Demo Abstract: A Decentralized MAC Protocol for Opportunistic Spectrum Access in Cognitive Wireless Networks

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***Abstract*— Cognitive MACs are becoming a reality for efficiently utilizing the constrained spectral resources. The spectrum opportunities are volatile and often difficult to predict. Furthermore, infrastructure based coordinated spectrum sharing is not a viable option for some applications and spectrum bands. Therefore, dynamic and decentralized medium access becomes highly desirable. We demonstrate a fully decentralized cognitive MAC protocol, which allows nodes to be asynchronous to each other and have reliable data communication even in harshly interfering environments. Our protocol works without the need for a common control channel and a coordinating infrastructure. We address the practical issues such as mobility and traffic awareness in our design. Our 'table top' demonstration will show the various features of the protocol and give audience the opportunity to interactively control the protocol parameters and the interferences conditions to observe the corresponding performance characteristics.**

I. Introduction

Cognitive Radios and Dynamic Spectrum Access paradigms require novel thinking for MAC design. In the past years, there have been a number of spectrum agile and cognitive MAC protocols proposed by the community [1][2]. Intelligent management of spectrum, advanced sensing techniques for detecting the primary user(s) and opportunistic access to the wireless medium are the key requirements for cognitive MAC protocols [3][4]. IEEE 802.22 [5] working group focuses on infrastructure based centralized coordination of the available channels to allow the coexistence of cognitive users in the TV frequency spectrum. Many of the spectrum bands, where white spaces can be utilized for cognitive access [6], lack infrastructure based centralized controlling entities and the possibility for dedicating control channels remains quite low. Besides efficiently identifying the wireless characteristics of the primary user, there are other desired properties for MAC protocols which enhance the network performance but have not drawn much attention of the research community [1]. These include 1) ability of a MAC protocol to work reliably in uncoordinated bands, 2) use of only one transceiver without the need for an interference free common control channel, 3) ability to function even in situations where the spectrum interference is unpredictable and spectrum occupancy models are less reliable and occluded, 4) the distributed protocol to handle node mobility and 5) support for variable traffic volumes. We design a highly flexible and decentralized MAC protocol which addresses the issues described above and is able to give a high packet throughput even in heavily interfering mobile ad hoc environments.

II. Design and Implementation

We use the channel polling principle in our protocol design, where nodes monitor the medium for any packet transmission activity at regular periods. Spectrum sensing characteristics for different channels are also gathered during the periodic activity monitoring intervals. Based on the gathered channel characteristics, channel selection for data communication is carried out. Dynamic channel selection is performed before packet transmissions and opportunistic utilization of an available channel is accomplished. Nodes are able to communicate with each other even without having any prior knowledge about the sensed spectrum characteristics of other nodes in the network. However in practice, nodes exchange the sensed channel characteristics (compressed in a binary format) inside the preamble sequence, which is transmitted before data. Channel maps of neighbours allow a node to avoid spatially local interferers as will be demonstrated. In each sensing cycle, a node scans the available channels sequentially for any potential spectral activity and updates the history and the associated channel weights. During the sensing operation, a node is also able to characterize the interferers, their strengths and occupancy levels. We use a heuristics based method for channel selection. Without compromising the baseline operation, any learning

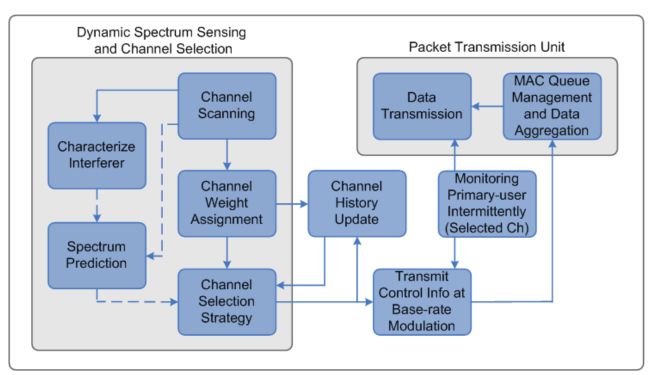

Fig. 1. Simplified component diagram involving a packet transmission.

algorithm predicting the spectrum occupancy can be plugged-in to the protocol for improving channel selection. Different components of the spectrum sensing and channel selection methods are shown in Fig. 1. A transmitting node sends a repeated sequence of short preamble frames using the base rate modulation in the selected channel followed by data. Each frame contains control information such as the destination address, source address, timing offset for the data frame, the modulation scheme for data transmission and its own channel characteristics map. Fig. 1 illustrates the various components of the MAC involving a packet transmission. A non-addressed node is also able to gather the spatial spectral characteristics of the transmitting node and other relevant meta-data by overhearing a preamble frame. If a unicast transmission is taking place, other nodes in the neighbourhood can also simultaneously utilize an available spectrum hole for data communication, resulting in higher capacity. In order to support variable data traffic volumes, the protocol is able to transmit multiple data frames back to back in the form of a frame-train. Since longer occupancy of the spectrum by a cognitive user may cause a clash with the primary owner of the spectrum, the protocol shortly listens to the medium between two consecutive frame transmissions to ensure the availability of the spectrum. Unlike the classical notion of fixed duty cycle operation as is the typical case in low-power embedded networking protocols [7], our protocol is able to adaptively tradeoff the effective duty cycle as per the traffic requirements. The periodic sensing interval of the protocol can be selected flexibly based on the latency requirements of the network. Data communication implicitly synchronizes the nodes in a neighbourhood. An available wireless channel can further be utilized for potentially subsequent transmissions by keeping the nodes listening to the available channel for a short time interval with only a little overhead as we will show in our demonstration.

We have implemented our MAC protocol on the Wireless Open-Access Research Platform (WARP) from Rice University, USA in highly modular fashion using a custom defined set of basic MAC APIs. Unlike our approach, most of the cognitive MACs are implemented in a monolithic fashion with tight coupling to the underlying hardware, which restricts adaptation and flexibility. Our design advances the development and experimental room for cognitive MACs.

III. Demonstration Description

We will demonstrate the various features of our protocol including its decentralized nature, which allows nodes to be completely asynchronous to each other. We will show that even in the presence of highly spontaneous and random interferences, our protocol is able to work reliably. Additionally, our demonstration will provide an opportunity for the audience to interactively play with the various parameters of the protocol and observe their implications on-the-fly.

A GUI based visualization tool (c.f. Fig. 2) will be used during the demonstration to generate different types and levels of user controlled interferences in the spectrum. Acting as a primary user, WLAN access points will be used to generate a controllable and variable traffic load. The transmit power and traffic generation loads will lead to different levels of spectrum occupancies. Our MAC protocol exposes a number of flexible parameters such as the number of allowed channels, initial and congestion back-off windows, persistence values, frame sizes, carrier sensing intervals and thresholds, preamble lengths, modulation schemes, transmission power levels and the settings for the channel selection algorithm. The parameters of the protocol will be set and modified at the run-time through our GUI based tool interfacing the WARP boards to a PC. The GUI based tool also provides means to live-stream a video from one PC to another over the MAC protocol running on the WARP boards. The quality of the streaming video will help to visually observe the throughput and reliability of the MAC protocol in the presence of wireless interferences. Online performance statistics of the MAC will also be displayed. In particular, we will show that even in uncoordinated bands, our protocol is able to efficiently find spectrum holes without the need for any infrastructure setup.

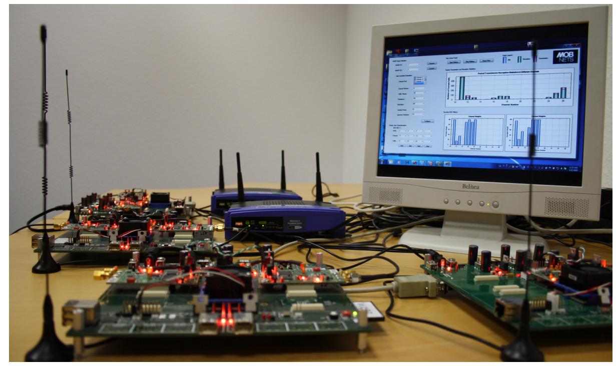

Fig. 2. Demonstration setup: a PC, WARP boards and WLAN APs.

Acknowledgment

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References

[1] C. Cormio and K. Chowdhury, "A survey on MAC protocols for cognitive radio networks," *Ad Hoc Netw.*, vol. 7, no. 7, pp. 1315–29, 2009.

[2] I. Akyildiz, W.-Y. Lee, M. Vuran, and S. Mohanty, "A survey on spectrum management in cognitive radio networks," *Communications Magazine, IEEE*, vol. 46, no. 4, pp. 40–48, April 2008.

[3] H. Kim and K. G. Shin, "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.

[4] H. Wang, H. Qin, and L. Zhu, "A survey on MAC protocols for opportunistic spectrum access in cognitive radio networks," *Int. Conf. on Computer Science and Software Engg.*, vol. 1, pp. 214–218, 2008.

[5] C. Cordeiro, K. Challapali, D. Birru and S. Shankar, "IEEE 802.22: The first world-wide wireless standard based on cognitive radios," in *Proceedings of IEEE DySPAN*, Nov. 2005, Baltimore, USA.

[6] M. M. Henry, "NSF Spectrum Occupancy Measurements Project Summary," Shared Spectrum Company, Tech. Rep., 2005.

[7] B. Yahya and J. Ben-Othman, "Towards a classification of energy aware MAC protocols for wireless sensor networks." *Wireless Communications and Mobile Computing*, vol. 9, pp. 1572 – 1607, 2009.