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# Performance analysis of Volterra-based nonlinear adaptive blind multiuser detectors for DS-CDMA systems

Guo Linlin, Sadasivan Puthusserypady*

*Department of Electrical & Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117576, Singapore*

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**Abstract**

The major limitation on the performance and capacity of direct sequence code division multiple access (DS-CDMA) communication systems is the multiple access interference (MAI) due to simultaneous transmission of several users. The linear minimum mean square error (MMSE) detector is a well-known method to suppress MAI adaptively and blindly, however, it is sub-optimal because of the inherent nonlinearity of the system. Therefore, in this paper, two nonlinear blind adaptive interference cancellation algorithms (the exact Newton (EXN) and the approximate Newton (APN)) were proposed and developed based on the 2nd order Volterra expansion. A complete performance analysis of the conventional matched filter (MF) detector, linear adaptive detector (which employs the standard Newton algorithm) and the proposed two nonlinear adaptive (EXN and APN) detectors was carried out in various DS-CDMA systems. Numerical results show that the three Newton type adaptive blind multiuser detectors yield significant bit error ratio (BER) improvement over the conventional MF detector in the presence of strong MAI. Further, the two nonlinear adaptive algorithms always outperformed the linear algorithm. Most attractively, the APN algorithm offers lower computation complexity, higher numerical stability and almost identical BER performance in comparison with the EXN algorithm.


*Keywords:* DS-CDMA; Volterra expansion; Nonlinear; Exact Newton; Approximate Newton; MAI; Multiuser detection

## 1. Introduction

Direct sequence code division multiple access (DS-CDMA) is the most popular CDMA technology in wireless communication systems [15]. In such a system, several users transmit information simultaneously over a common channel using pre-assigned signature waveforms called the spreading waveforms. These users can be synchronous in the sense that the transmission rate is the same for all users and their bit streams are perfectly aligned at the receiver, or asynchronous, in which, their bit streams need not be aligned at the receiver. By

*Corresponding author. Tel.: +65-6874-2262; fax: +65-6779-1103.
*E-mail addresses:* engp1601@nus.edu.sg (G. Linlin), elespk@nus.edu.sg (S. Puthusserypady).

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using a set of mutually orthogonal spreading sequences for all users, they each may achieve interference free single user performance in both synchronous and asynchronous CDMA systems. It is however not possible in a real mobile environment to maintain orthogonality of the spreading sequences at the receiver, and hence causes the multiple-access interference (MAI) to arise. This is the major limitation on the performance and capacity of the CDMA systems. This is especially so, when the transmitters have different geographical locations relative to the receiver, where, a weak signal from a distant unit is overwhelmed by a strong signal from a nearby interferer, the near-far problem [8].

Demodulation of DS-CDMA signals is conventionally achieved with a matched filter (MF) detector. However, the MF detector performs poorly when it suffers from the near–far problem. To overcome this, there are several multiuser detection schemes reported in the literature [1–4,6,8,10,15–17]. Multiuser detection refers to the process of demodulating one user's data stream from a non-orthogonal multiplex, which can substantially increase the capacity of CDMA systems.

In [1,2,6,10,16], it has been shown that minimum mean squared error (MMSE) receivers can be used to suppress MAI adaptively and blindly, in which only the spreading sequence of the desired user is available. In synchronous DS-CDMA systems, minimum mean output energy (MMOE) method [2,6] and subspace-based method [3,16,17] were presented for blind multiuser detection with the knowledge of only the desired user's spreading sequences and (possibly) the timing. Because of the existence of multi-path phenomenon, the MMSE detector in such an environment was studied in [4]. However, all of these detectors have linear structures, which circumscribe their performances, due to the inherent nonlinearity of the signals involved. It is known that nonlinear structure in the detector is required to obtain the optimum performance [7,9]. A Volterra function based adaptive nonlinear detector with least mean square (LMS) updating rule is studied in [14]. This method suffers from drawbacks such as slow convergence and high computation complexity due to the higher order (3rd and 5th) Volterra expansion.

In this paper, two Volterra-based (2nd order) Newton type nonlinear adaptive algorithms (the exact Newton (EXN) and the approximate Newton (APN) [5]) are proposed for blindly minimizing the MAI and the additive white Gaussian noise (AWGN). Linear adaptive algorithm (the conventional Newton, or recursive least square (RLS)) is also developed in order to compare the performance with the proposed nonlinear algorithms.

There are basically two problems associated with the proposed EXN algorithm: (i) the Hessian matrix (2nd derivative of the cost function) may not be invertible (or nearly singular), which leads to numerical instability, (ii) high computational complexity because of the need to calculate the inversion of the exact Hessian at each iteration. These problems can be overcome by using an approximated Hessian matrix instead of the exact Hessian matrix. This approximation results in the APN algorithm, which has the desirable features such as higher numerical stability and lower computational complexity. These issues will be discussed in detail in Section 3.

Computer simulations of the conventional MF, linear RLS algorithm, and nonlinear EXN and APN algorithms were carried out in various DS-CDMA systems. The numerical results show that the three Newton type adaptive blind multiuser detectors yield significant bit-error-ratio (BER) improvement over the conventional MF detector in the presence of strong MAI. Further, the proposed two Volterra-based nonlinear adaptive schemes always outperformed the conventional linear RLS scheme. The most important contribution of this paper is that the proposed APN algorithm shows almost identical BER performance as that of the EXN algorithm, at much lower computational complexity and at higher numerical stability. Interestingly, the proposed two nonlinear adaptive receivers perform well in the asynchronous and Rayleigh fading DS-CDMA systems, where only the spreading sequences of the desired users are available.

This paper is organized as follows. The next section explains the system models of the basic synchronous and asynchronous DS-CDMA