Contention-Sensing and Dynamic Spectrum Co-Use in Secondary User Cognitive Radio Societies

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***Abstract*—Emerging standards in Cognitive Radio seek to alleviate the problem of spectrum scarcity by leveraging spectrum under-utilization through dynamic spectrum access (DSA). Unlicensed users ("secondary") may opportunistically make use of channels during times when the licensed ("primary") user is absent. The "open access" paradigm proposed by FCC mandates the study of primary-secondary dynamics, as well as secondary-secondary dynamics to better understand the implications of uncoordinated competition for limited number of resources between secondary users. In this paper, we consider long term etiquette between secondary users engaged in spectrum co-use. In order to maximize throughput, by avoiding over-crowded channels, we propose a novel approach wherein secondary users have the ability to "sense" very approximate contention levels at a single spectrum band at each point in time. System performance under the contention-sensing paradigm is compared to two schemes: first, a previously defined non-cooperative game model; second, a new model which allows for spectrum foraging, but without providing secondary users the ability to sense contention in a band. Through simulation experiments, we show that the contention-sensing paradigm results in significantly better co-use of spectrum resources. Additionally, our experiments demonstrate that the proposed contention-sensing paradigm continues to outperform when the ratio of secondary users to spectrum bands is increased. Thus, the new schemes described here may be of critical importance in a future where we expect the number of secondary users to grow exponentially and thus require a scalable mechanism for opportunistic scavenging of unused spectrum.**

***Index Terms*—Cognitive radio networks, self-coexsitence, dynamic spectrum access, contention-sensing.**

I. Introduction

Cognitive Radio [4] has emerged as a promising technology for dynamic spectrum access (DSA) networks. The significant increase in wireless service demands has resulted in spectrum scarcity [11], and yet although few segments of spectrum remain for new services, the licensed spectrum appears to be underutilized. Specifically, the Federal Communication Commission (FCC) reports that licensed, or "primary", users are leaving their bands idle for a significant fraction of time [6]. During periods when a band is unused by its primary user (PU) – referred to as a "spectrum hole" [2] – the band may be legally used in an opportunistic manner by one or more unlicensed "secondary" users (SU), provided the SUs relinquish the band when the PU returns.

Because FCC regulations mandate that secondary users not interfere with primary user transmission, most prior research has focused on the interaction of primary users with secondary users. Since there are multiple secondary users, each secondary user decision to transmit in a band potentially impacts other secondary users, since channel bandwidth degrades as greater numbers of SUs share a channel.

Relatively few researchers have looked at the implications and issues surrounding SU-SU interactions [9], [7], [17]. In [10] Tan et. al. consider secondary coexistence in 802.22 networks as a non-cooperative mixed-strategy game; in [9], they consider minority game variations. Evolutionary game theoretic formulations of spectrum sharing have also been recently considered [7]. Indeed, non-cooperative game theory has been used extensively in prior work, to model the competition between secondary users over a limited amount of resources [8], [9]. Unfortunately (see Xu et. al [13] and others), a frequent limitation of these approaches is that *the game is repeatedly played for just one step*. In contrast, here we advance the performance of non-cooperative mixed-strategy approaches [10] when applied to *dense CR societies of secondary users that play the game continuously over long time intervals*. Achieving this requires the development of new behavioral models of SU spectrum co-use etiquette, outlined below, and subsequently analyzed in Sections II, IV, and VI, below.

To capture the transmission state of primary users, a two state Markov Chain with on and off states has often been used [12]. We use a similar Markov Chain approach in this work to represent the historical trajectory of a secondary user across spectrum bands. In our model SUs can either be transmitting in a spectrum band (i.e. in the consume state) or seeking a spectrum band with less contention (i.e. in the forage state). When an SU is transmitting, it receives a utility mitigated by channel interference due to the contention with other SUs also opportunistically using the same band. Every time an SU switches bands, transmitter reconfiguration necessitates an associated cost. We show that allowing secondary users to forage for spectrum (even without precise sensing of contention levels), yields significantly better utilization of spectrum resources. Then, we extend our model by allowing

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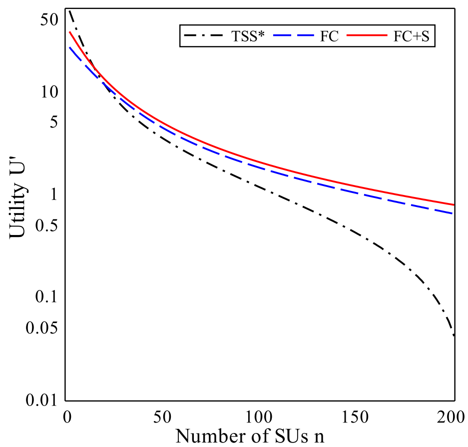

Fig. 4. Varying the number of secondary users n

means that asymptotically, channel contention-sensing costs must remain below 11% of the channel switching cost c—which is to say less than 3% of channel bandwidth B—in order for $FC{+}S$ to continue to be a justifiable SU etiquette. This 3% bound is on the actual cost of making 1-bit measurements of band contention levels, not on the "opportunity cost" of not transmitting while in forage state, since the latter is already fully accounted for in (10), which assigns SUs who are in foraging state a 0 reward in the computation of mean SU utility.

IX. Conclusion and Future Work

We have presented a paradigm for secondary spectrum co-use in DSA networks that is built on an extended SU capability of "sensing" channel occupancy levels. Through simulation, we demonstrate that the new $FC{+}S$ contention-sensing model frequently provides a significant (up to 1724%) higher average (per user per unit time) utility when compared to earlier models of SU etiquette such as TSS^*, and a noticeable improvement (122%) over foraging schemes without contention-sensing. This performance advantage is present as long as the ratio of SUs to bands exceeds 4, and continues to be exhibited as ever greater numbers of SUs fight for a fixed number of resources. Although our experiments have assuming zero cost for contention-sensing, the $FC{+}S$ continues to provide better utility and be a better SU etiquette even with non-zero contention-sensing costs, as long as instantaneous contention-sensing cost remains below 3% of total channel bandwidth.

Future extensions of this work presently underway include:

-Validate these simulation results in a hardware testbed implementation: We hope to implement the $FC + S$ model within a cognitive radio testbed consisting of laptops with Orinoco 802.11 PCMCIA cards based on the Atheros 5212 (802.11 a/b/g) chipset.

-Choosing τ and ϵ dynamically by estimating the number of secondary users n. At present, it is assumed that all secondary users know the value of n, the static constant number of SUs, and so can set optimal values of FSM transition probabilities, τ and ϵ. In practice this is unlikely to be the case. For these types of scenarios, it will be necessary for SUs to run a parallel process which estimates the current value of n, on the basis of which they each independently set their behavioral parameters vis-a-vis FSM transition probabilities, τ and ϵ.

-Validating robustness of the scheme by varying simulation parameters and incorporating SU diversity.

X. Acknowledgments

The authors would like to thank Shamik Sengupta and Kirk Dombrowski for many helpful discussions.

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