

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

Sennur Ulukus, *Student Member, IEEE*, and Roy D. Yates, *Member, IEEE*

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 i th 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

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

where A_i and α_i are received amplitude and the transmitted bit (± 1 equiprobably) of the i th 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

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

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

Manuscript received June 5, 1997. The associate editor coordinating the review of this letter and approving it for publication was Prof. H. V. Poor. This work was supported by the National Science Foundation under Grant NCR-95-06505.

The authors are with the Department of Electrical and Computer Engineering, Rutgers University, Piscataway, NJ 08855 USA (e-mail: cnyes@ece.rutgers.edu).

Publisher Item Identifier S 1089-7798/98/00734-3.

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

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

$$\begin{aligned} \mathbf{a}^* &= \underset{\mathbf{a} \in \{-1, 1\}^N}{\text{arg max}} f_{\mathbf{n}}(\mathbf{y} - \mathbf{\Gamma} \mathbf{A} \mathbf{a}) \\ &= \underset{\mathbf{a} \in \{-1, 1\}^N}{\text{arg max}} \mathbf{a}^T \mathbf{R} \mathbf{a} - 2 \mathbf{a}^T \mathbf{A} \mathbf{y} \end{aligned} \quad (3)$$

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

$$\mathbf{b}^* = \underset{\mathbf{b} \in \{0, 1\}^N}{\text{arg max}} \mathbf{b}^T \mathbf{R} \mathbf{b} - \mathbf{b}^T \mathbf{y} \quad (4)$$

where $\mathbf{y} = \mathbf{R} \mathbf{u} + \mathbf{A} \mathbf{y}$. 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 $V = \{0, 1, \dots, N+1\}$ 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]

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

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 $(1, b_1, b_2, \dots, b_N, 0)$ where $b_i \in \{0, 1\}$ for $i = 1, \dots, N$ 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

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

Computational Complexity Of Optimum Multiuser Detection

Jianjun Gao



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web dec 29 2021 how to leverage payroll analytics from an hr data warehouse an hr data warehouse can unlock the promise of payroll analytics the biggest roadblock to effective payroll analytics is that critical data is often siloed into different sources this usually happens as organizations grow in size

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web may 24 2018 automated payroll system is an application that will manage and compute the employee s salary

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web sep 19 2020 the objectives of this study are to carry out a study on the existing cloud based payroll management system to design a payroll data model for calculating basic salary and enables retrieval of

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web aug 27 2021 first and foremost an automated payroll system can take the lead on approximately 70 80 of repetitive rule based tasks that make up payroll calculation so that employees can focus on more value added responsibilities for instance it can compute pay rates

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web it is about harmonizing the global payroll process and creating a global first methodology that brings in the payroll data in real time that is different in each country and then categorizing and standardizing it all in a global template this makes your multicounty payroll data comparable and helps leaders make decisions based on payroll data

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web sep 12 2023 for example hr data often records an employee s annual base salary or hourly rate but users put the actual amount paid to an employee in the payroll system using one system for hr and payroll enables the incorporation of hr related data in payroll reports and vice versa 11 reduced licensing costs a company s annual

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web feb 11 2017 1 answer sorted by 0 you should start by going through the references here or here on xml schema the idea is that you want to create a salary element with total amount and federal tax deduction elements first you define the basic elements total and federal along these lines

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web in a centralized global payroll model a single provider carefully coordinates payroll requirements and manages the payroll activity of all in country providers for your company benefits with a centralized global payroll partner payroll validation is provided a single language and currency reducing inconsistencies and the chance for error

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web mar 22 2022 this is a database design for a simple payroll management system this erd entity relationship diagram is the one i used for developing payroll management system using php mysql the payroll system allows the company management to manage and calculates the payslip of their employees

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web recently developed enterprise systems such as workday and rea technology have applied the core of the model in their architecture while many erp systems that do not fully embrace the rea