# Evolution of Bio-Socially Inspired Strategies in Support of Dynamic Spectrum Access

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***Abstract*—Human and animal societies exhibit complex cognitive and social processes of coordination, cooperation, and competition among their members. Among other functions, these processes can facilitate fairer sharing of resources among community members and enhance individual survival outcomes. In this work, three bio-socially inspired models for secondary users of spectrum in cognitive radio networks are defined and compared to one other within an evolutionary framework. The proposed models reflect successively more sophisticated capabilities of secondary users in distributed spectrum access. The simplest of the three, blind channel access, is shown to be evolutionarily dominant when residual channel capacities are homogeneous. The second more advanced model assumes a capability to sense channel utilization; this model is shown to dominate when the channels have intermediate load and heterogeneous capacities. Finally, the most complex model (additionally) allows for social coalitions and within-group deference; this model is seen to dominate in high load heterogeneous resource settings. We explore the long term evolutionary pressures within societies whose members choose between these three schemes, with natural selection operating via a utility-based fitness function. Our research is based on systematic ns-3 simulation experiments of heterogeneous societies under a range of assumed channel conditions, population sizes, resource demands, and initial user attributes. Our results demonstrate that the secondary user population always evolves to adopt a unique and stable strategy, but that the winning strategy selected depends strongly on channel conditions. Our results further show that this kind of leaderless evolution leads to a significant 12-116% overall improvement in performance compared to systems in which a fixed strategy is deployed. In summary, we conclude that evolving bio-social behavioral models can be applied to great advantage in understanding dynamic environments such as those envisioned by distributed spectrum access.**

***Index Terms*—Dynamic Spectrum Access; Cognitive Radio; Bio-Social Spectrum Access Strategies; Strategy Evolution.**

## I. Introduction

The Federal Communications Commission (FCC), and similar regulatory bodies around the world are responsible for licensing the inherently scarce resource of radio spectrum. In spite of this, spectrum bands are typically underutilized by their licensed owners (i.e. the "Primary Users" or PUs); indeed the findings of Wang et al. [1] and others show spectrum occupancy in the U.S. is presently below 6%. The FCC prompted the research community for innovative solutions to spectrum underutilization, resulting in the development of cognitive Radio (CR) and distributed spectrum (DSA) access models [2] which allow unlicensed "Secondary Users" (SUs) to access licensed spectrum while guaranteeing transmission priority for PUs.

In the DSA paradigm, managing SU-SU interactions is crucially important. Uncoordinated SU access to resources can lead to unbalanced resource usage, and leave some channels crowded and others underutilized. In this work, we investigate SU-SU interactions within a bio-socially inspired evolutionary framework, to obtain more efficient spectrum utilization strategies long term. In our framework, we allow SUs to adapt their strategies gradually over time by mimicing their more successful peers. Our approach to CR societies reflects what we know about its biological counterparts, wherein we observe a variety of individuals with different capabilities and behaviors, adapting over time. We consider three types of SUs:

- **Baseline:** Users select their transmission channel randomly, operating in the absence of external data about the states of the different channels.
- **Foraging Behavior:** Users can dynamically sense the channel state information, and use this external data to determine their channel selection and data transmission strategy.
- **Social Behavior:** Users can dynamically sense the channel state information as well as the properties of its co-users, and use this external data to determine their channel selection and data transmission strategy.

In this paper, we will consider heterogeneous ecosystems containing a mix of SUs spanning the three behav-

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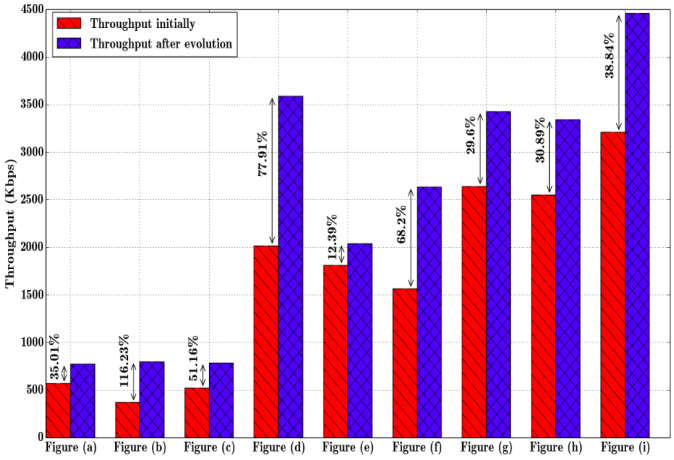


Fig. 5. Throughput improvement due to strategy evolution

## VI. Conclusions and Future Work

In this work we presented three bio-socially inspired strategies for DSA by secondary users. We demonstrated through simulation experiments that each of these strategies has the potential to dominate the others over long time scales where natural selection is at play. We showed that the winning strategy depends on the underlying channel conditions and the demographics of the SUs. ACUs emerge when the channel capacities are homogeneous and under light load; FCUs emerge when the channels capacities are heterogeneous and under intermediate load; SFCUs emerge when the channels capacities are heterogeneous and under heavy load.

In our future research work, we plan to replicate the experimental results of this paper formally using evolutionary game theory. We also plan to verify the conclusions in a experimental hardware testbed in which some of the simplifying assumptions of the simulation models are no longer present.

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