequences identification and symbols recovering process. Hence, Section VI will focuss on performances in term of mean chip error rate (MCER) and mean bit error rate (MBER) at the receiver after synchronizing using both MEVB and FSNB criteria. We did not compare both criteria with others, since all schemes adressed in the literature need prior knowledge of at least one transmission parameter.

VI. Simulation Results

Simulations were carried out in uplink with 4 signals of $170\mu s$, each of them spread by a complex Gold sequence of length $L = 127$. The chip frequence was $F_c = 100$ MHz, the initial sampling frequence was $F_e = 300$ MHz, the SNR was $-5dB$ at the detector input, i.e., only the MAI noise is considered. The initial number of windows was $N = 58$, with a duration of $550\mu s$, and the number of samples was 32768. The symbols belong to a $QPSK$ constellation. The symbol period is blindly estimed as described in [11] and was $T_s = 1.27\mu s$. So, it was set: $T_F = T_s$, and normalized arbitrary analysis windows shifts at the beginning of the process was set: $\alpha_0 = 0.3228$, $\alpha_1 = 0.4226$, $\alpha_2 = 0.7533$, $\alpha_3 = 0.9423$.

Fig. 4 illustrates the experimental MEVB criterion curve and evidences 4 synchronization peaks. Hence, there are 4 users transmitting at this data rate, as expected.

Fig. 5 shows the probability of synchronizing at least one user, i.e. the probability of detecting and estimating at least a synchronization peak. It cleary confirms that this probability is higher when using the MEVB-based criterion than that when using the FNSB-based one.

Fig.6 highlights the performances in term of mean chip error rate (MCER), i.e. the average ratio of the number of erroneous sequences chips on the total number of sequences chips after synchronizing using either MEVB or FSNB criteria. It is shown that, after synchronizing using the MEVB-based criterion, the MCER obtained is lower than this obtained after synchronizing using the FSNB one, with a gain of 3 dB. Then, since the sequences length is 127, we can notice that in average, only one chip at most is erroneous. Those results are very important since a non cooperative context is assumed here. Hence, once a synchronization has been performed through the MEVB criterion or the FSNB one, the MCER is very low, even at very low SNRs, and it is the lowest after synchronizing using the MEVB criterion.

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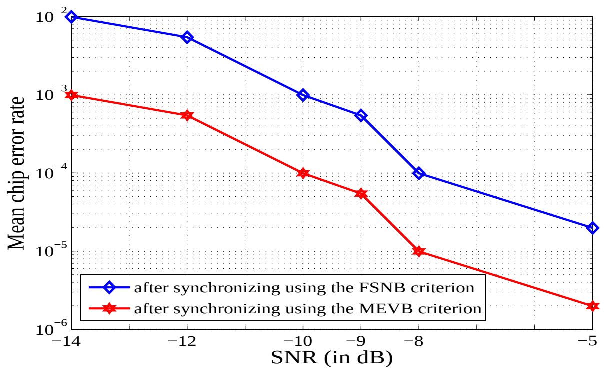

Figure 6. Mean Chip Error Rate, $N_u^i = 4$

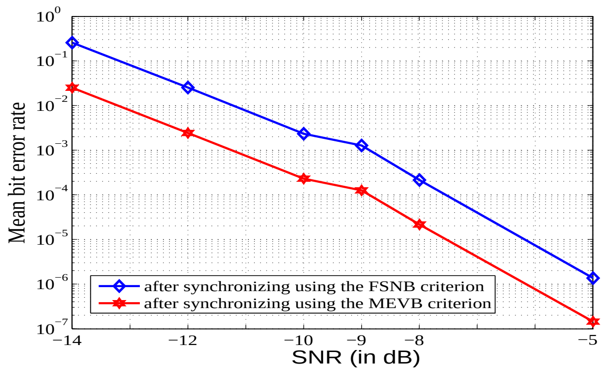

Figure 7. Mean bit error rate for differents SNRs, $N_u^i = 4$

Fig.7 shows the performances in term of mean bit error rate (MBER). It clearly evidences very good performances in term of MBER after synchronizing using both criteria and estimating transmitted symbols. In agreement with the results shown on Fig.6, after synchronizing using

the MEVB criteria, the MBER is the lowest, with a gain of $2\ dB$. Typicaly, in some cooperative systems, the MBER is about 10^{-8} which very close to one obtained here after synchronization using the MEVB criterion at $-5\ dB$.

VII. Conclusion

In this paper, taking benefit of the blind multirate multiuser detection scheme previously proposed in [11], led us to develop and perform a new blind synchronization method based no longer on the study of the Frobenius square norm behaviour (FSNB) [1]–[3], but rather on the evolution of eigenvalues maxima with analysis window shifts, denoted MEVB (Maximum EigenValue Behaviour), whithin each group of interfering users transmitting at the same data rate.

Indeed, theoretical analysis of the extended FSNB-based criterion [1]–[3] to the multiuser case, evidence the performances degradation due to an increase of synchronization peaks masking. We proved that the masking of synchronization peaks is due to the definition of the FSNB-based criterion. Then, we demonstrated that the MEVB-based citerion exhibits better performances than the FSNB-based criterion due to the lack of synchronization peaks masking. Moreover, this new method always allows the determination of the number of interfering users transmitting at the same data rate, since synchronization peaks are never masked, even at very low SNRs.

Then we showed that, synchronizing using both criteria allowed one to obtain very good peformances in terms of mean chip and bit error rates, but the lowest rates were obtained after synchronizing using the MEVB-based criterion, in agreement with theoretical results. However, computation of the FSNB criterion is faster. Consequently, the choice between those two blind synchronization criteria depends on expected performances and available computational power.

VIII. Acknowledgement

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References

[1] G. Burel and C. Bouder, “Blind estimation of the pseudo-random sequence of a direct spread spectrum signal,” in *IEEE-MilCom*, Los Angeles, California, USA, October 2001.

[2] R. Gautier, C. Nsiala Nzéza, and G. Burel, “Synchronisation et estimation aveugle de séquences d'étalement pour une transmission de type cdma en liaison descendante,” in *IEEE-SCS (Signaux, Circuits, Systèmes)*, Monastir, Tunisie, Mars 2004.

[3] C. Nsiala Nzéza, R. Gautier, and G. Burel, “Blind synchronization and sequences identification in CDMA transmissions,” in *IEEE-AFCEA-MilCom*, Monterey, California, USA, November 2004.

[4] R. L. Picholtz, D. L. Schilling, and L. B. Milstein, “Theory of spread-spectrum communications - a tutorial,” *IEEE Transaction on Communications*, vol. 30, no. 5, pp. 855–884, May 1982.

[5] D. T. Magill, F. D. Natali, and G. P. Edwards, “Spread-spectrum tehcnology for comercial applications,” in *Proceedings of the IEEE*, vol. 82, no. 4, April 1994, pp. 572–584.

[6] X. Wang and H. Poor, “Blind multiuser detection: A subspace approach,” *IEEE Transactions on Information Theory*, vol. 44, no. 2, pp. 677–690, March 1998.

[7] A. Haghighat and M. R. Soleymani, “A subspace scheme for blind user identification in multiuser ds-cdma,” in *IEEE-WCNC*, vol. 4, no. 1, March 2003, pp. 688–692.

[8] S. Buzzi, M. Lops, and A. Pauciullo, “Iterative cyclic subspace tracking for blind adaptative multiuser detection in multirate cdma systems,” *IEEE Trans. on Vehicular Technology*, vol. 52, no. 6, pp. 1463–1475, November 2003.

[9] X. Wang and H. Poor, “Blind adaptive interference suppression for CDMA communication based on eigenspace tracking,” in *Conf. Information Science and Systems*, Baltimore, MD, USA, 1997, pp. 468–473.

[10] M. Honig, “Blind estimation of the pseudo-random sequence of a direct spread spectrum signal,” in *IEEE-MilCom*, vol. 2, Monterey, California, USA, November 1997, pp. 836–840.

[11] C. Nsiala Nzéza, R. Gautier, and G. Burel, “Blind multiuser detection in multirate cdma transmissions using fluctuations of correlation estimators,” in *IEEE-GlobeCom*, San Francisco, California, USA, November 2006, accepted.