AN INTELLIGENT COGNITIVE MAC for UNDETERMINED PRIMARY USER ACTIVITY PATTERN

Mukiza E. Bwakea, Olabisi E. Falowo
Department of Electrical Engineering
University of Cape Town, Private bag X3, Rondebosch 7701
Tel: +27 21 6502813, Fax: +27 21 6503465
email: {mukiza, bisi}@crg.ee.uct.ac.za

Abstract- Dynamic spectrum access and management is poised to be a sustainable solution to the seemingly overcrowded radio spectrum, with cognitive radio forming the basis of this solution. A cognitive user operating on a foreign channel has to learn about its environment and transmit accordingly without posing interference to a primary user (PU) with rights to that channel. This non-interference mode of operation imposed on a secondary user essentially abstracts the MAC functionality into three intertwined modules: A channel statistics management module, a dynamic channel allocation module, and a dynamic spectrum access/sharing module. Current solutions to channel statistics collection are partially optimized with respect to the dimensions which have a bearing on the performance of a cognitive network. Sub-optimal channel allocations techniques are prevalent as optimal ones are computationally intensive, hence limiting the degree to which QoS requirements are met. Dynamic spectrum access protocols proposed in the literature do not complement channel sensing and allocation policies, effectively offsetting optimization gain achieved by them. This research aims at tailoring self-learning techniques to enable a cognitive user to autonomously infer PUs activity pattern from accumulated channel statistics, and decide on the optimal channel sensing strategy. Also, an optimal channel allocation algorithm will be developed, as well as a channel access protocol that supports and complements the aforementioned functionality.

Index Terms—cognitive radio, intelligent algorithms, dynamic spectrum access.

I. INTRODUCTION

The traditional command-and-control spectrum allocation scheme has led to the increasing overcrowding and inefficient utilization of the radio spectrum in the space-time domain [1]. To support bandwidth-hungry applications and more users, it is imperative to address these inefficiencies, a task that translates to designing more efficiency-aware channel access strategies. A study by the FCC in the US has revealed perpetual availability of space-time variant spectrum holes [5]. The dynamic nature of spectrum holes availability warrants a deviation from the traditional channel allocation strategies which assume allocated channels are always available, hence the growing interest in dynamic spectrum access.

To allow a secondary user (SU) to opportunistically access primary-user-owned bands, three shared access models were proposed, namely: underlay, overlay, and interweave access models. The underlay access models allow a SU to transmit concurrently with a PU provided interference caused to the latter is below a specified threshold. The limited power in the transmission of a SU severely limits the range of communication, and generally, this model is unreliable as interference caused to PUs is significant [1, 2].

The overlay access model assumes PU activity pattern is known in advance, hence SUs channel access can be scheduled accordingly. However, in mobile communications, occurrence of hotspots is quite common [5], and in such circumstances existing PU activity models become obsolete. The interweave access model operates under the assumption that PUs activity pattern is unknown, and SU nodes are allowed to exploit spectrum holes as long as they don't interfere with PUs. Interference may be mitigated by sensing PU band periodically, and vacating within a predetermined time window whenever a PU transmission is detected.

Various dynamic channel allocation techniques have been proposed, and they usually entail optimizing individual and network-wide objectives with respect to the available channels. If an optimization objective is not met, then certain users may be refused admission to the network, thus forming a basis for admission control as in [4]. To support self-coexistence and coexistence with other PUs, a dynamic channel access/sharing protocol is required. Support for in-band and out-of-band sensing is also necessary. Control information exchange protocol determines the extent to which hidden and exposed terminal problems affect SUs performance [2].

This research is aimed at designing a functional cognitive MAC which addresses shortcomings of previous solutions with regard to Channel sensing strategy, dynamic channel allocation, and a supporting channel access/scheduling protocol.

II. RELATED WORK

In [6], Channel sensing and allocation problem is modeled as a Partially Observable Markov Decision process (POMDP). The number and sequence of sensed channels are not optimized except for transmission rate. Channel sensing period may be optimized to allow for maximum discovery of spectral opportunities as in [7].

In learning-based dynamic channel allocations schemes, such as in [8], a SU learns about PUs activities in the RF environment, and uses past and current data to make an intelligent decision on an optimal set of channels to access. Nevertheless, the performance of the multichannel MAC protocol used is significantly limited by the control channel (CC). CC saturation renders free data channels unusable for a considerable amount of time [9], hence the sub-optimal throughput.

In [10], a cognitive MAC is proposed in which all channels are logically divided into recurring frames. Quiet Periods (QP) are scheduled in a non-overlapping manner to allow for efficient out-of-band sensing. However QPs in this design are inherently static, hence discovery of spectral opportunities is minimal. An adaptive QP scheduling as proposed in [11] could be modified and used to address the shortcoming of [10].

III. IDENTIFIED PROBLEMS

Most MAC-initiated channel sensing strategies assume the general activity pattern of primary incumbents is known in advance. However, erratic behavior in bandwidth consumption is common in wireless communications, and in such instances adaptive (learning) models prevail. Most cognitive MAC protocols entail sensing a fixed number of out-of-band channels and in a fixed sequence, hence limiting the discovery of transmission opportunities.

Dynamic channel allocation algorithms are usually formulated as solutions to optimization problems. Most of these formulations translate to NP-hard convex problems, which being computationally intensive, they require that their sub-optimal counterparts be used. Access protocols in the literature are not tailored to support some of the MAC sub-functionality such as adaptive channel sensing scheduling, a problem unaddressed even in the current IEEE802.22 standard.

IV. RESEARCH GOALS

The primary goal of this research is to design an integrated cognitive MAC solution that thoroughly addresses issues described in the previous section. Figure 1 depicts a high level overview of the envisioned solution. Evaluation and testing will be done using NS-3 by extending its capability in order to support these cognitive concepts As shown in Figure 1, the Channel Statistic Collection Module (CSCM), which contains Measurement Management Module (MMM) and Channel Statistics Database (CSD), is going to relay information between the physical layer (PHY) and the Dynamic Channel Allocation Module (DCAM). DCAM is going to house the Link Management Module (LM) and the Resource Allocation Module (RAM). The Media access Protocol module (MAP) will determine how SUs share channels and observe multiple access rules.

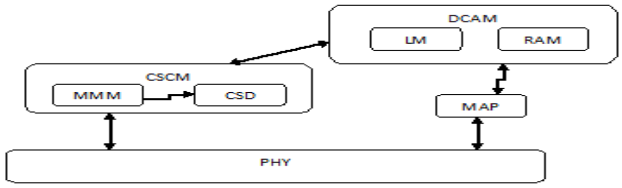

Fig. 1. The proposed cognitive MAC modules

V. CONCLUSION

A brief account of up-to-date practices in dynamic spectrum access with cognitive radio has been given. The shortcomings associated with these practices drive this research, and the entire MAC solution is expected to be boxed in three interconnected sub- modules, namely: channel statistics management module, a dynamic channel allocation module, and a dynamic spectrum access/sharing module. The proposed solution will address the shortcomings of the existing solutions, which are highlighted in the paper.

REFERENCES

[1] E. Hosssain, D. Niyato, and Z. Han, Dynamic Spectrum Access and Management in Cognitive Radio Networks. Cambridge University Press, 2009.

[2] A.D Domenico, E.C Strinati, and M.D Benedetto, “A survey on MAC strategies for cognitive Radio Networks”, *in IEEE Communications surveys & tutorials*, vol. 14, no. 1, pp. 21-44, 2012.

[3] T.C Clancy, “Dynamic spectrum access using the interference temperature model”, *Annals of Telecommunications, Springer,* vol. 64, no. 7. pp. 573-592, 2009.

[4] L.M Zhang, “Joint admission control and power allocation in CR networks”, *in proceedings of IEEE international conference on Accoustics,* vol 3, April 2007, pp. 673-676.

[5] “Report of spectrum efficiency group”, FCC SPTF report, November 2002.

[6] Q. Zhao et al, ”Decentralized cognitive MAC for opportunistic spectrum access: a POMDP framework” *IEEE journal* ,vol. 25, no. 3, pp. 589-600, April 2007.

[7] H. Kim et al, “Efficient discovery of spectrum opportunities with MAC layer sensing in cognitive radio networks”, *IEEE transactions on mobile computing”,* vol. 7, no. 5, pp. 533-545, 2008.

[8] A. Motamedi and A. Bahai, “MAC protocol design for spectrum-agile wireless networks”, in *Proceedings of IEEE International symposium on new frontiers in DySpan,* April 2007, pp.448-451.

[9] L. Wang et al, “Latency analysis for dynamic spectrum access in cognitive radio: dedicated or embedded control channel?”, *IEEE international symposium on personal, indoorand mobile radio communications,* pp. 1-5, 2007.

[10]C. Cordeiro and K. Challapali, “C-MAC: a cognitive MAC protocol for multichanhnel wirelessnetworks”, *IEEE international symposium on new frontiers in dynamic spectrum access networks,* pp. 147-157, April 2007.

[11]Y. Hsieh et al, “Quiet period scheduling across heterogeneous dynamic spectrum access-based systems”, in *IEEE transactions on wireless communications”,* volume:PP, issue: 99, pp 1-10, 2012.

Mukiza Bwakea received his BSc(Eng) in Electrical and Computer Engineering degree with first class honors from the University of Cape Town in 2010.He is presently studying towards his MSc at the same institution. His research interests include cognitive radio, learning algorithms, and optimization algorithms.