Optimal Allocation of Resource in Cooperative CR Network using Routing Protocols

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***Abstract*— Cooperative cognitive radio networks (CCRNs) incorporates cooperative communication into cognitive radio networks, in which, primary users lease their spectrum to secondary users, and in exchange, the primary users leverage secondary users as cooperative relays to enhance their own throughput. However, by employing the CCRN scheme, the mobile operator can lease a licensed channel to the AP, so that it effectively doubling its capacity and its performance. In this project, we propose an implementation of the CCRN framework applied to IEEE 802.11 WLANs. The cooperation is cast as a two-player bargaining game where the two players are the primary users (users of the mobile operator) and the secondary users (users of the AP before spectrum leasing) who bargain for either throughput share or channel access time share. The optimal resource allocation that ensures efficiency as well as fairness among users is provided by the Nash solution, it analysis behavior and characteristics of both users. Simulation results show that the users achieve higher throughput via the proposed CCRN scheme and three different routing protocols namely SAMER, coolest path and CRP, thus providing the mobile operator and the private Wi-Fi provider with incentives for cooperation.**

Keywords—Cooperative cognitive radio network; optimal resource allocation; Routing protocols

I. INTRODUCTION

MOBILE data offload to small cell technology such as Wi-Fi or femtocell provides a compelling solution for mobile operators who want to relieve the strain on their core networks. Compared to cellular macrocells, small cells provide increased spectrum reuse in the coverage area, higher signal to noise ratio in the cell (hence superior link bit rate for its users), and are highly cost effective even for large scale deployments. Furthermore, the reduced transmission times enabled by the superior link bit rates in the small cells directly translate into battery power saving for the user devices. Wi-Fi hotspots operate in the unlicensed bands and suffer from severe interference due to scarce spectrum availability. On the other hand, macro cells and femtocells require the use of the same costly and scarce licensed spectrum and suffer from co-site interference problems.

To expedite spectrum sharing in small cells, FCC in its recent ruling [3] has eliminated spectrum sensing as a requisite for cognitive radio devices. Instead, FCC mandates that devices learn of spectrum availability at their respective locations from an external source such as a location based query to the database of the incumbent, for example the Google Spectrum Database [4]. Devices with such “cognitive” or “frequency-agile” transceivers are regarded as the main enabler of spectrum sharing in small cell technology. Although, spectrum leasing simplifies commercial deployment and promotes better spectrum utilization, developing a workable pricing model between the primary network (owner of the spectrum) and the secondary network (beneficiary of the leased spectrum) is not trivial. To expedite spectrum leasing in real-world deployments, researchers have recently advocated for schemes that employ spectrum leasing, not necessarily on the basis of fees or charge, but in return for improved quality-of-service of the primary network via cooperation with secondary network.

One such proposal is the new cognitive radio paradigm in [5] termed cooperative cognitive radio networks (CCRNs). In CCRNs, the primary users select a set of secondary users (which have better channel conditions) to relay the primary traffic cooperatively and in return the secondary users are granted channel access opportunities in the licensed (leased) spectrum. CCRNs exploit cooperative diversity in cognitive radio networks by combining cooperative communication [6], a physical layer technology, and the spectrum leasing feature enabled by cognitive radios.

Consider the scenario in Fig. 1a where the primary users initially connect to their cellular base station (BS) using cellular technology such as LTE in the licensed spectrum, while the secondary users connect to the IEEE 802.11 Wi-Fi AP and use the standard 802.11 DCF protocol for channel access in the unlicensed bands. The primary users along with the BS form the primary network, while the secondary users along with the AP form the secondary network. If all primary users offload their traffic to the Wi-Fi AP, although they might connect to the AP at superior link bit rate, the corresponding increase in contention can significantly degrade throughput of all the users (both primary and secondary). Instead, assume that spectrum leasing is enabled via the CCRN scheme for the network in Fig. 1. The primary network (i.e., the mobile operator) leases an additional channel from the licensed spectrum to the secondary AP. In exchange, the secondary AP adds the extra channel to its auxiliary interface and reassigns both the primary and secondary users in the two resulting WLAN cells—the original cell that continues to operate in the unlicensed channel and the new cell operating in the newly leased channel as shown in Fig. 1b. With the capacity of the AP now effectively doubled, both primary and secondary users can expect significant improvements in their achievable throughput, as well as power savings (owing to reduced transmission time). Hence the CCRN scheme offers a win-win scenario for both the cellular network operator (e.g., AT&T) as well as the WLAN owner (e.g., a Starbucks coffee shop).

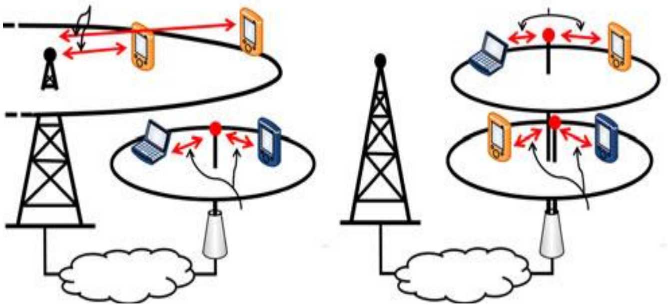

Fig.1. Network diagram showing the base station of the primary network, the access point (AP) of the secondary network, and the primary and secondary users (PUs and SUs) in the range of the AP (a) before, and (b) after spectrum sharing under CCRN scheme.

II. SYSTEM MODEL

In the proposed CCRN scheme, the primary network agrees to lease the channel to the AP only if the AP is offering a bargain that improves the primary network throughput. The user devices are assumed to support service differentiation (readily available for 802.11 devices implementing 802.11e). The AP has the freedom to reassign any user in either of the two WLAN cells (Fig. 1b), and to assign different service weights to different users. As a result, depending on the distribution of the users in the two cells and the service weight of each user, different throughputs for the users in the primary and secondary networks are achievable. If we denote with Xp and Xs the aggregate throughputs for the primary and secondary users respectively, we can define the bargaining set ðXp;XsÞ 2 B. Fig. 2a depicts the bargaining set B of achievable throughputs as well as the disagreement point ðXdp;Xds Þ representing the throughputs of the two networks in the absence of cooperation (i.e., when the cellular users communicate with the BS in the licensed channel, and the AP users are all in the unlicensed channel). A bargaining point is a recommended solution for the two players given the bargaining set, the disagreement point and a bargaining solution, which is a rule for finding the bargaining point. A thorough treatment of various bargaining solutions can be found in [14]; however, we restrict our discussion to the well-known Nash bargaining solution [15]. Achieving fairness and efficient uses of resources (channel time or achievable throughput) are essential in WLANs. For this reason, in the proposed CCRN scheme, we impose either a weighted time or a weighted throughput fairness constraint in the WLAN. When served by the WLAN AP, the primary and secondary users are assigned separate service classes, classp and classs respectively, with wp and ws representing the weights for the service classes. Under the weighted time fairness constraint, users share their channel occupancy time in proportion to their assigned weights; while under weighted throughput fairness constraint, the user share their achievable throughput in proportion to their assigned weights. Our CCRN algorithm attempts to find the

1) service weights (wbp, wbs) and,

2) the distribution of the users in the two WLAN cells, that will achieve the aggregate network throughputs ðXbp;XbsÞ at the Nash bargaining solution.

Our CCRN scheme requires an IEEE 802.11 DCF like contention based channel access mechanism that will achieve the chosen fairness constraint (weighted time or weighted throughput) in the WLAN. The proposed WLAN model for our CCRN scheme is built on the recent work in[16] that calculates an optimal fixed contention window for each contending station in an IEEE 802.11 multi-rate WLAN to jointly achieve aggregate WLAN throughput maximization and time fairness (equal channel occupancy time for all stations).

To fit our CCRN needs, the WLAN model in [16] is extended in the following directions in Section 3:

1) To support weighted time or weighted throughput fairness constraint among stations in the WLAN, and 2) to support both uplink as well as downlink traffic. Although the extended WLAN models are able to find the optimal contention window, they however require solving an order n polynomial where n is the number of stations in the WLAN. To reduce the computation complexity, we derive a computationally inexpensive closed-form approximation for the optimal contention window in Section 3. Using the closed form approximation, we show that under a chosen fairness constraint (time or throughput), when all stations adopt optimal contention window sizes, the aggregate throughputs of the two service classes, Xp and Xs, evaluated for all feasible weights, wp and ws, closely follow a straight line of the form: cpXp + csXs = 1; where cp and cs are constants that are only a function of the bit rates of the links in the WLAN. The expressions for cp and cs are different under weighted time and weighted throughput fairness constraints. In Section 4, we take advantage of the result in (1) to show that when all users in the WLAN use optimized contention window under a fairness constraint (time or throughput), the bargaining set of the CCRN problem can be approximated by a straight line (as shown in Fig. 2b). The expression for the approximate linear bargaining set is only a function of bit rates of the participating users (primary and secondary users which are being served by the AP) and hence easily calculated. Also, a closed-form expression for the network aggregate throughputs (Xbp;Xbs) and their service weights (wbp; wbs) at the Nash bargaining solution exists and is a function of the disagreement point and the bit rates of users. Finally, a method to find an effective user distribution in the two WLAN cells is proposed that will achieve aggregate network throughputs close to the Nash solution (Xbp;Xbs), while maintaining the weights wbp and wbs for the service classes. Section 3 introduces the necessary WLAN models, while Section 4 discusses the proposed CCRN scheme under both the time and throughput fairness constraints

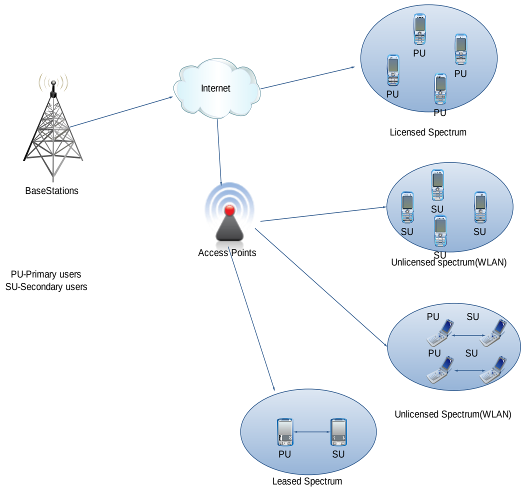

Fig 2: Architecture diagram describes various users in spectrum environment and their leasing concept

III. WLAN OPTIMIZATION

The recent work in [16] proposes a MAC algorithm for IEEE 802.11 multi-rate WLAN that computes an optimal contention window for every contending station in the network to jointly achieve network throughput maximization and time fairness among stations. The time fairness constraint requires each competing station to receive approximately equal channel occupancy time. We build on the work in [16] and extend their WLAN model to support service differentiation in terms of weighted time and weighted throughput fairness where the stations share the available channel occupancy time and achievable throughput respectively in proportion to their assigned weights. The proposed WLAN model adopts a medium access mechanism very closely related to 802.11 DCF access mechanism, but which, instead of the binary exponentially back off mechanism in DCF uses a fixed contention window for every access attempt. This approach improves short-term fairness1 and has been adopted in several works on WLAN optimization [16], [17], [18], [19], [20]. Consider a typical 802.11 multi-rate WLAN with one AP and n competing stations. We assume a saturated network where each competing station always has packets to transmit. Each station uses the same packet payload size, sd (in our numerical results we use sd ¼ 12;000 bits), although, our work can be easily extended to accommodate heterogeneous payloads. Also, an ideal channel is assumed where packet losses are only due to packet collisions. Notations are defined in Table 1.

Consider the event where station i is attempting to transmit a packet of size sd in a given time slot. The attempt probability can be calculated as in [19] when the exponential binary backoff is disabled:

$$p_i = \frac{2}{CW_i} + i$$

The expression for Pti; Pidle; Pc can be calculated as:

$$P_{t_i} = P_i \pi (1 - P_j)$$

1. With binary exponential backoff the collided stations choose long backoffs with higher probability, thereby benefiting other stations from increased channel access.

TABLE 1
Notations Used throughout the Paper

pi	channel access probability of station i
CWi	contention window of station i
Pti	successful transmission probability of station i
Pidle	probability that a slot is idle
Pc	probability of collision in a slot time
Tc	average collision duration
Tti	transmission duration for station i
Tslot	duration of an empty slot
sd	packet payload size in bits
n	total user stations in the network

$$P_{idle} = \prod_{i=1}^{n} (1 - P_i)$$

$$P_c = 1 - P_{idle} - \sum_{i=1}^{n} P_{t_i}$$

IV.CCRN SCHEME

In this section we apply the models we developed in Section 3 to the CCRN problem we consider. Under the CCRN scheme, a cellular operator acts as the primary network and offloads traffic to a secondary network that owns an AP. In exchange, the cellular operator leases an additional (licensed) channel to the AP, effectively doubling the capacity of the AP. We assume that there are ns secondary users associated with the AP, and np primary users that are initially cellular users, but which are in the range of the AP and will be offloaded to the AP if a suitable arrangement for both parties is found (Fig. 1b). In the rest of the section, we first determine a closed-form expression for the bargaining set. We then find the connected closed-form expression for the bargaining point (Nash solution). Finally, we give the closed-form expression for the service weights of the user classes at the bargaining point and present a method to determine a user distribution in the two WLAN cells that will result in aggregate throughput of primary and secondary network close to the bargaining point.

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Algorithm 1 CCRN Approach
Inputs: hRp;Rsi are the uplink and downlink bit rates of the primary and secondary users respectively; w is the preassigned weight of the downlink traffic relative to the uplink traffic; (Xdp;Xds ) is the disagreement point.
1: calculate rb for the inputs {Rp,Rs,Xdp ,Xds };
2: using fRp;Rs; rb; wg in the pseudo-polynomial algorithm, find the distribution, hCb1; Cb2i, of the primary and secondary users in cell1 and cell2, at the bargaining point.
3: find the corresponding optimal access probabilities, hPb1;Pb2i, for the users in cell1 and cell2 using the WLAN model.
4: return hCb1;Pb1i, hCb2;Pb2i;
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V. PERFORMANCE EVALUATION

In this section, we provide a brief review of the three routing protocols we consider in our study.

In **Coolest Path**, a channel's temperature for an SU link is defined as the fraction of time during which the channel is unavailable due to PU activity in the neighborhood of any of the two SUs. The link's temperature is then defined as the minimum channel temperature among all available channels between the two SUs. Coolest Path provides three different definitions of the path temperature based on the link temperature: (i) *accumulated temperature*, i.e., the sum of the link temperatures along the path, (ii) *highest temperature*, i.e., the maximum link temperature among the links along the path, and (iii) mixed temperature – a combination of the first two. The protocol selects the path with the minimum path temperature. In [12], the performance of mixed temperature was always found to lie between the performances of the other two path metrics. For this reason, we do not consider mixed temperature in our study. **SAMER** tries to find a high-throughput path by opportunistically utilizing high-throughput links while still guaranteeing a path's long-term stability. To quantify channel availability, SAMER considers both PU and SU activity. Each SU estimates the fraction of time during which a channel can be used, i.e., it is not used by any PU and any other SU. Since two neighboring nodes may estimate different channel availabilities, the channel availability for a link is given by the smallest of the two values. SAMER's link metric is based on ETT, one of the most popular routing metrics for traditional WMNs. For each channel, SAMER estimates the expected throughput as the product of channel availability, link bandwidth, and loss rate. The link metric is then defined as the sum of throughput values of all available channels. Hence, different from Coolest Path's link temperature, which reflects only a link's stability, the link metric in SAMER reflects both link stability (channel availability) and link quality (bandwidth, loss rate). The path metric in SAMER is the minimum throughput among all links along a path, i.e., a bottleneck metric. **CRP** [13] considers two different routing classes that offer different levels of protection to PUs. Class I aims to minimize the end-to-end delay while still providing satisfactory protection to PUs. On the other hand, Class II allows a level of performance degradation and prioritizes PU protection by selecting as relays SUs that are far from PU receivers. Since in this study we focus on performance, we only consider Class I routes. In CRP, when an SU receives a route request, it selects a rebroadcast delay by calculating a cost function based only on local information. The cost function considers the SU's estimates of channel availabilities, variance of intensities of PU activities, etc. An SU with a lower cost (e.g., with higher channel availability) will rebroadcast the route request earlier. When the destination SU receives a route request, it simply sends a route reply back along the path over which it received the route request, without performing any local computation. Based on this cost-delay mapping, CRP can be easily implemented via minor modifications to AODV.

Table I summarizes the differences among the three protocols in the estimation of (i) channel availability for a node or a link, (ii) link metric, and (iii) path metric.

Table 1 QUALITATIVE COMPARISON AMONG THE THREE PROTOCOLS CONSIDERED IN THIS STUDY

Protocol	**Node Channel availability**	**Link Channel Availability**	**Link metric**	**Path metric**
Coolest path	Based on PU Activity	Product of channel availability observed by two neighbors.	Minimum of all available channel temperatures.	Accumulated or maximum or mixed link metric values.
Samer	Based on PU & SU Activity	Minimum channel availability among two neighbors.	Sum of all available channel throughputs.	Minimum link metric values.
CRP	Based on PU Activity	Channel availability observed locally neighbor's channel availability is ignored.	Cost function reflecting delay or protection to PU receivers.	Accumulated link metric values.

VI. RELATED WORK

Resource allocation and spectrum trading are treated as two separate problems in the spectrum sharing model of cognitive radios. Optimal resource allocation of frequency channels, channel access time, transmission power, throughput etc. between primary and secondary users holds the key to efficient spectrum sharing. Spectrum trading is the economic aspect of spectrum sharing, where secondary users pay for the leased channel. Existing literature used a combination of game theory, market theory and price theory to model the problems in optimal resource allocation and economic interactions. CCRNs combine the spectrum sharing scheme with the physical layer cooperative communication technique in which one or more relay terminals are recruited to assist in the communication when the direct link suffers from severe signal fading [6]. The CCRN scheme in [5] uses Stakelberg games for optimal resource sharing between the primary link (Stakelberg leader) and the secondary ad hoc network (Stakelberg follower). The primary link optimizes its strategy (lease time and amount of cooperation in terms of distributed space-time coding) to maximize its transmission rate, being aware that its decision will influence the strategy adopted by the secondary network, namely the transmission power expended for relaying the primary traffic. The work in [7] extends [5] to include a revenue/payment mechanism and a Stakelberg game is adopted to solve the joint problem of resource allocation and spectrum trading. The restriction of only one primary link in the system model of [5], [7] is addressed in [8], which extends the work in [7] to two co-located infrastructure based primary and secondary networks. The work in [5], [7], [8] employs a three phase TDMA based scheme for cooperation, where the primary traffic is broadcasted in phase 1, one or more secondary users are recruited to relay the traffic to the destination in phase 2 and the secondary users access the leased channel using TDMA in phase 3. The work in [13] proposes a CCRN scheme based on Stakelberg games for secondary users that employ slotted Aloha access method in phase 3. The work in [10] extends [5] to equip secondary users with multiple input multiple output (MIMO) antennas. Since MIMO allows concurrent transmission of multiple independent data streams, the need for phase 3 is eliminated where now the secondary users cooperatively relay the primary traffic in phases 1 and 2 while obtaining spectrum access opportunities for their own traffic. While [10] leverages the degrees of freedom (DoFs) offered in the spatial domain, [12] exploit the DoFs provided by the orthogonal dimensions in quadrature phase shift keying (QPSK). The secondary users employ in-phase binary phase shift keying (I-BPSK) to relay the primary traffic and use the quadrature BPSK (Q-BPSK) to transmit their own traffic. A two-phase FDMA scheme is proposed in [9], where the primary users grant secondary users exclusive access to a portion of their spectrum in exchange for cooperation. To the best of our knowledge, the current work is the first to propose a CCRN scheme for WLANs employing contention based access schemes such as IEEE 802.11 DCF.

VII. CONCLUSION

In this paper, we have investigated and proposed an implementation of the CCRN framework for IEEE 802.11 WLANs. In the proposed CCRN scheme, the mobile operator leases a channel from the licensed spectrum band to a privately owned Wi-Fi AP, and in return, the mobile operator leverages the AP as cooperative relays to offload its Internet traffic. The cooperation between the primary (cellular) and secondary (WLAN) networks is analyzed using a two player bargaining game where the utility function for the players are their respective aggregate network throughputs. we conducted the first detailed empirical performance study of routing protocols for CRNs using both the ns-2 simulator and a testbed based on the USRP2 platform. Our main findings are: i) Taking link quality and interference among SUs into account can greatly improve throughput and end-to-end delay under low PU activity; in contrast, path stability and path length become the dominant factors that affect performance under high PU activity. ii) Considering interference among SUs in the case of multiple flows can result in more disjoint paths and increase total throughput at the cost of reduced fairness. iii) Link and path stability are not always good performance indicators. iv)For link routing metrics that ignore link quality, limiting the path length through the use of an additive instead of a bottleneck path metric typically improves performance. This conclusion does not always hold true for link quality-based routing metrics. v) Estimating spectrum availability based only on local observations cannot guarantee path stability. Overall, we found that the performance of routing protocols in CRNs is affected by a number of factors, in addition to PU activity, and different protocols perform well under different scenarios. Our study motivates the design of self-adaptive protocols that choose different link/path routing metrics in different scenarios, in an online manner. We plan to investigate this direction as part of our future work.

REFERENCES

[1] (2013). 1000x: More spectrum-especially for small cells in Presentation by QUALCOMM Inc. [Online]. Available: www.qualcomm. Com/1000x
[2] (2013). Enabling spectrum sharing and small cell wireless broadband services in the 3.5GHz band [Online]. Available: www.fcc.gov
[3] (2012). FCC frees up vacant TV airwaves for" super WI-FI" technologies [Online]. Available: www.fcc.gov
[4] (2012). Google's spectrum database [Online]. Available: www. google.com/get/spectrum database/
[5] O. Simeone, I. Stanojev, S. Savazzi, Y. Bar-Ness, U. Spagnolini, and R. Pickholtz, "Spectrum leasing to cooperating secondary ad hoc networks," IEEE J. Sel. Areas Commun., vol. 26, no. 1, pp. 203–213, Jan. 2008.
[6] G. Kramer, I. Mari_c, and R. Yates, "Cooperative communications," Found. Trends Netw., vol. 1, pp. 271–425, 2007.
[7] J. Zhang and Q. Zhang, "Stackelberg game for utility-based cooperative cognitive radio networks," in Proc. 10th ACM Int. Symp. Mobile Ad Hoc Netw. Comput., 2009, pp. 23–32.
[8] Y. Yi, J. Zhang, Q. Zhang, T. Jiang, and J. Zhang, "Cooperative communication-aware spectrum leasing in cognitive radio networks," in Proc. IEEE Symp. New Frontiers Dyn. Spectrum, 2010, pp. 1–11.
[9] W. Su, J. Matyjas, and S. Batalama, "Active cooperation between primary users and cognitive radio users in cognitive ad-hoc networks," in Proc. IEEE Int. Conf. Acoust. Speech Signal Process, 2010, pp. 3174–3177.
[10] S. Hua, H. Liu, M. Wu, and S. Panwar, "Exploiting MIMO antennas in cooperative cognitive radio networks," in Proc. IEEE Conf. Comput. Commun., 2011, pp. 2714–2722.