HYBRID INTERFERENCE SUBSPACE REJECTION FOR MULTI-RATE WCDMA

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***Abstract*— Interference subspace rejection (ISR) offers a wide range of canonic suppression modes that outperform interference cancellors and linear receivers both in performance and complexity. In this contribution, we propose a hybrid ISR scheme that, instead of suppressing all users with the same canonic ISR mode, splits them into several groups based on their data-rates before applying different canonic ISR modes for their nulling. The resulting receiver provides a much better performance/complexity tradeoff. Simulations suggest that a hybrid of the two simplest canonic ISR modes performs almost as well as the more complex mode with 30 to 60% less complexity, while it outperforms the simpler of the two by several dB gains with minimal increase in complexity.**

I. Introduction

In order to support the simultaneous transmission of diverse information sources such as voice, video or data in future cellular communication systems, several multi-rate access schemes have been proposed such as multi-code, variable spreading factor or different modulation format. In such mixed-rate traffic scenarios, the conventional receiver fails to demodulate transmissions from the weak low-rate users. It is therefore desirable to use more sophisticated multi-user receivers with better near/far resistance.

A variety of multi-user receivers that can decouple the superimposed received signals have been investigated for multi-rate CDMA systems [1]-[7]. Most of these receivers have focused on a particular detection technique: the optimum receiver [1], the decorrelator-based receiver [2], the MMSE receiver [3], or the successive interference cancellation (SIC) [4]. Moreover, except the work on SIC, all previous papers did not consider the multi-modulation scheme. Hybrid receivers that combine different multi-user detection techniques have been proposed [5], however, they apply multi-user detection to the high-rate users only while neglecting the presence of other users in the system.

In this paper, we propose a new data block processing structure well suited to multi-rate data traffic. The new data decomposition enables implementation of a new flexible multi-user receiver that simultaneously supports multi-code, variable spreading factor and different modulation format. Additionally, in contrast to previous works, the proposed receiver combats both the intersymbol interference (ISI) and the multiple access interference (MAI).

We have proposed a new technique for multi-user detection in CDMA networks referred to as ISR [8]. This technique offers different detection modes (referred to as canonic in the following) that range in performance and complexity between IC detectors and linear receivers. Each canonic mode characterizes the interference vector by a different set of null constraints - their number increasing for modes with higher performance and complexity - and accordingly suppresses it. For example the TR (total realizations) mode nulls the total interference vector and hence requires accurate estimation of all the channel and data parameters of the *NI* interferers. The R (realizations) mode nulls the signal vector of each interferer and hence becomes robust to power estimation errors. The H (hypotheses) mode nulls the signal vector from each interfering symbol of each interferer and hence introduces robustness to symbol data estimation errors.

In this contribution, we investigate a modified ISR scheme, called hybrid ISR, which offers a wider range of improved performance/complexity tradeoffs for multi-rate transmissions. Instead of detecting all active users targeted for suppression with the same canonic ISR mode, hybrid ISR splits them into several groups based on their data rate using the new block data structure, then applies different canonic ISR modes for their nulling, the number of nulling constraints being larger for groups with higher transmission rates.

II. New Block Data Model for Multi-Rate CDMA

We consider CDMA uplink transmissions to M receiving antennas at the base station over a multipath Rayleigh-fading channel with number of paths P. The system consists of U active users that transmit data with different spreading factors and different modulation formats (extension to the multi-code scheme is *ad hoc*). The data $b_n^u \in C_{\mathcal{M}_u}$ for user with assigned index u is $\mathcal{M}_u$-PSK modulated at rate $1/T_u$, where T_u is the symbol duration and $C_{\mathcal{M}_u} = \{\ldots, e^{\frac{j2\pi m}{\mathcal{M}_u}}, \ldots\}$, $m \in \{0, \ldots, \mathcal{M}_u - 1\}$. The data sequence is then spread by a long spreading code $c^u(t)$. The spreading factor L_u is defined as the ratio of the symbol duration T_u and the chip duration T_c.

Regardless of the spreading factor or modulation, the receiver implements down conversion, matched pulse filtering and chip-rate sampling followed by framing the observation into overlapping blocks of constant length of N_P chips. The resulting processing block duration $T_P = N_P T_c$ is equal to $T_{max} + \overline{\Delta\tau}$. The processing period $T_{max} = Q_u T_u$, which is also equal to the maximum spreading factor L_{max} times T_c, contains integer numbers of symbols Q_u targeted for detection in each block for user u. The frame overlap $\overline{\Delta\tau} < T_{max}$, which is larger then the delay spread to allow multipath

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tracking [9], comprises $Q_{\overline{\Delta},u} = \lceil \overline{\Delta\tau}/T_u \rceil$ symbols for user u. Hence we obtain the $M \times N_P$ matched-filter observation matrix [8]:

$$\mathbf{Y}_n = \sum_{u=1}^{U} \psi_n^u \mathbf{Y}_n^u + \mathbf{N}_n^{th}, \quad (1)$$

where each user u contributes its user-observation matrix $\mathbf{Y}_n^u$ and where the base-band preprocessed thermal noise contributes $\mathbf{N}_n^{th}$. In the following, we assume that the base station targets *NI* interfering users (presumably with high data-rate and/or strong power) for joint suppression among the U active users (*e.g.*, all incell users). For a desired user assigned index $d \in \{1, \ldots NI\}$, we can rewrite the vector-reshaped matched-filtering observation matrix with respect to its kth symbol targeted for detection for $k = 0, \ldots, Q_d - 1$ as [8]:

$$\underline{Y}_n = \underbrace{s_n^{d,k} \underline{Y}_{k,n}^d}_{\text{desired signal}} + \underbrace{\sum_{\substack{i=1 \\ i \neq d}}^{NI} \psi_n^i \underline{Y}_n^i}_{\underline{I}_{\text{MAI},n}^d} + \underbrace{\sum_{\substack{k'=-Q_{\overline{\Delta},d} \\ k' \neq k}}^{Q_d + Q_{\overline{\Delta},d} - 1} s_n^{d,k'} \underline{Y}_{k',n}^d}_{\underline{I}_{\text{ISI},n}^{d,k}} + \underline{N}_n, \quad (2)$$

where $s_n^{d,k} = \psi_n^d b_{nQ_d+k}^d$ and $\left(\psi_n^d\right)^2$ are the kth signal component and the total received power of the desired user, respectively, and $\mathbf{Y}_{k,n}^d$ is the partial user-observation vector due to the k-th symbol [8]. $\underline{I}_{\text{MAI},n}^d$ and $\underline{I}_{\text{ISI},n}^{d,k}$ are the multiple access interference and the inter-symbol interference to be suppressed with the respect to the kth symbol of user d. The noise vector $\underline{N}_n$ comprises the preprocessed thermal noise and the rest of the active users.

III. Hybrid ISR for Multi-Rate CDMA

In the general case, the total interference $\underline{I}_n^{d,k} = \underline{I}_{\text{MAI},n}^d + \underline{I}_{\text{ISI},n}^{d,k}$ is an unknown random vector which lies in an interference subspace spanned by a user-symbol-specific constraint matrix $\mathbf{C}_n^{d,k}$ with dimension that depends on the number of interference parameters estimated separately [8]. A number of alternative modes are available to construct the constraint matrix $\mathbf{C}_n^{d,k}$ [8].

The canonic implementation modes offered by ISR (TR, R and H) range in performance from that of interference cancelling detectors to that of linear multi-user detectors. Yet the TR mode, which significantly outperforms IC receivers with the same complexity [8], stands out as the least complex and the more practical ISR mode for implementation. Potential upgrade to the R mode can offer a relatively large performance gain (as illustrated later by simulations); however, this also requires a more than twofold increase in complexity. The H mode, which performs the same as linear ZF and MMSE receivers with less complexity, offers even more computationally-expensive performance gains. The complexity of the ISR technique is mainly determined by the number of users to be cancelled NI, and the total number of constraints N_c imposed by the rejection mode. Hence, for a given multiuser system, reducing N_c will reduce the complexity of the detection technique.

In multi-rate transmissions, however, low-rate users require increased protection from the strong interference of high-rate users. Unfortunately the simplest TR mode (*i.e.*, $N_c = 1$) is unable to provide adequate protection. Hybrid ISR strives to provide a wider range of improved performance/complexity tradeoffs in multi-rate traffic. Instead of detecting all active users targeted for suppression with the same canonic ISR mode, it splits them into several groups based on their data rate, then applies different canonic ISR modes for their nulling, the number of nulling constraints N_c being larger for groups with higher transmission rates.

Consider, for example, the combination of the TR and R modes in hybrid ISR[1]. The NI users targeted for suppression can be split into two groups, a larger number of N_{TR} users with low data rate and a smaller number of N_R users with high data rate. The hybrid TR/R mode will then null the low and high data-rate groups with the canonic TR and R modes, respectively, with only $N_c = N_R + 1 \leq NI = N_R + N_{TR}$ constraints in total. With minimal increase in complexity relative to the TR mode (see Fig. 1), TR/R offers significant gains in performance as confirmed by simulations in the next section. Upon estimation of the constraint matrix $\hat{\mathbf{C}}_n$,

$$\hat{\mathbf{C}}_n = \left[\sum_{i=1}^{N_{TR}} \hat{\psi}_n^i \underline{\hat{Y}}_n^i \,, \left\{ \ldots, \underline{\hat{Y}}_n^i, \ldots \right\}_{i=N_{TR}+1}^{NI=N_{TR}+N_R} \right] \quad (3)$$

the following hybrid ISR spatio-temporal combiner $\underline{W}_n^{d,k}$ [8]:

$$\mathbf{Q}_n = \left(\hat{\mathbf{C}}_n^H \hat{\mathbf{C}}_n \right)^{-1}, \quad (4)$$

$$\mathbf{\Pi}_n^{d,k} = \mathbf{I}_{N_T} - \hat{\mathbf{C}}_n \mathbf{Q}_n \hat{\mathbf{C}}_n^{d,kH}, \quad (5)$$

$$\underline{W}_n^{d,k} = \frac{\mathbf{\Pi}_n^{d,k} \underline{\hat{Y}}_{k,n}^d}{\underline{\hat{Y}}_{k,n}^{d^H} \mathbf{\Pi}_n^{d,k} \underline{\hat{Y}}_{k,n}^d}, \quad (6)$$

extracts the kth signal component of the dth user as:

$$\hat{s}_n^{d,k} = \underline{W}_n^{d,k^H} \underline{Y}_n, \quad (7)$$

where $N_T = M \times N_P$ is the total space dimension and $\mathbf{I}_{N_T}$ denotes an $N_T \times N_T$ identity matrix. Such a hybrid multi-user detector adapts efficiently to multi-rate transmissions with mixed spreading factors and/or modulations (as well as multi-code). It offers a wider range of suppression modes with improved complexity/performance tradeoffs, as illustrated by simulations in the next section.

IV. Link-Level Performance Analysis

We consider the uplink of a WCDMA base-station with $M = 2$ antennas operating at a chip rate of 3.840 Mcps and a carrier frequency of 1.9 GHz. The Rayleigh fading channel is frequency selective with 3 equal-power paths and a Doppler shift of 8Hz (*i.e.*, speed of 5 Km/h). We assume a frequency offset $\Delta f = 200$Hz (*i.e.*, about 0.1ppm) and a linear delay drift of 0.07 ppm for each path. We implement closed-loop power control operating at 1600 Hz and adjusting the power in steps of ± 0.5 dB. An error rate on the power control bit of 5% and a feedback delay of 0.625 ms are simulated. All the channel parameters, varying in time, are estimated by the spatio-temporal array-receiver (STAR) [9].

[1]Extension of hybrid ISR to more than two transmission rates or groups and to other combinations of the canonic modes is *ad hoc*.

(a) (b) (c)

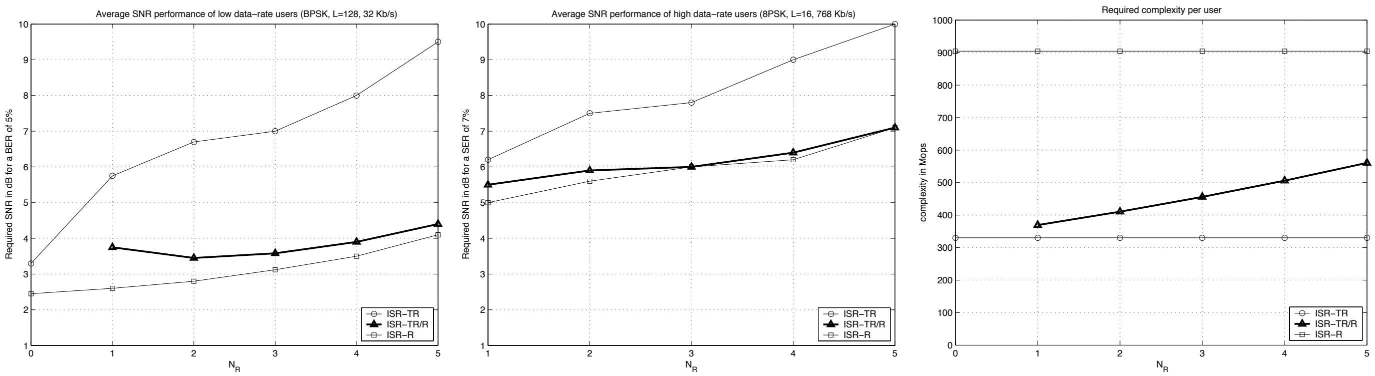

Fig. 1. (a): required SNR in dB for BPSK, (b): required SNR in dB for 8PSK, and (c): required complexity per user, for ISR-TR, ISR-R and hybrid ISR-TR/R versus the number of high data-rate users N_R.

The multi-rate environment is simulated with N_{TR} BPSK users and N_R 8PSK users with spreading factors of $L = 128$ and $L = 16$, corresponding to transmission rates of 32 Kb/s and 768 Kb/s, respectively. The number of high data-rate users N_R ($N_R < N_{TR}$ practically) is varied while keeping constant the total number of users to $NI = N_R + N_{TR} = 11$.

In Fig. 1-(a)(b) we plot the required SNR[2] of both BPSK and 8PSK users versus N_R for the TR, R and hybrid TR/R modes. Fig. 1-(a)(b) shows that the TR/R hybrid performs better than TR and slightly worse than R in protecting low-rate and high-rate users. As the throughput of the system is increased with N_R, the performance of ISR-TR quickly degrades, whereas the performance of TR/R remains stable and close to that of ISR-R. In Fig. 1-(c), we provide the complexity per user in Mops (Million operation per second) versus N_R of the canonic modes TR and R and the hybrid mode TR/R. Since the complexity is dominated by the number of constraints N_c, the complexity of the TR ($N_c = 1$) and R ($N_c = NI$) remain constant while the complexity of hybrid ISR ($N_c = N_R + 1$) increases with the number of high-rate users.

The hybrid ISR TR/R offers a significantly improved performance/complexity tradeoff. Indeed, with 5 8PSK users and 6 BPSK users in each cell, the hybrid ISR mode outperforms the simplest ISR mode (TR) by about 5 and 3 dB gains for the low and high data-rate users, respectively. In this high throughput system, the hybrid TR/R mode performs almost as well as the R mode but with 30% less complexity than the R mode. As the number of high data-rate decreases, the orders of complexity of both the TR mode and the hybrid TR/R mode become closer. With 1 8PSK and 10 BPSK users hybrid ISR provides an SNR gain of 2 dB for low-rate and 1 dB for high-rate users. This gain in performance comes with almost no increase in complexity compared to the TR mode (60% less complexity than the R mode). For the in-between BPSK/8PSK user distributions, TR/R performs almost as well as the more complex mode with 30 to 50% less complexity, while it outperforms the least complex of the two by 3 to 4 dB and 1.5 to 2.5 dB in required SNR for BPSK and 8PSK users, respectively.

[2]Measured at a BER and an SER of 5 and 7%, respectively, in order to achieve a QoS of 10^{-5} after FEC decoding.

V. Conclusions

In this contribution, we proposed a new hybrid ISR scheme that offers a wider range of improved performance/complexity tradeoffs for multi-rate transmissions. Instead of suppressing users with the same canonic ISR mode, the proposed hybrid ISR scheme splits them into several groups based on their data-rates before applying different canonic ISR modes for their nulling, the number of nulling constraints being larger for groups with higher transmission rates. Simulations suggest that a hybrid of the two simplest canonic ISR modes outperforms the simpler of the two with minimal increase in complexity, while it performs almost as well as the more complex mode with 30 to 60% less complexity. Current investigations address extension of the proposed hybrid multi-user detection scheme to the downlink.

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