

# Comparative Study of Joint-Detection Techniques for TD-CDMA Based Mobile Radio Systems

Marius Völlmer, Martin Haardt, *Senior Member, IEEE*, and Jürgen Götz

**Abstract**—Third-generation mobile radio systems use time division-code division multiple access (TD-CDMA) in their time division duplex (TDD) mode. Due to the time division multiple access (TDMA) component of TD-CDMA, joint (or multi-user) detection techniques can be implemented with a reasonable complexity. Therefore, joint detection will already be implemented in the first phase of the system deployment to eliminate the intracell interference. In a TD-CDMA mobile radio system, joint-detection is performed by solving a least squares problem, where the system matrix has a block-Sylvester structure. In this paper, we present and compare several techniques that reduce the computational complexity of the joint detection task even further by exploiting this block-Sylvester structure and by incorporating different approximations. These techniques are based on the Cholesky factorization, the Levinson algorithm, the Schur algorithm, and on Fourier techniques since they have the smallest computational complexity and achieve the same performance as the joint detection algorithm that does not use any approximations. Similar to the well-known implementation of fast convolutions, the resulting Fourier-based joint detection scheme also uses a sequence of fast Fourier transforms (FFTs) and overlapping. It is well suited for the implementation on parallel hardware architectures.

**Index Terms**—Cholesky factor, fast Fourier transform, joint detection, Levinson algorithm, overlap save, Schur algorithm, TD-CDMA, Toeplitz structure.

## 1. INTRODUCTION

THE UITS terrestrial radio access (UTRA) that has been specified in the Third-Generation Partnership Project (3GPP) consists of a frequency division duplex (FDD) and a time division duplex (TDD) mode. Wideband code division multiple access (WCDMA) has been chosen for UTRA FDD, whereas UTRA TDD uses time division CDMA (TD-CDMA) [1].

In a CDMA-based system, several co-channel users (that transmit at the same time and on the same frequency) can be separated in the code domain, i.e., by exploiting their different spreading codes. Due to the additional separation in the time domain, the number of co-channel users that are active at the same time in UTRA TDD is smaller than in a pure CDMA

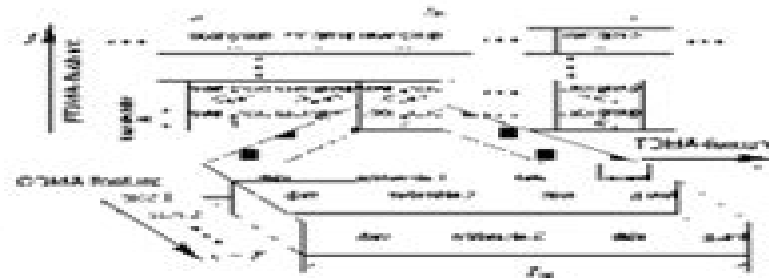


Fig. 1. Frame structure of the TD-CDMA system. Here,  $B$ ,  $T_f$ ,  $N$ ,  $T$ , and  $K$  denote the bandwidth of a frequency slot, the duration of a TDMA frame, the number of bursts per TDMA frame, the burst duration, and the number of CDMA codes per frequency and time slot, respectively.

system, cf. Fig. 1. Therefore, joint (multi user) detection techniques can be implemented with a reasonable complexity. Joint detection eliminates the intracell multiple access interference (MAI) that is caused by users that are located in the same cell and transmit at the same time and on the same frequency (co-channel users) [2], [3].

A joint detector combines the knowledge about all users that share one burst into one large system of equations. This knowledge consists of the channel impulse responses that have been estimated from training sequences, the spreading codes, and the received antenna samples from all antenna elements. An efficient algorithm should exploit the special structural characteristics of the system matrix, i.e., its block-Sylvester structure (see Fig. 3 for a preview of this structure). Sylvester matrices are Toeplitz matrices with a band structure. The Sylvester structure is the manifestation of the fact that the TD-CDMA system uses spreading codes that are periodic with the spreading factor and that the channel is assumed to be constant for one burst.

There are several algorithms that have been specifically developed to work efficiently with Toeplitz matrices. We will briefly look at both the Levinson algorithm, which can directly solve a system of equations involving a positive-definite system matrix with Toeplitz structure, and at the Schur algorithm, which efficiently computes the upper triangular factor  $K$  of the  $Q/R$  factorization of the Toeplitz matrix. However, the band structure of the system matrix together with the Toeplitz structure enables the use of far reaching approximations in the solution process. These approximations reduce the computational requirements of all involved algorithms, and in fact, make it possible that an algorithm such as the Cholesky

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