Stochastic Stability of Perturbed Learning Automata in Positive-Utility Games

Georgios C. Chasparis

Abstract—This paper considers a class of reinforcement-based learning (namely, *perturbed learning automata*) and provides a stochastic-stability analysis in repeatedly-played, positive-utility, finite strategic-form games. Prior work in this class of learning dynamics primarily analyzes asymptotic convergence through stochastic approximations, where convergence can be associated with the limit points of an ordinary-differential equation (ODE). However, analyzing global convergence through an ODE-approximation requires the existence of a Lyapunov or a potential function, which naturally restricts the analysis to a fine class of games. To overcome these limitations, this paper introduces an alternative framework for analyzing asymptotic convergence that is based upon an explicit characterization of the invariant probability measure of the induced Markov chain. We further provide a methodology for computing the invariant probability measure in positive-utility games, together with an illustration in the context of coordination games.

I. INTRODUCTION

Recently, multi-agent formulations have been utilized to tackle distributed optimization problems, since communication and computational complexity might be an issue under centralized schemes. In such formulations, decisions are usually taken in a *repeated* fashion, where agents select their next actions based on their *own* prior experience. In the case of finite number of actions for each agent, such multi-agent interactions can be designed as strategic-form games, where agents are repeatedly involved in a strategic interaction with a fixed *payoff* or *utility* function. Such framework finds numerous applications, including, for example, the problem of distributed overlay routing [2], distributed topology control [3] and distributed resource allocation [4].

Given the repeated fashion of the involved strategic interactions in such formulations, several questions naturally emerge, including: a) *Can agents "learn" to asymptotically select optimal actions?*, b) *What information should agents share with each other?*, and c) *What is the computational complexity of the learning process?* Under the scope of engineering applications, it is usually desirable that each agent

shares minimum amount of information with other agents, while the computational complexity of the learning process is small. Naturally, *payoff-based learning* has drawn significant attention. Under such class of learning dynamics, each agent receives *only* measurements of its own utility function, while the details of this function (i.e., its mathematical formula) are unknown. Furthermore, each agent cannot access the actions selected or utilities received by other agents.

In such repeatedly-played strategic-form games, a popular objective for payoff-based learning is to guarantee convergence (in some sense) to Nash equilibria. Convergence to Nash equilibria may be desirable, especially when the set of optimal centralized solutions belongs to the set of Nash equilibria.

Reinforcement-based learning has been utilized in strategic-form games in order for agents to gradually learn to play Nash equilibria. It may appear under alternative forms, including discrete-time replicator dynamics [5], learning automata [6], [7] and *Q*-learning [8]. In all these classes of learning dynamics, deriving conditions under which convergence to Nash equilibria is achieved may not be a trivial task, especially in the case of large number of agents (as it will be discussed in detail in the forthcoming Section II).

In the present paper, we consider a class of reinforcement-based learning introduced in [9] that is closely related to both discrete-time replicator dynamics and learning automata. We will refer to this class of dynamics as *perturbed learning automata*. The main difference with prior reinforcement-based learning schemes lies in a) the *step-size sequence*, and b) the perturbation (or *mutations*) term. The step-size sequence is assumed constant, thus introducing a fading-memory effect of past experiences in each agent's strategy. On the other hand, the perturbation term introduces errors in the selection process of each agent. Both these two features can be used for designing a desirable asymptotic behavior.

We provide an analytical framework for deriving conclusions over the asymptotic behavior of the dynamics that is based upon an explicit characterization of the invariant probability measure of the induced Markov chain. In particular, we show that in all finite strategic-form games satisfying the *Positive-Utility Property* (i.e., games with strictly positive utilities), the support of the invariant probability measure coincides with the set of pure strategy profiles. Furthermore, we provide a methodology for computing the set of stochastically stable states in all positive-utility games. We illustrate

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