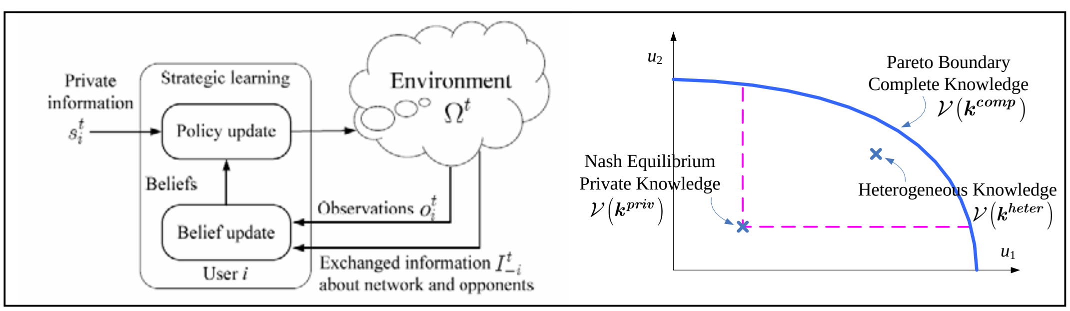
Strategic learning and heterogeneous knowledge in multi-agent communication systems at UCLA Multimedia Communications and Systems Lab

Goal and relevance.

Our research aims at developing a paradigm shift in architecting communication systems, where network entities, referred to here as agents (devices, users), *learn, forecast and proactively influence* the inter-agent interaction based on their *decentralized and asymmetric knowledge*. Specifically, we investigate how cognitive agents can *individually harvest knowledge* (about other agents' behaviors and the available network resources) by *learning* from their local observations and information exchanged with agents, such that they can improve their network performance. The ultimate goal of the project is to develop a *fundamentally new way to design and optimize communication networks, where network entities evolve over time and become smarter*. This research will therefore develop methods and techniques that enhance the performance, survivability and resilience of communication networks in a variety of deployment scenarios.

To achieve this goal, we investigate how to construct operational solutions that achieve new performance bounds by enabling agents with different knowledge availabilities to interact. In contrast with static equilibrium characterization, the technique of learning in games focuses on developing constructive methods to achieve various points in the utility space, where agents may or may not be person-by-person optimal. Thus, our goal is *to understand what will be the emergent behavior of interacting agents that use simple learning methods to adapt and optimize their strategies based on their asymmetric information*. While the origins of the multi-agent learning field were to develop *descriptive* models in artificial intelligence, social systems or robotics, the proposed interactive learning solutions developed as part of our research will be instead used as a *constructive* solution to design and guarantee the QoS supported by the multi-agent interaction in communication networks.

Our research (see below) is one of the first in the literature to design interactive learning solutions that enable foresighted, anticipatory interaction of users in communication networks. This is described briefly below.



(Left Figure) *Strategic learning*: An agent i, participating in a multi-agent interaction[1] (game) Ω, can compute its belief $\mathcal{B}_i = \mathcal{L}_i(o_i, \mathcal{I}_{-i})$ about Ω based on its observations o_i and, possibly, explicit

---

[1] The agent interacts with the environment which is defined by the other agents' actions as well as the available network resources.

information exchanges with the other agents $\mathcal{I}_{-i}$, by deploying a strategic learning algorithm $\mathcal{L}_i$.

This belief about Ω, together with its private information s_i, will determine the policy based on which it selects its actions for interacting with the other agents.

A key challenge for the agent, in this informationally-decentralized, multi-agent interaction, is thus, finding the learning strategy $\mathcal{L}_i$, which maximizes its expected utility. Various multi-agent learning strategies have been proposed by us in the past (for details, see the references to our work below).

It is also important to note that the observations that an agent can make and the information exchanged with other agents, will also play a major role on the performance of strategic learning. Hence, designing protocols which enable users to efficiently gather such information becomes paramount.

Thus, from a network perspective, designing network interaction rules (e.g. using mechanism design or axiomatic bargaining) and protocols that enable such agents to achieve Pareto efficiency with minimum information exchanges is another key challenge.

[For more information, see the following papers:

- M. van der Schaar and F. Fu, "Spectrum Access Games and Strategic Learning in Cognitive Radio Networks for Delay-Critical Applications, Proc. IEEE 2009
- F. Fu and M. van der Schaar, "Learning to Compete for Resources in Wireless Stochastic Games," *IEEE Trans. Veh. Tech.*, to appear
- H. P. Shiang and M. van der Schaar, "Feedback-Driven Interactive Learning in Dynamic Wireless Resource Management for Delay Sensitive Users," *IEEE Trans. Veh. Tech.*, to appear.
- Y. Su and M. van der Schaar, "Minimum Required Learning and Impact of Information Feedback Delay for Cognitive Users," *IEEE Trans. Veh. Tech.*, to appear
- H. Park and M. van der Schaar, "A Framework for Foresighted Resource Reciprocation in P2P Networks," *IEEE Trans. Multimedia*, to appear.
- Y. Su and M. van der Schaar, "A Simple Characterization of Strategic Behaviors in Broadcast Channels," *IEEE Signal Process. Lett.*, vol. 15, pp. 37-40, 2008
- H. P. Shiang and M. van der Schaar, "Distributed Resource Management in Multi-hop Cognitive Radio Networks for Delay Sensitive Transmission," *IEEE Trans. Veh. Tech.*, to appear.]

(Right Figure) *Heterogeneous knowledge and learning:* The performance of multi-agent communication systems with either no or complete knowledge about other agents has been solved in many setting. However, the more realistic, intermediate scenario, where agents having heterogeneous, partial, knowledge (beliefs) about each other has been much less investigated. Hence, the performance region spanned by solutions based solely on the private knowledge of the agents and solutions assuming complete knowledge about all agents, remains largely unexplored for many communication problems. However, studying this heterogeneous knowledge scenario is essential for achieving new performance bounds as well as new, improved, operational solutions for informationally-decentralized multi-agent communication systems.

[For more information, see above references and also

- Y. Su and M. van der Schaar, “A New Look at Multi-user Power Control Games”, Proc. Int. Conf. Commun. 2008 (ICC 2008), pp. 1072-1076, May 2008.
- Y. Su and M. van der Schaar, "Conjectural Equilibrium in Water-filling Games"]