Optimum Multiuser Detection Is Tractable for Synchronous CDMA Systems Using M-Sequences

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Abstract— The optimum multiuser detection problem was shown to be NP-hard, i.e., its computational complexity increases exponentially with the number of users [1], [2]. In this letter, we show that the optimum multiuser detection problem for a synchronous code–division multiple access (CDMA) system is equivalent to the minimum capacity cut problem in a related network and propose an optimum multiuser detection algorithm with polynomial computational complexity for a certain class of signature sequences. The minimum cut problem is solvable in polynomial time if the capacities of the links not incident to source and sink are nonnegative. This condition in the optimum detection problem is equivalent to all cross correlations between the signature sequences of the users being negative. One example of such set of signature sequences is obtained when shifted versions of the maximal length sequences (or m-sequences) are used. In this case the cross correlation between users i and j is given as $\Gamma_{ij} = -1/G$ for all i, j, where G is the processing gain.

Index Terms—CDMA, optimum multiuser detection.

I. INTRODUCTION

IN CODE-DIVISION multiple access (CDMA) systems users are assigned unique signature waveforms which they use to modulate their information bits. Let the signature sequence of the ith user be $s_i(t)$ for $t \in [0, T]$ where T is the bit duration. The received signal for a synchronous CDMA system with binary phase–shift keying (BPSK) modulation is given by

$$r(t) = \sum_{i=1}^{N} A_i a_i s_i(t) + n(t) \tag{1}$$

where A_i and a_i are received amplitude and the transmitted bit (± 1 equiprobably) of the ith user and $n(t)$ is the additive white Gaussian noise (AWGN) process with power spectral density σ^2. The received signal vector at the output of the conventional receivers is given by

$$\mathbf{y} = \mathbf{\Gamma A a} + \mathbf{n}. \tag{2}$$

The vector $\mathbf{y}$ is a sufficient statistics for the multiuser detection problem. In (2), $\mathbf{\Gamma}$ is a nonnegative definite matrix where Γ_{ij} is $\int_0^T s_i(t) s_j(t)\, dt$. $\mathbf{A}$ is a diagonal matrix containing the received amplitudes of the users with $A_{ii} = A_i$. $\mathbf{a}$ is the vector

containing the information bits of the users and $\mathbf{n}$ is a Gaussian random vector with auto covariance matrix $E[\mathbf{n} \mathbf{n}^T] = \sigma^2 \mathbf{\Gamma}$.

The aim of the multiuser detection is to recover the information bits transmitted by the users in this multiaccess environment. Optimum multiuser detection [1] is based on the maximum likelihood criteria. The optimum multiuser detector chooses $\mathbf{a}^*$ as the transmitted bit vector if for $\mathbf{a} = \mathbf{a}^*$ the conditional probability density of $\mathbf{y}$ given $\mathbf{a}$ is maximized. Denoting the probability density function of $\mathbf{n}$ by $f_{\mathbf{n}}(\cdot)$, the optimum detection problem is given as

$$\mathbf{a}^* = \arg \max_{\mathbf{a} \in \{-1, 1\}^N} f_{\mathbf{n}}(\mathbf{y} - \mathbf{\Gamma A a})$$
$$= \arg \min_{\mathbf{a} \in \{-1, 1\}^N} \mathbf{a}^T \mathbf{R a} - 2 \mathbf{a}^T \mathbf{A y} \tag{3}$$

where $\mathbf{R} = \mathbf{A \Gamma A}$ with $R_{ij} = A_i A_j \Gamma_{ij}$. We can convert (3) to a 0–1 programming problem by introducing a vector $\mathbf{b}$ where $\mathbf{b} = (\mathbf{a} + \mathbf{u})/2$ and $\mathbf{u}$ is an N-dimensional vector of all ones, $\mathbf{u} = [1 \quad 1 \quad 1 \quad \cdots \quad 1]^T$ as

$$\mathbf{b}^* = \arg \min_{\mathbf{b} \in \{0, 1\}^N} \mathbf{b}^T \mathbf{R b} - \mathbf{b}^T \tilde{\mathbf{y}} \tag{4}$$

where $\tilde{\mathbf{y}} = \mathbf{R u} + \mathbf{A y}$. Note that the solutions of (3) and (4) are related by the one-to-one relationship $a_i^* = 2b_i^* - 1$.

II. NETWORK PRELIMINARIES

Consider a network $G = [V, A]$ with vertices $V = \{0, 1, \cdots, N + 1\}$ and arcs A. For any two vertices i and j in G, c_{ij} denotes the capacity of the arc connecting (i, j). Let the nodes 0 and $N + 1$ represent the source and the sink, respectively. A cut separating 0 and $N + 1$ is a partition of the nodes $(\mathcal{S}, \bar{\mathcal{S}})$ where $0 \in \mathcal{S}$, $N + 1 \in \bar{\mathcal{S}}$, $\mathcal{S} \cup \bar{\mathcal{S}} = V$, and $\mathcal{S} \cap \bar{\mathcal{S}} = \emptyset$. The capacity of the cut $(\mathcal{S}, \bar{\mathcal{S}})$ is given by [3]

$$C(\mathcal{S}, \bar{\mathcal{S}}) = \sum_{i \in \mathcal{S}} \sum_{j \in \bar{\mathcal{S}}} c_{ij}. \tag{5}$$

The minimum cut separating nodes 0 and $N + 1$ is defined to be the cut separating nodes 0 and $N + 1$ and having the minimum capacity.

In [4] it was shown that any cut separating nodes 0 and $N+1$ can be represented by a vector $(1, b_1, b_2, \cdots, b_N, 0)$ where $b_i \in \{0, 1\}$ for $i = 1, \cdots, N$ is an indication for membership in $\mathcal{S}$. That is $\mathcal{S} = \{i | b_i = 1\}$ and $\bar{\mathcal{S}} = \{i | b_i = 0\}$. It was also shown in [4] that the capacity of the cut $(\mathcal{S}, \bar{\mathcal{S}})$ is given by

$$C(b) = \sum_{i=0}^{N+1} \sum_{j=0}^{N+1} c_{ij} b_i (1 - b_j) \tag{6}$$

Computational Complexity Of Optimum Multiuser Detection

Arturo Cuomo

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from among 2 875 submissions These papers offer important findings and insights into the field of intelligent computing

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other suboptimal detectors including the SDPR detector However the computational complexity involved in the proposed detectors is much lower relative to that involved in Verdu s ML detector as well as our SDPR detector The third detector entails a subspace estimation based constrained optimization approach for channel estimation in DS CDMA systems with multipath propagation channels The proposed approach offers an improved approximation for the noise iii subspace compared with that offered by several existing algorithms Computer simulations show that the performance of the proposed detector offers nearly the same performance as that of existing subspace detectors but leads to a significant reduction in the amount of computation Relative to some existing constrained optimization methods the proposed detector offers a significantly improved performance while requiring a comparable amount of computation The fourth detector is proposed based on a vector constant modulus VCM approach This detector is designed for DS CDMA systems with multipath propagation channels where the effective signatures observed at receiver are distorted by multipath propagation and aliasing concurrently In this detector detection is carried out by solving a linear constrained optimization problem whose objective function is formulated based on the VCM criterion Two adaptation algorithms namely the constrained stochastic gradient algorithm and the recursive vector constant modulus algorithm are developed Analysis are presented to investigate the performance of the proposed detector Computer simulations show that the proposed detectors are able to suppress multiuser interference and inter symbol interference effectively More importantly they offer robust detection performance against the effective signature distortion caused by aliasing at the receiver   Conference Proceedings ,2003   *Proceedings* ,2000

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