Emergence of pecking order in social Cognitive Radio societies

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***Abstract*—In the face of the exponential growth of Internet of Things (IoT) devices, the limited capacity of radio spectrum is likely to reach saturation. Cognitive Radio technology has been proposed to relieve over-saturated channels by allowing for licensed channels to be opportunistically accessed by unlicensed users during periods of time when the license holder is absent from its channel. Un-coordinated competition over a limited number of resources among unlicensed spectrum users leads to complex co-existence challenges. Here we present a new bio-social inspired paradigm for cognitive radio, extending our previous work where we showed a plausible evolutionary trajectory of intra-groups dynamics over time as groups abide by two social behavioral rules, in-group deference and out-group avoidance. In this paper, we relax these social behavior rules in order to allow groups to organize into different social structures. More specifically, we observe how a hierarchical society compares to a classless society. We show that as the system scales, the hierarchical social structure is more likely to emerge in a distributed cognitive radio network. The bio-social paradigm presented here has consequences both in suggesting potential improvements for dynamic spectrum access, and in understanding the natural evolvement of social structures as cognitive radio devices form groups to gain advantage in the competition over resources.**

I. Introduction

The rapid growth of the Internet of Things (IoT) is expected to significantly impact wireless service demands. Limited spectrum availability, more affordable hardware, and increased demand for end-user applications lead to device coexistence challenges. Although IoT devices are most often thought of as low power sensors with limited hardware capabilities, the need to support Big Data transmission is inevitable. As IoT devices become more sophisticated, Dynamic Spectrum Access (DSA) networks [4] using Cognitive Radio (CR) technology offers a potential solution to relieve over-crowded wireless channels [11], [13].

The current approach of static spectrum assignment by the FCC has led to underutilization in some bands since spectrum license holders (primary users) transmit periodically leaving behind "spectrum holes" while being idle [8]. Cognitive Radio technology alleviate underutilized bands by allowing CR equipped devices "secondary users" (SUs) to transmit in a licensed spectrum band as long as they abandon the band upon the primary user's arrival. To avoid interference with primary users, SUs are capable of dynamically identifying and opportunistically forage for unused spectrum bands by adjusting transmission/reception parameters accordingly. In addition to primary user avoidance, SUs compete with other SUs while foraging for a limited amount of resources.

Computer science research on resource allocation in networks recognizes the potential relevance of knowledge on resource use in human and animal societies [7], [12]. There has been considerable prior work seeking to apply models of animal foraging strategies to the design of protocols in the Internet [17], [9], towards routing and management in mobile ad-hoc networks [6], [2], within sensor networks [14], [3], and now most recently, in the domain of cognitive radio (CR) networks [1], [10], [5], [15].

As competition over resources becomes increasingly more challenging in wireless networks, a bias toward devices belonging to the same group (e.g. the same manufacturer, carrier, etc.) could potentially alter the resource sharing efficiency. In our previous work [19], we introduced two simple social behavioral rules, in-group deference and out-group avoidance. In-group deference allows SUs to avoid causing interference with its group members by waiting to transmit. Out-group avoidance causes SUs to switch bands if they detect that too many SUs from competing groups are present in their band, i.e. a fraction exceeding some system wide comfort threshold parameter. We showed that this behavioral model significantly increases system utility for intermediate comfort threshold values as it results in the epiphenomenon of group based segregation across bands.

In this work, we extend our previous bio-social scheme by relaxing the deference and avoidance rules to allow for more

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$\theta = 0.30$ and $\theta = 0.31$. The benefit in utility that a low-entropy state yields in a mutual-avoidance society becomes harder to achieve as the group-to-bands ratio increase since the segregation interval narrows. Similar utility benefits are obviously not achievable if the number of groups exceeds the number of bands in the network.

IV. Conclusion

A dense heterogeneous IoT population competing over a limited amount of resources poses complex co-existence challenges. Considering bio-inspired approaches and the study of animal foraging strategies, may play an important role in addressing these challenges. Here we extended our previously defined bio-social paradigm [19] to incorporate different social structures. Our objective was to determine if there is an evolutionary pressure with respect to utility for the emergence of hierarchy in a social SU population.

We showed that a hierarchical social structure is more likely to emerge when compared to mutual-avoidance as the population size grows. Mutual-avoidance outperforms hierarchy when the society experiences a low-entropy state (segregation across bands) since defering to group members lowers transmission interference. This occurs for a narrowing range of comfort threshold choices (segregation interval) as population size increases. Thus hierarchy is more likely to emerge since it yields higher utility when compared to mutual-avoidance for a broader range of comfort threshold values.

We showed that as the number of bands-to-SUs ratio decreases or the number of groups-to-bands ratio increases, the range of the segregation interval in mutual-avoidance narrows and a hierarchical society is more likely to emerge.

Given that the precise values defining the segregation interval are a complex function of population size n, the number of bands m, and the number of groups g, if these parameters are dynamic, SUs would need to coordinate their comfort threshold settings. We do not dismiss mutual-avoidance since it yields maximum utility but argue that in the absence of global coordination, SUs have an incentive to choose a hierarchical social structure. In a system that is growing, hierarchy will arise and mutual-avoidance will be abandoned.

A. Future work

We intend to implement the proposed scheme in real hardware testbed in the CR and IoT context, using nodes that are capable of switching Wi-Fi channels using a microcontroller together with ns-3 emulation/testbed engine.

We hope to extend the model where CR nodes can evolve by independently choosing group membership to allow for dynamic social structures.

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