# When Brands fight over Bands: Sociality in the Cognitive Radio Ecosystem

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***Abstract*—As wireless devices continue to proliferate, spectrum management is essential to a healthy and functioning digital ecosystem. Here we present an evolutionary analysis of how inter-brand relationships can be expected to evolve in the cognitive radio domain over long time scales. We find that a range of trajectories are possible, and that the eventual outcomes depend on a variety of system parameters including the number of users and transmission band switching costs. Starting from previous bio-socially inspired fair spectrum sharing protocols, we put forward an extended model of secondary user etiquette that allows for a range of inter-group dynamics to arise in the natural course of competition over and co-use of spectrum resources. We show that as populations grow, increases in transmission switching costs lead to evolutionary pressures toward increasing antagonism between brands, and that in such scenarios devices tend to segregate by brand across bands. Understanding the drivers behind emerging inter-brand dynamics from an evolutionary perspective is an important input to the long term view of the successful application of distributed spectrum access and cognitive radio.**

***Index Terms*—Cognitive radio networks; bio-social networking; self-coexistence; dynamic spectrum access; contention-sensing**

## I. Introduction

Remarkable advances in wireless device technologies continue to be driven by the demands of an increasingly diverse set of *new* higher bandwidth end-user applications. These technological advances have over time, yielded corresponding reductions in hardware production costs. Not surprisingly, this positive feedback loop has led to an exponential growth of total numbers of devices and their cumulative bandwidth demands, while available radio spectrum has remained largely unchanged. The current scenario (or the one which we are inexorably headed) is one in which wireless devices face severe problems of "coexistence" as co-users of the limited resource of radio spectrum. Dynamic Spectrum Access (DSA) networks [1] using Cognitive radio (CR) technology [2] has been proposed to alleviate contention in spectrum bands [3], [4]. The historical approach of static spectrum assignment has led to underutilization in some bands because spectrum license holders (primary users) transmit periodically leaving "spectrum holes" while being idle [5]. With CR technology "secondary users" (SUs) can transmit in a licensed spectrum band provided they immediately leave the band upon primary user arrival to avoid interference. SUs dynamically identify and opportunistically forage for unused spectrum, adjusting transmission/reception parameters accordingly. In addition to primary user avoidance, SUs compete with other SUs over limited resources. We attempt to map out the most plausible long-term evolutionary trajectories of spectrum co-use strategy under the pressures and dynamics of inter-group competition.

We consider a population where all SUs belong to one out of two groups. We think of these groups as being identified by **brands**. Our goal is to understand how the relationship between brands might evolve over time. In answering this question about brands competing over spectrum, we draw upon prior work from the bio-social domain where the competition between species over natural resources has been extensively studied [1]

We start from a previous bio-social model of CR nodes [9], wherein each SU can at each point in time either "forage" (search) for good spectrum bands or "consume" (transmit in) its present band of interest. While the SU is foraging, it is accumulating untransmitted data; following the bio-social metaphor, we say that it is experiencing increasing "hunger". An SU decides to transmit stochastically based on its hunger

[1]The leap is not that far fetched, given that CR networks in DSA environments are autonomous and (at least in theory) capable of sensing, learning, and adaptation, they may evolve over time, much as humans and other social animal species have in analogous contexts of resource sharing/conflict [6]. Computer science research on resource allocation in networks recognizes the potential relevance of knowledge on resource use in human and animal societies. There has been considerable prior work seeking to apply models of animal foraging strategies (and derivative theories of marginal use) to the design of protocols in the domain of CR networks [7], [8].

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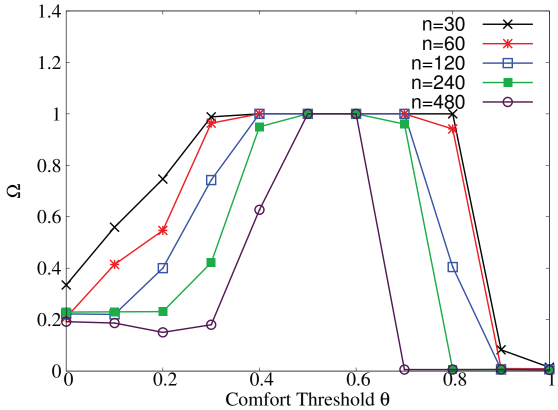


Fig. 7: Band based segregation $\Omega$ for varying comfort thresholds.

some group and $\Omega = 0$ when both groups occupy majority status with equal frequency in all bands. The graph shows $\Omega$ for different population sizes $n$ and different comfort threshold $\theta$ settings. Regardless of populations size, societies will segregate at intermediate values of $\theta$. When consumers have low comfort threshold levels, the population does not segregate since consumers are comfortable with a large fraction of consumers from the other group consuming in their BoI. On the other hand, when comfort threshold levels are high, SUs are only comfortable consuming their BoI if a large fraction of co-consumers are from their own group; this results in frequent switching (Figure 3) and failing to segregate (Figure 7).

## V. Conclusion

The diverse device population in the Internet of Things poses coexistence challenges. The protocol presented here builds on earlier bio-socially inspired "fair" need-to-transmit based protocols [9]. Our objective in this paper was to determine *what could be expected to happen in the future*, if SUs with similar characteristics (e.g. the same brand) group together and act according to two basic principles (i) in-group deference and (ii) out-group avoidance. Holding in-group deference fixed, we considered CR societies with a range of out-group avoidance. This was implemented using a comfort threshold parameter $\theta$. By examining societies with different $\theta$ settings side-by-side and through the lens of a fitness function (net utility), we came to see the evolutionary pressures at play. We showed that there are always pressures towards the emergence of (intermediate) non-zero comfort threshold societies, but that large tolerant CR societies are more robust (evolutionarily stable) in this regard, compared to smaller ones. We showed that the strength of evolutionary pressures is closely linked to both population size and transmitter reconfiguration costs. Larger CR societies are more susceptible to responding to small increases in transmitter reconfiguration cost by deviating from policies of tolerance; the emergence of such discriminatory and avoidant behaviors can be explained directly in terms of survival needs (the requirement that per SU net utility be positive). We also saw that band-based segregation can arise as an epiphenomenon in societies with such intermediate comfort threshold value.

**Future Work** The proposed scheme considers only two groups of CR devices; we intend to consider the dynamics of multiple groups, and settings in which the groups can be of different sizes. We hope to extend the model so that CR nodes can evolve by independently choosing the comfort thresholds based on collective beliefs about the relative merits of different settings. 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.

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