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

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

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

$$\mathbf{y} = \mathbf{\Gamma A a} + \mathbf{n}. \qquad (2)$$

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 $E[\mathbf{n}\mathbf{n}^\top] = \sigma^2\mathbf{\Gamma}$.

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 $f_{\mathbf{n}}(.)$, the optimum detection problem is given as

$$\begin{aligned}\mathbf{a}^* &= \arg \max_{\mathbf{a} \in \{-1,1\}^N} f_{\mathbf{n}}(\mathbf{y} - \mathbf{\Gamma A a}) \\ &= \arg \min_{\mathbf{a} \in \{-1,1\}^N} \mathbf{a}^\top R \mathbf{a} - 2\mathbf{a}^\top \mathbf{A y}\end{aligned} \qquad (3)$$

where $R = \mathbf{A\Gamma A}$ 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, $\mathbf{u} = [1 \ 1 \ 1 \ \cdots \ 1]^\top$ as

$$\mathbf{b}^* = \arg \min_{\mathbf{b} \in \{0,1\}^N} \mathbf{b}^\top R \mathbf{b} - \mathbf{b}^\top \tilde{\mathbf{y}} \qquad (4)$$

where $\tilde{\mathbf{y}} = R\mathbf{u} + \mathbf{A y}$. 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 $(S, \bar{S})$ where $0 \in S$, $N+1 \in \bar{S}$, $S \cup \bar{S} = V$, and $S \cap \bar{S} = \emptyset$. The capacity of the cut $(S, \bar{S})$ is given by [3]

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

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 S. That is $S = \{i | b_i = 1\}$ and $\bar{S} = \{i | b_i = 0\}$. It was also shown in [4] that the capacity of the cut $(S, \bar{S})$ is given by

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

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Computational Complexity Of Optimum Multiuser Detection

RC Schank

Computational Complexity Of Optimum Multiuser Detection:

Computational Science - ICCS 2006 Vassil Alexandrov,2006-05-26 The four volume set LNCS 3991 3994 constitutes the refereed proceedings of the 6th International Conference on Computational Science ICCS 2006 held in Reading UK in May 2006 The main conference and its 32 topical workshops attracted over 1400 submissions The 98 revised full papers and 29 revised poster papers of the main track presented together with 500 accepted workshop papers were carefully reviewed and selected for inclusion in the four volumes The papers span the whole range of computational science with focus on the following major themes tackling grand challenges problems modelling and simulations of complex systems scalable algorithms and tools and environments for computational science Of particular interest were the following major recent developments in novel methods and modelling of complex systems for diverse areas of science scalable scientific algorithms advanced software tools computational grids advanced numerical methods and novel application areas where the above novel models algorithms and tools can be efficiently applied such as physical systems computational and systems biology environmental systems finance and others *Multiuser Detection* Sergio Verdú,1998-08-13 Originally published in 1998 Multiuser Detection provides a comprehensive treatment of the subject of multiuser digital communications *Hardware Implementation of Intelligent Systems* Horia-Nicolai Teodorescu,Abraham Kandel,2013-11-11 Intelligent systems are now being used more commonly than in the past These involve cognitive evolving and artificial life robotic and decision making systems to name a few Due to the tremendous speed of development on both fundamental and technological levels it is virtually impossible to offer an up to date yet comprehensive overview of this field Nevertheless the need for a volume presenting recent developments and trends in this domain is huge and the demand for such a volume is continually increasing in industrial and academic engineering 1 communities Although there are a few volumes devoted to similar issues none offer a comprehensive coverage of the field moreover they risk rapidly becoming obsolete The editors of this volume cannot pretend to fill such a large gap However it is the editors intention to fill a significant part of this gap A comprehensive coverage of the field should include topics such as neural networks fuzzy systems neuro fuzzy systems genetic algorithms evolvable hardware cellular automata based systems and various types of artificial life system implementations including autonomous robots In this volume we have focused on the first five topics listed above The volume is composed of four parts each part being divided into chapters with the exception of part 4 In Part 1 the topics of Evolvable Hardware and GAs are addressed In Chapter 1 Automated Design Synthesis and Partitioning for Adaptive Reconfigurable Hardware Ranga Vemuri and co authors present state of the art adaptive architectures their classification and their applications Advanced Intelligent Computing Theories and Applications De-Shuang Huang,2007-08-09 This volume in conjunction with the two volumes CICS 0002 and LNCS 4681 constitutes the refereed proceedings of the Third International Conference on Intelligent Computing held in Qingdao China in August 2007 The 139 full papers published here were carefully reviewed and selected from among 2 875 submissions These papers offer important findings and insights into the field of intelligent computing

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