A Parallel Interference Canceller Scheme For Multirate DS-CDMA Systems

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Abstract— ***The Multi-Code (MC) multirate DS-CDMA (Direct Sequence-Code Division Multiple Access) transmission system's performance is analyzed, associated to a Multistage Parallel Interference Cancellation (MPIC) structure, with hyperbolic tangent decision device in the intermediate stages. Extensive Monte Carlo Simulations (MCS) considering total and partial cancellation (with factor $\xi < 1$) in Additive White Gaussian Noise (AWGN) and Flat Rayleigh channels indicated great performance gain of the MC-MPIC structure when compared to the conventional MC detection. The results show the feasibility of the proposed structure for future third generation (3G) systems***

I. INTRODUCTION

Multiuser Detection (MuD[1]) combined with multirate schemes will assist the requirements of high performance and flexibility inherent to the 3G systems. MuD structures based on some kind of IC[2] (Interference Cancellation), like SIC and PIC (Successive and Parallel IC, respectively) and ZF-DF (Zero-Forcing Decision Feedback), presuppose the explicit detection and cancellation of each user's information from the others [1], [2]. In IC detectors interference estimates are used in order to regenerate the Multiple Access Interference (MAI) and later subtract them from the input signal, following some users' ordination criteria, individual or in-groups. This ordination happens, for instance in SIC, by evaluating the individual correlation receiver outputs or comparing all received users' signals [3]. Already PIC accomplishes the users' simultaneous detection without considering any power disparities. In the Group (or Hybrid) Interference Cancellation (GIC or HIC) this will be done with simultaneous group of users' with similar received power; such groups will be cancelled in decreasing power order [4].

The subtractive structures can be combined in multiple stages obtaining better performance for each new cancellation stage, or they can be associated to other types of MuD, mainly the blind adaptive type in order to make possible the treatment of intercellular interference, forming hybrid MuD structures [5]. Subtractive IC techniques will be effective when there is available, in the receiver, reliable information on the more significant interference in the system, needing also efficient energy and delay estimation. Additionally, due to its low complexity, high capacity, low latency and robustness, the MPIC becomes an attractive technique for practical system implementation. However, there is a power control mechanism necessity; the MPIC's capacity will be significantly larger than in the SIC approach, when perfect power control is guaranteed (this fact will be defined ahead as Near-Far Ratio $NFR = 0$ dB). The SIC suffers from the excessive processing delay (KT, where K denotes the number of users and T the data period interval), while the PIC, due to its topology, is capable of processing simultaneously all users with a delay of one bit period T for each stage.

Four basic strategies exist to obtain systems with data transmission of multiple rate, besides variations and combinations of these, applicable to mobile communication systems: Multi-Modulation (or Mixed Modulation, MM) scheme, where different rates are reached with different modulation formats at constant symbol rate; MC (or Parallel Channels) is a method of multiple rate access with multiple code attribution for users, maintaining constant chip rate and processing gain; Variable Processing Gain (VPG) where the chip rate is constant and the processing gain varies with the user's rate (this scheme is also named Multiple Processing Gain (MPG) or still Variable Spreading Length (VSL)); and, finally, the Variable Chip Rate (VCR) scheme where the fixed processing gain is obtained with a variable chip rate according to the user's data rate.

In the MC scheme all users multiplex their information bits using several spreading sequences of low rate, transmitting information bits in parallel. Each user transmits at the same basic rate and with the same modulation format. Therefore, to vary the data rate, R_k, it is permitted for the user to send, simultaneous and synchronously, the amount of necessary parallel channels to assist its specific data rate. In this way, all of the user's parallel channels will present the same channel characteristics, such as fading and propagation delays. All users will have the same processing gain, making possible the use of a group of spreading sequences with good cross-correlation properties, since this type of access can result in large number of interfering signals if the relation of the largest to smallest data rate is elevated.

For multirate DS-CDMA systems, with MuD in AWGN and Rayleigh multipath fading channels, performance description see [6] and [7]. Among MuD structures, the non-linear MPIC are a particularly strong candidate for integrating reception solutions in the reverse channel, due mainly to the acceptable implementation complexity and the relative immunity to system parameter estimation errors. Among multirate schemes the MC solution results in simplicity for the spreading sequence project and ease of implementation. The combination of detecting structures based on IC with multirate systems was analyzed previously in [4], [5], [8] and [9]. Multistage IC with a hyperbolic

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[1] Sometimes used also as an acronyms for Multiuser Detector.

[2] Sometimes used also as an acronyms for Interference Canceller

tangent (named hereafter as Tanh) decision device will have better performance, mainly for highly loaded systems, when compared to those with hard or unlimited linear soft decision in AWGN channels [10], as it minimizes the mean squared error between the true data bit and the estimation from the subtractive IC. For Flat Rayleigh channels this advantage is still valid, however the performance difference between both solutions becomes modest [11]. So, the multirate IC systems analyzed here will use a Tanh decision device for the intermediate cancellation stages.

In the MC approach the maximum number of supported multirate users limitation with groups of conventional sequences like Gold or Kasami-L can be avoided using Pseudo Noise (PN) or purely random sequences, with some loss in the system's global performance, due to the worst mean correlation characteristics for this type of sequence. Alternatively, groups of extended sequences, like as Kasami-VL, have better correlation properties than groups of PN sequences and simultaneously they make available a huge number of spreading sequences [12]; the W-CDMA system, for instance, presents an option for the use of extended Kasami-VL sequences with length 256. In this paper, extended Gold sequences of length $N = 32$ will be used, these are groups of conventional Gold sequences with the addition of one chip of value $+1$ or -1 in the last position, resulting in groups with better correlation properties than with PN.

This paper was organized in to the following sections: In section II the MPIC structure, applicable to DS-CDMA systems of multiple rate with MC scheme is presented in detail and followed by the performance results; section III presents some MCS results and section IV the main conclusions.

II. System Model

Considering an MC multirate scheme, it is assumed that all of the K users have the same chip rate, R_c and they use the same bandwidth. For the generic k^{th} user, R_k and E_{bk} denote data rate and its bit's energy respectively; the processing gain is constant and equal for all users $N_k = N$. The data bits, transmitted on the $m_k = \frac{R_k}{R}$ parallel codes (the two rates are so that m_k is admitted integer), are given by:

$$\mathbf{b_k(i)} = [\mathbf{b_{k,1}(i)}, \mathbf{b_{k,2}(i)}, ...\mathbf{b_{k,m_k}(i)}]^{\top} \qquad (1)$$

with R denoting the basic data rate (smallest data rate). Being assumed that the k^{th} user employs BPSK (Binary Phase Shift Keying) modulation, the transmitted signal for this user can be expressed as

$$u_k(t) = \sqrt{P_k} \sum_i \mathbf{b_k^{\top}(i) \bar{s}_k(t - iT)} \qquad (2)$$

with $P_k = E_{b_k}/T$ gives the received power; $\mathbf{\bar{s}_k(t)} = [\mathbf{\bar{s}_{k,1}(t)}, \mathbf{\bar{s}_{k,2}(t)}, ...\mathbf{\bar{s}_{k,m_k}(t)}]^{\top}$ representing the spreading codes matrix with dimension $m_k \times N$, where each line represents one normalized waveform vector defined by:

$$\mathbf{\bar{s}_{k,j}(t)} = \sqrt{\frac{\mathbf{2}}{\mathbf{T}}} \mathbf{s_{k,j}(t)} \cos(\boldsymbol{\omega} \mathbf{t} + \boldsymbol{\varphi}_\mathbf{k}) \qquad (3)$$

where ω and φ_k represent the carrier's frequency and phase, respectively, and $\mathbf{s_{k,j}(t)}$ is the spreading sequence used for the transmission of the j^{th} symbol of the k^{th} multirate user, $b_{k,j}$, defined by:

$$\mathbf{s_{k,j}(t)} = \sum_{\mathbf{i=0}}^{\mathbf{N-1}} \mathbf{c_{k,j}^{(i)} p_{T_c}(t - iT_c)} \qquad (4)$$

with $j = 1, 2, ..., m_k$; $\mathbf{c_{k,j}^{(i)}}$ = chip vector with elements $c_{k,j}^{(i)} \in \{\pm 1\}$ with duration T_c and used in the chip interval defined by i; $p_{T_c}(.)$ is a rectangular pulse with unitary amplitude in the interval $[0, T_c)$. Therefore we have the result of $m_1 + m_1 + ... + m_K$ effective users (K_{ef}) in the system. Additionally it is assumed a DS-CDMA system with short codes, that is processing gain given by $N = \frac{T}{T_c}$. The chips vector in (4) can be designated starting from a group of orthogonal spreading sequences obtained from a set of Walsh-Hadamard sequences or Gold[3] sequences, or even OVSF (Orthogonal Variable Spreading Factor) code sequences. The group of orthogonal sequences choice will be particularly advantageous if it is possible to maintain the synchronism among all users' signals, as for instance in the direct channel or in S–CDMA or QS–CDMA (synchronous and quasi-synchronous, respectively) systems. For an infinite message, the asynchronous DS-CDMA multirate BPSK signal in scalar notation, complex baseband representation and considering a Flat Rayleigh channel, can be written as:

$$\begin{aligned} r(t) &= \\ &= \sum_{i=1}^{\infty} \sum_{k=1}^{K} \sum_{j=1}^{m_k} \sqrt{P_k} C_k(i)\, b_{k,j}(i)\, s_{k,j}(t - iT - \tau_k) \\ &\quad + \sigma n(t) \qquad\qquad t \in [0, T] \end{aligned} \qquad (5)$$

where τ_k is the k^{th} user's delay; $n(t)$ represents the AWGN with unitary power spectral density and power in a band B given by $2\sigma^2 B$ ($2\sigma^2$ is frequently denoted by N_0 which is the unilateral noise power density); $C_k(i)$ is the k^{th} user fading channel coefficient given by:

$$C_k(i) = |C_k(i)| \exp[j\theta_k(i)] \qquad (6)$$

C_k is the result of two statistical distribution compositions: the module $|C_k|$ has a Rayleigh distribution and the phase θ_k has a uniform distribution in the interval $[0; 2\pi)$. It should be noted that all of m_k parallel channels designated to the k^{th} MC multirate user try the same channel conditions. It is assumed that the channel's fading is slow enough so that the coefficients can be considered constant during some symbol periods, T.

A. MC Multirate Receiver with MPIC

Figure 1 schematizes the MC multirate MuD receiver based on the asynchronous post-detection scheme for three data rates, R, $2R$ and $4R$, using MPIC with Tanh

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[3] Orthogonal Gold (more precisely: quasi-orthogonal would be better), also named as extended Gold sequences, can be constructed with the addition of one bit $+1$ or -1 at the end of each "traditional" Gold sequence.

decision device. The number of effective users, K_{ef}, in an MC multirate scheme corresponds to the total number of parallel channels needed to serve all active users in the system. Therefore, for ten physical users of data rate R, five with data rate $2R$ and three with data rate $4R$ it will be necessary to use $10\times1+5\times2+3\times4 = 32$ spreading codes with processing gain $N = 32$.

After they go through the matched filters bank (MFB), matched to the respective sequences, the MC multirate user signals are detected, rebuilt and partial or totally cancelled to the output of MFB in a similar way as a post-detection MPIC, except that here, the final parallel channels estimation of each user with data rate larger than R should be time multiplexed in order to obtain the correct information rebuilding. The k^{th} MFB's output signal correspondent to the i^{th} transmitted bit is given by

$$\begin{aligned} z_{Conv\_k}^{(i)} &= \int_{iT+\tau_k}^{(i+1)T+\tau_k} \mathrm{Re}\left\{r(t)\, s_k(t-iT-\tau_k)\, e^{-j\phi_k}\right\} dt \\ &= \sqrt{P_k}\, b_k^{(i)} + I_k^{(i)} + n_k^{(i)} \qquad (7) \end{aligned}$$

where ϕ_k represents the received carrier's phase (modified by the channel) for the k^{th} user; the first term is the desired signal and the last term represents the filtered noise. In a first analysis, it is reasonable to admit that the delays and phases, of all active users are exactly known and ordered in the following manner: $0 \leq \tau_1 \leq \tau_2 \leq, ..., \leq \tau_K$. The MAI for a post-detection scheme with asynchronous signals in a Flat Rayleigh channel can be written as

$$\begin{aligned} I_k^{(i)} = \Bigg(&\sum_{\ell=k+1}^{K} W_\ell \rho_{k\ell}(1)\, b_\ell^{(i-1)} e^{j\phi_\ell(i-1)} + \\ &+ \sum_{\ell\neq k} W_\ell \rho_{k\ell}(0)\, b_\ell^{(i)} e^{j\phi_\ell(i)} + \\ &+ \sum_{\ell=1}^{k-1} W_\ell \rho_{k\ell}(-1)\, b_\ell^{(i+1)} e^{j\phi_\ell(i+1)} \Bigg) e^{-j\phi_k(i)} \qquad (8) \end{aligned}$$

where $W_\ell^{(i)} = \sqrt{P_\ell}\, |C_\ell(i)|$ is the channel gain for the ℓ^{th} interfering user (for AWGN $|C_\ell(i)| = 1$ for all i). The MAI calculation for asynchronous signals depends on the current, previous and subsequent transmitted bit and the partial correlation is given by:

$$\rho_{k\ell}(i) = \frac{1}{T} \int_{-\infty}^{\infty} s_k(t-\tau_k)\, s_\ell(t+iT-\tau_\ell)\, dt \qquad (9)$$

where s_k is the spreading sequence; $i = -1$ or 0 or $+1$ indicates the corresponding part of the spreading sequence, i. e., previous, current and subsequent bits, respectively.

Using S stages and MAI estimation, $\widehat{I}_k(s)$, the MPIC structure removes the MAI resulting in a better performance when compared to the conventional matched filter detector. In the first stage ($s = 1$) the decision attempts for the K_{ef} users are obtained by passing the outputs of the MFB by respective soft Tanh decision devices directly. These soft bits estimations are used for the MAI estimation on the next stage ($s = 2$). In a generic stage (s) estimated MAI for the k^{th} virtual user, $\widehat{I}_k^{(i)}(s)$, is subtracted from the respective MFB output, $z_{Conv\_k}^{(i)}$, and the result, denoted by $z_k^{(i+1-s)}(s)$, is sent to the respective soft Tanh decision device; so, generically:

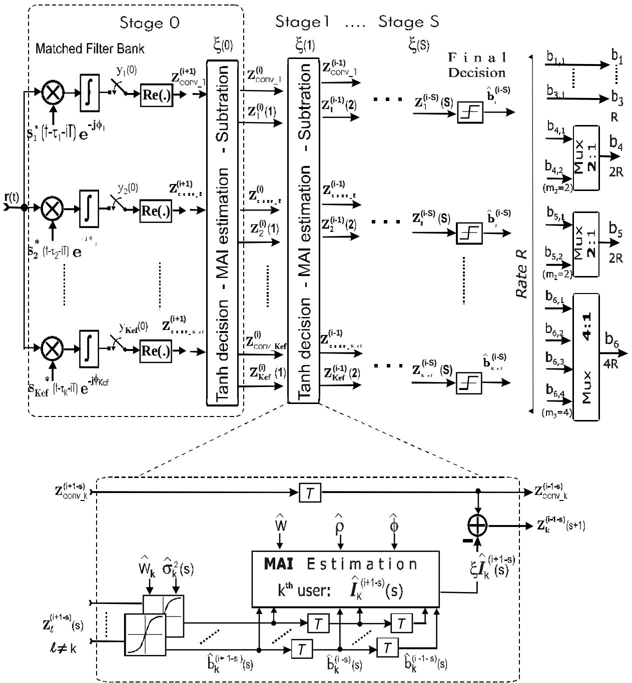

Fig. 1. MC triple rate scheme for six users (3 LR users, 2 MR and 1 HR) with post-detection MPIC reception structure implemented with S stages and Tanh decision device resulting in $K_{ef} = 11$ effective users.

$$\begin{aligned} z_k^{(i)}(s) &= z_{Conv\_k}^{(i)} - \widehat{I}_k^{(i)}(s) \qquad (10) \\ &= b_k^{(i)}\sqrt{P_k} + \underbrace{n_k^{(i)} + \underbrace{I_k^{(i)} - \widehat{I}_k^{(i)}(s)}_{\text{residual MAI}}}_{\text{residual noise}} \end{aligned}$$

where the residual noise remains after imperfect MAI cancellation. In a post-detection MPIC scheme, the MAI estimation in the s^{th} cancellation stage, $\widehat{I}_k^{(i)}(s)$, are obtained computing (8) from the estimation of current, previous and subsequent bits, obtained in the previous cancellation stage, $\widehat{b}_k(s-1)$. It is still necessary to obtain estimation for the channel gains and phases of the received carriers for all of users. Finally, the reconstruction of the interfering signals in (8) still involves the calculation of the partial correlations between the desired user and all of interfering users. All decision devices in a soft Tanh MPIC, except the last, operate on $z_k(s)$, on the channel gains estimation and on the noise variance of the considered canceling stage; for the k^{th} user follows:

$$\widehat{b}_k^{(\ell)}(s) = \tanh\left[\frac{z_k^{(\ell)}(s)\, \widehat{W}_k}{\widehat{\sigma}_k^2(s)}\right] \qquad (11)$$

or it simply accomplishes the hard decision on $z_k(s)$ in the last stage:

$$\widehat{b}_k^{(\ell)}(s) = sign\left[z_k^{(\ell)}(s)\right] \tag{12}$$

Estimation for amplitudes (or channel's gain), necessary in any PIC with attempt of bit decision[4] and estimation for residual noise variance, necessary in a PIC with soft Tanh and dead zone decision device, are obtained, for instance, starting from the temporal average over J samples at the MFB's output; for the k^{th} user results:

$$\widehat{W}_k = \frac{1}{J}\sum_{\ell=i+1-S-J}^{i-S}\left|z_k^{(\ell)}(S)\right| \tag{13}$$

$$\widehat{\sigma}_k^2(s) = \frac{1}{J}\sum_{\ell=i+1-S-J}^{i-S}\left[z_k^{(\ell)}(s) - \widehat{W}_k\widehat{b}_k^{(\ell)}(S)\right]^2 \tag{14}$$

where $1 \leq s < S$; ℓ varies for the J consecutive information bits; $z_k^{(\ell)}(s)$ is the k^{th} MFB's output after MAI cancellation in the s^{th} stage and $\widehat{b}_k(S)$ indicates hard decision bits in the final stage for the k^{th} user. Seeking to facilitate the algorithm construction, the users' channel gains estimation were simply obtained by taking the average of J samples at the MFB's output, or in other words, it was used $\left|z_{Conv\_k}^{(\ell)}\right|$ directly in the equation (13). For the residual noise variance estimation the calculation was simply obtained in the form:

$$\widehat{\sigma}_k^2(s) = \frac{1}{2J}\sum_{\ell=i+1-S-J}^{i-S}\left|\left[z_k^{(\ell)}(s)\right]^2 - \left[\widehat{W}_k\right]^2\right| \tag{15}$$

where $1 \leq s \leq S$; for the developed algorithms and AWGN channels it was adopted $J = 300$ (@ $\frac{E_b}{N_0} \leq 5$ dB), $J = 200$ (@ $5 < \frac{E_b}{N_0} \leq 10$ dB) and $J = 150$ (@$\frac{E_b}{N_0} > 10$ dB). Notice that the PIC detector with soft Tanh decision needs additional estimation for the channel gain and for the total noise variance at each stage besides the traditional carrier's delay and phase estimation. Three data rates were attributed to the users: low rate (LR) users with rate R, medium rate (MR) with 2R and high rate (HR) with 4R, where R is the basic (smallest in the system) data rate.

III. SIMULATIONS

The topology characterization includes $\overline{BER}\times$ users' population, $\overline{BER}\times \frac{E_b}{N_0}$ and Near-Far robustness[5] (Υ) considering a group of users with three data rates. The MPIC algorithm's performance was compared considering coherent BPSK modulation, perfect parameters estimation, square chip format, three parallel cancellation stages, soft or total Tanh decision device, extended Gold sequences with addition of -1 chip in the last position, as these result in smaller cross-correlation than the one of extended Gold with random chip in the last position [14], [15], resulting a processing gain $N = 32$.

Seeking to obtain a closer situation to practical cases in the reverse channel, the asynchronous signals were considered transmitted with a delay uniformly distributed in the interval $[0; N - \frac{1}{N_s}] \times Tc$, with discrete steps given by T_c/N_s, and the number of samples per chip was adopted as $N_s = 3$.

Simulation results were obtained considering medium and highly loaded systems, that is, effective load of $L = 62,5\%$ ($K_{ef} = 20$ users; with 4 LR, 4 MR and 2 HR users) and $L = 100\%$ ($K_{ef} = 32$ users; with 10 LR, 5 MR and 3 HR users), respectively.

Finally, perfect channel parameters estimation was assumed. Although in practical systems this condition is not verified, the hypothesis is justified because the main objective here is to compare the potential performance of the proposed multirate IC topologies. Estimation errors will be included in a subsequent stage of our investigation.

In a fixed power disparities scenario the characterization was considered with simultaneous Near-Far effect from one LR user, one MR and one HR. For power disparity in the interval $[-15; +25]$ dB for a single user, characterizing the Near-Far robustness, the signal to noise ratio of the system was maintained fixed, resulting in $\frac{E_b}{N_0} = 8$ dB for AWGN channels and $\frac{E_b}{N_0} = 24$ dB for Flat Rayleigh channels. All BER performance was obtained for the system's "weak" users.

The coefficients' samples for a Flat Rayleigh channel were generated from the Jakes modified model [16] with normalized Doppler displacement, $D_{dpl} = 0.01$ and $D_{dpl} = 0.1$ characterizing a slow and almost fast channel, respectively.

For the partial cancellation case, the ξ coefficient values were not optimized as this would involve additional complexity for the algorithms, mainly with respect to the time spent for the MCS. The ξ values were obtained from a non-exhaustive iterative search procedure resulting in $[0.7; 0.8; 0.9]$ whose value for each stage was assumed identical for all signals of the multirate users, even under Near-Far condition. In spite of coefficients non-optimization, in an AWGN channel the IC detectors with partial Tanh resulted in superior performance when compared with the total canceling case, under certain conditions for $\frac{E_b}{N_0}$. When maintaining the same ξ values in Flat Rayleigh channel, this tendency was not confirmed, indicating that optimization is necessary for this type of channel.

Figure 2 shows the MC-MPIC structure's performance for three IC stages in an asynchronous AWGN channel, for $L = 100\%$ and under perfect power control. For the purpose of comparison, mean performances are indicated considering for each group(LR, MR and HR users): total ($\xi = 1$) and partial ($\xi < 1$) Tanh decision device, conventional detector with all of users (Conv. all users) and, finally, the single user case (when there is just one user in the system, SUB (bpsk)).

The system's mean performance improves when the

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[4] Decision devices as sign, Tanh, dead zone, unlimited linear, limited linear (clipper) among others.

[5] For definition, see [13]

load is reduced from $K_{ef} = 32$ to $K_{ef} = 20$. Due to the perfect power control and exact channel parameters hypotheses, assumed in all of the MCS, the performance of the asynchronous MC-MPIC detector with Tanh decision device, extended Gold sequences, three IC stages and a load of $L = 62,5\%$ approaches the SUB case.

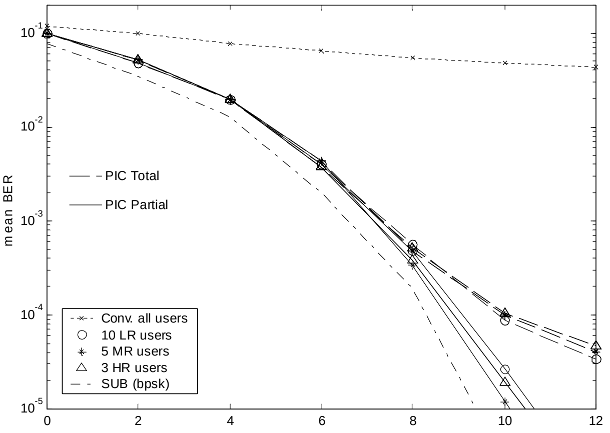

Fig. 2. $\overline{BER} \times \frac{E_b}{N_0}$ for asynchronous multirate MC-MPIC structure with Tanh decision device, extended Gold31 sequences, three group of users, three IC stages, $K_{ef} = 32$ users and $NFR = 0dB$ (perfect power control).

In a MC multirate scheme all parallel channels from the same user have identical delays (same channel conditions), so the extended Gold sequences adoption will result in total MAI reduction, due to orthogonality for the same user's parallel channel sequences. Maintained constant the number of effective users, K_{ef}, this reduction will still be larger when the number of users at a higher rate grows, which implies a larger number of required orthogonal sequences. The ideal limit case is a perfectly synchronous system with extended Gold (group orthogonal) sequences where the MAI would be virtually zero, resulting in single user performance for any load.

The mean performance behavior for all users from the same rate group (with $NFR = 0$ dB condition) as a function of the population increase, maintaining fixed the users from other groups and using $\frac{E_b}{N_0} = 8$ dB, is synthesized in Figure 3. There is a great performance improvement when the cancellation is accomplished in multiple stages. The mean performance obtained with the third stage (stg 3 in the figure), for partial and total IC, doesn't suffer appreciable degradation with load increase. Additionally, the performance results would not change significantly under the condition of few interfering power disparities in the range from 10 dB to 15 dB.

Due to the ξ factors non-optimization, the MPIC structure with total IC gives better results for low and medium loads; for the chosen ξ values, partial cancellation becomes better only for high loads and in an AWGN channel. The ξ optimization depends on the load and system's signal to noise ratio. Therefore, it can be stated that the adopted values are close to the optimum values for a load near to $L = 100\%$, $\frac{E_b}{N_0} \approx 8$ to 9 dB and in an AWGN channel. Note the similarity of the mean performance results among different data rate users. This is due to the adopted MC-MPIC structure's characteristics, allowing symmetry in the parallel cancellation process for all multirate signals.

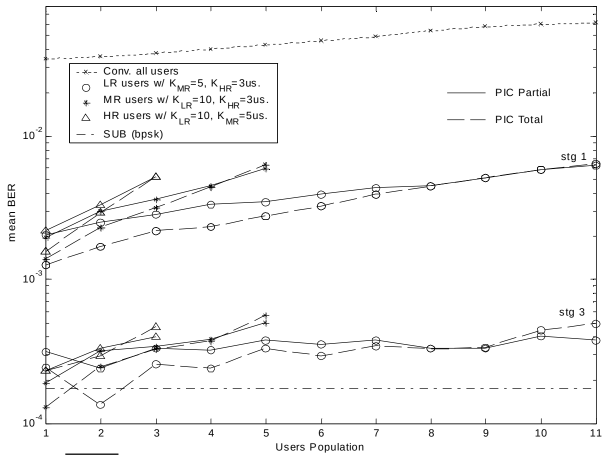

Fig. 3. $\overline{BER} \times K_{Group}$ for asynchronous MC-MPIC with Tanh decision device, perfect power control, $\frac{E_b}{N_0} = 8$ dB, Extended Gold31 sequences.

Near-Far robustness results for the asynchronous MC-MPIC structure with Tanh decision device were obtained. Mean performances of weak users are shown considering interfering power disparities ($NFR \neq 0$ dB). Due to the ξ factors non-optimization better performance for the first and third stages were obtained with the total IC, when the system operates with $\frac{E_b}{N_0} = 8$ dB, for medium and also high load. However this situation can be reverted by cancellation factors optimization or moving the system's operation point. For instance, growing the ratio $\frac{E_b}{N_0}$ by only 1 dB ($E_b/N_0 = 9$ dB) and considering the high load scenario, Figure 4 shows that the partial IC works better than the total IC for a wide range of NFR besides resulting in larger Near-Far robustness in the third stage for the three groups: $\Upsilon^{LR} = 17$ dB, $\Upsilon^{MR} = 15$ dB and $\Upsilon^{HR} = 12$ dB; in this graph, the limit $10 \times Pe_{SUB}$ (used for robustness determination) is indicated as $10\times$.

In a generic form, the results for Near-Far robustness indicate that even for highly loaded systems the asynchronous MC-MPIC structure with Tanh decision device is capable of operating satisfactorily in AWGN channels under Near-Far effect of one or two users. For systems with medium load, the Near-Far robustness will be larger and could put up with at least one user with $NFR > +25$ dB.

Expressive performance gains are obtained with multirate IC structures when compared with a conventional multirate receiver, even if considering only one IC stage.

The simulation results for slow Flat Rayleigh channel ($D_{dpl} = 0.01$) and almost fast ($D_{dpl} = 0.1$) indicated that the performance obtained with the MC-MPIC structure with partial Tanh decision device in the intermediate stages is inferior to that obtained with total Tanh. This behavior can be explained by the use of partial coefficients $\xi = [0.7; 0.8; 0.9]$ as for an AWGN case and with the same arguments. The multirate MC-MPIC structure with three stages and a medium load ($L = 62.5\%$) presents a performance close to the single-user case in Flat Rayleigh channel, under a perfect power control condition or even with power disparities of the order of +10 dB for one LR user, one MR and one HR. Even under strong load ($L = 100\%$) the structure with total Tanh IC presents excellent results in the perfect power control condition. Under power disparities of three users (one LR, one MR and one HR, all of them with $NFR = 10$ dB), the mean performance for LR users reaches an irreducible BER around 2×10^{-4} for the third IC stage, Figure 5 (results for MR and HR users follow the same pattern). Also in this figure the effectiveness of the IC stages in the MC-MPIC structure can be observed through the improvement obtained with the second and third stages.

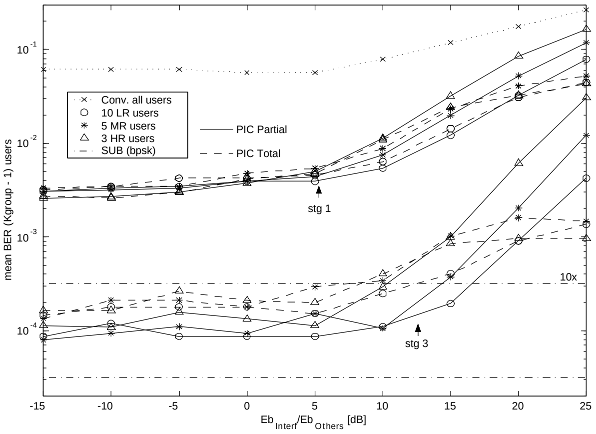

Fig. 4. Near-Far Robustness for the asynchronous MC-MPIC with Tanh decision device considering $\frac{E_b}{N_0} = 9dB$, extended Gold31 sequences.

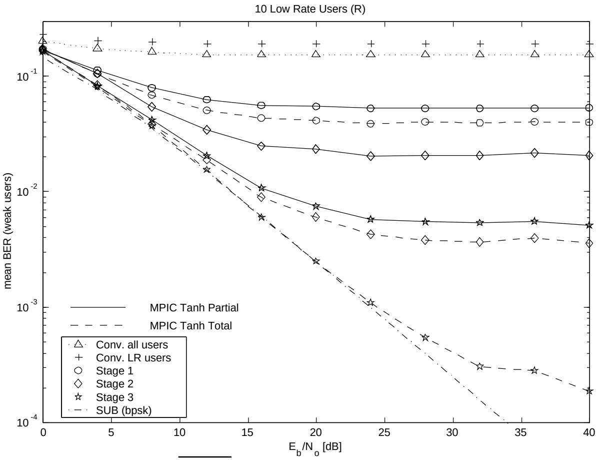

Fig. 5. LR users' $\overline{BER} \times E_b/N_0$ for the MC-MPIC structure in Flat Rayleigh channel with $D_{dpl} = \mathbf{0.01}$, $L = \mathbf{100\%}$ and one user from each rate group with $NFR = \mathbf{10}$ dB.

Evidently, as the NFR condition increases (in terms of power disparity and/or number of interfering users with power disparity) the system's performance worsens as this structure is based on PIC, for which perfect power control is the optimum scenario.

IV. Conclusions

In this paper the MPIC structure was characterized through extensive MCS, considering an asynchronous DS-CDMA system. The simulations for AWGN and Flat Rayleigh channels indicated that, maintaining the condition of a reasonable power control, the MC-MPIC performance results in excellent mean performance for all multirate groups of users, even for strong loads and hostile Flat Rayleigh channels. In spite of the fact that the partial cancellation coefficients have been optimized for an AWGN channel with a non-exhaustive search procedure, extensive simulation results showed the validity of adopting partial cancellations for MPIC with Tanh decision device.

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