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A Study of the Design and Performance of Algorithms for Adaptive Filtering and Distributed Learning

Thesis Outline

This dissertation is motivated by the need for a unified analysis of the behavior of sophisticated adaptive filtering schemes and a new perspective on the design of modern adaptive and distributed learning algorithms based on some recent progress in convex optimization theory.

The first part of this dissertation deals with the development of a unified approach to the analysis of three large classes of adaptive filtering algorithms employing error and data nonlinearities, as described in Chapters 3, 4 and 5. By applying similar assumptions across the different classes of algorithms, systematic evaluation and comparison of the performance of the adaptive schemes are provided, which help reveal similarities that exist between various types of algorithms. As much as possible, we shall attempt to answer three main issues regarding the operation of the adaptive schemes – their stability, transient behavior and steady-state performance. The proposed treatment not only brings about the unified derivation of earlier results, but it also leads to the realization of new performance results for fairly sophisticated algorithms without relying on restrictive assumptions on the statistics on the input data. Moreover, a sufficient framework that allows one to easily build on for analyzing the performance of adaptive schemes in stationary and nonstationary environments is given. Several interesting relations of the performance of the algorithms with some of their design parameters are also discussed.

In the second part of this work, we propose a framework for the design of adaptive and distributed learning schemes that can exploit a priori information such as sparsity based on proximal splitting methods, as discussed in Chapter 6. By combining the proximal formalism with robust distributed strategies known as diffusion adaptation techniques, several adaptive and distributed learning algorithms can then be developed. Under the proposed unified framework, various new adaptive and distributed learning schemes can be designed and existing algorithms can be derived as special instances. Different regularization and fidelity terms are then discussed to highlight the new adaptation and learning abilities the proposed algorithms may endow adaptive filtering systems and networks. Some of the arguments used for the analysis of adaptive filters are also extended in order to analyze the stability of the algorithms. Numerical simulations are finally presented to demonstrate the advantage of using the proposed algorithms compared to conventional schemes.

Here is an overview of the contents of this study.

- Chapter 2 provides the basic notation employed throughout this dissertation. We motivate different data models for adaptive filtering and distributed learning that we will adopt in order to understand different aspects of the adaptive learning problem. We also introduce some useful error quantities and provide a discussion of standard simplifying assumptions that we will employ throughout the dissertation.
- Chapter 3 presents a unified tracking performance analysis of the large class of adaptive filters with error and scalar data nonlinearities. Using energy-conservation arguments, we derive a fundamental variance relation that implies, in general, that the transient behavior of an adaptive filter with error and scalar data nonlinearities can be characterized by a nonlinear time-invariant state-space model. The steady-state performance of these adaptive filters can then be derived without assuming the input data to being Gaussian or white.
- Chapter 4 describes an extension of the techniques used in Chapter 3 to obtain a unified tracking analysis of the larger class of adaptive filters that employ error and matrix data

nonlinearities. As may be expected, this class of algorithms is more difficult to analyze, so stronger versions of some assumptions are necessary in order to obtain a tractable performance analysis.

- Chapter 5 contains an analysis of the performance of the class of data-reusing adaptive algorithms with nonlinear projections. Members of this class of algorithms are in general more sophisticated, and several extensions of simplifying assumptions are required. Moreover, we employ a slightly different approach to analyze the transient and steady-state performances of this class of adaptive filters.
- Chapter 6 motivates the application of the proximal formalism for the adaptive learning problem. We introduce well-known proximal splitting methods and discuss several data fidelity and convex regularization functions that may be employed in order to obtain a plethora of adaptive proximal schemes. We then extend the proximal splitting approach to distributed learning over adaptive networks. By combining adaptive proximal techniques with diffusion strategies, we derive efficient adaptive and distributed learning algorithms that endow networks with new adaptation and learning abilities. We also analyze the stability and feasibility of the use of such algorithms compared to standard distributed schemes.
- Chapter 7 concludes the dissertation.