Enabling Cognitive-Radio Paradigm on Commercial Off-The-Shelf 802.11 Hardware

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ABSTRACT

Cognitive Radio paradigm (CR) is recognized as key enabler for next generation wireless networking: accessing the limited radio spectrum in an opportunistic manner allows secondary users to boost their transmission performance without interfering with existing primary networks. Full testing and experimenting with this paradigm, however, is still a tough task, given either the i) limited capabilities above the PHY layer of cheap SDR solutions, or the ii) heavy investment required for setting up multi-node testbeds powered by FPGAs. In this demo we show how we leveraged our Wireless MAC Processor architecture to tackle the two issues at the same time, providing a highly reconfigurable cognitive solution for wireless local area networks on top of commercial off-the-shelf (COTS) 802.11 devices. We demonstrate a typical CR use case where local and network-wide cognitive loops interact for configuring secondary users real time channel switching in reaction to channel state mutation. We also prove the flexibility of our Wireless MAC Processor (WMP) architecture for extensive testing of the CR paradigm.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless Communications

Keywords Wireless MAC Processor; Cognitive Radio

1. INTRODUCTION

Dynamic spectrum access and cognitive technologies are suggesting a new networking paradigm, with devices able to sense the environment and reprogram themselves. Several Cognitive Radio platforms have been proposed so far for testing PHY related reconfiguration [1, 2]. The GNU Radio front-ends displayed high potentials for handling complex de/modulation schemes on general purpose PC backends [3]: unfortunately, high communication latencies preclude experiments involving even basic MAC schemes. Though technical solutions for extending cognitive reconfiguration above the PHY layer exist [4], they are usually built on expensive FPGAs (e.g. WARP boards): their high cost prohibits large scale experiments. To counter these issues we extend the Wireless MAC Processor (WMP) [5], a novel programmable MAC stack architecture that we developed in the EU-FP7 project FLAVIA, to support the CR paradigm. The WMP is a flexible platform able to run MAC programs, that we call MAClets, defined in terms of state machines acting on a core set of actions, signals and events available in the hardware transceiver. The flexibility of the platform allows easy reconfiguration of the MAC/PHY stack, going well beyond parameter tuning or switching between pre-defined solutions: as we demonstrated in [6], in fact, the WMP implementation on commercial WiFi cards enables a wide range of MAC protocols (like TDMA, CSMA, and multi-channel MAC) and incremental MAC adaptations that can significantly improve the experiments on cognitive MAC schemes. Furthermore, given the limited cost per node in the current implementation[1], our architecture can be used for experimenting with cognitive MAC adaptations in dense networks.

2. CR MAC ADAPTABILITY

In our testbed we exploit WMP, MAClets and the control architecture envisioned in [7]. Here the WMP executes the MAClets that encode specific MAC programs: as the WMP enables real-time MAClet switching, channel access can be opportunistically adapted to network conditions with the coordination and orchestration of a MAClet Controller.

As shown in Fig. 1 we implement the cognitive paradigm for reacting to mutated conditions with two cognitive loops that include *measurement, decision* and *enforcement* phases. The **network-wide cognitive loop** (big circle) is managed by the MAClet Controller: it leverages the accurate knowledge of the network state provided by *measurements* collected at every nodes for taking *decisions*, that are *enforced* by sending MAClets and their parametric configuration (policies) to MAClet Managers running on every network node. The **node-local cognitive loop** (smaller circles) loops around the node and provides quick reactions with reduced local awareness by applying the **node-local MAC adaptation policies** decided by the MAClet controller, e.g., switching the current MAClet in reaction to a given event. While the node-level loop provides high-speed node-level cognition, reactions driven by the MAClet Con-

[1]Our system is supported by the Broadcom 4318 chipset which can be found in several COTS equipments.

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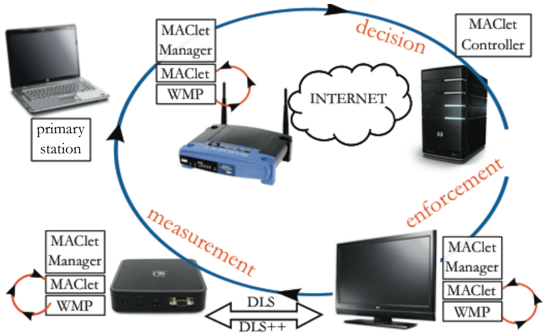

Figure 1: Interaction between the two cognitive loops lead secondary users to Direct Link Setup

troller on the network-wide loop are slowed down by network latencies and MAClet setup time: for this reason the duration of a cognitive global loop can sum up to several seconds.

3. DEMO DESCRIPTION

In this demo we use the scenario in Fig. 1 where two secondary stations (the TV and the streaming box at the bottom) are connected to the Basic Service Set managed by the 802.11 Access Point. At the beginning, standard DCF is running: packets transmitted by the streaming box and going through the AP may easily saturate the network. To prevent connectivity issues affect other "primary" stations (e.g., the laptop accessing the Internet), the AP monitors collisions and reports channel usage information to the MAClet Controller. If collisions exceed a given threshold, e.g., because a "primary" station is transmitting to the AP while streaming is active, the MAClet Controller sends a Direct-Link-DCF (DL-DCF) MAClet to the secondary stations and configure them to periodically switch between the DCF and the DL-DCF MAClets. We call this MAC adaptation policy Direct-Link-Setup (DLS). With DLS, the streaming box transmits packets directly to the TV set, relieving network resources. As the two secondary stations periodically switch to standard DCF, they maintain connection to the BSS. If collisions do not decrease, or show up again because of more primary stations, the MAClet Controller sends new configuration data for the DL-DCF MAClets that in addition to direct-linking packets, transmit the video on a different channel: the adaptation policy becomes DLS++.

3.1 MAC adaptation and the cognitive loops

In our scenario the node-local loop is responsible for fast MAClet switching and allows secondary users to either exchange packets directly (DL-DCF, also on a different channel) or communicate with other primary users (DCF). The decision taken by the controller depends on the collision ratio estimated at the AP by the node-local loop, which monitors the retry-bit in received packets and sends collected data to the controller. After decision, the controller eventually sends to nodes the DLS(++) policies with MAClets and synchronization instructions, concluding the network-wide loop.

We report in Fig. 2 an example of network adaptation driven by the proposed approach with all nodes being COTS WMP-enabled devices. The initial throughput of the video stream (continuous line) is 10Mb/s, which fits with the DCF performance that exhibits low collisions (dashed line with cross-like markers at the bottom). At t = 21s, a primary

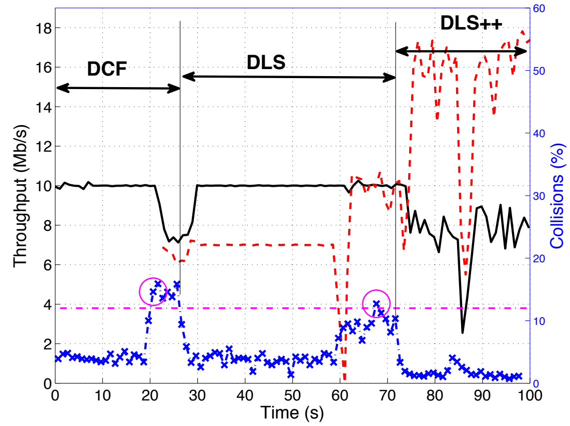

Figure 2: Throughputs evolution and collision ratio estimated at the AP

station starts transmitting a 7Mb/s data flow (dashed line): as the total bandwidth is not enough for sustaining the three flows, collisions rise above the 12% threshold (first circle) and the controller starts the DLS phase. After a few seconds, collisions drop and requested throughputs fit again as the new scenario saves one (of the two) streaming flows. At t = 60s, the primary flow data rate increases to 18Mb/s: collisions raise again and when they exceed the threshold (second circle to the right), the controller starts the DLS++ phase. Here throughput is not constant because secondary stations periodically jump back to the BSS channel: for the same reason the video throughput is lower than before. In any case, the throughput of the primary data flow is maximized.

4. CONCLUSIONS AND FUTURE WORKS

In this demo we add cognitive features to the WMP platform, using local and network-wide cognitive loops. This allows secondary users to adapt their MAC to the needs of primary users. As future work we plan to reduce the network reaction latency with better usage of the local loop.

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5. REFERENCES

[1] M. Dardaillon, K. Marquet, T. Risset, A. Scherrer, "Software Defined Radio Architecture Survey for Cognitive Testbeds", IWCMC'12, Limassol, Cyprus, Aug. 27-31, 2012.

[2] P. Pawelczak, K. Nolan, L. Doyle, S. Wah Oh, D. Cabric, "Cognitive radio: Ten years of experimentation and development", IEEE Commun. Mag., 49(3), pp. 90–100, 2011.

[3] L. Sanabria-Russo, J. Barcelo, A. Domingo, B. Bellalta, "Spectrum Sensing with USRP-E110", Lecture Notes in Computer Science, Volume 7642, pp. 79–84, 2012.

[4] J. Ansari, X. Zhang, A. Achtzehn, M. Petrova, P. Mahonen, "A flexible MAC development framework for cognitive radio systems", WCNC'11, Cancun, Mexico, Mar. 28-31, 2011.

[5] I. Tinnirello, G. Bianchi, P. Gallo, D. Garlisi, F. Giuliano, F. Gringoli, "Wireless MAC Processors: Programming MAC Protocols on Commodity Hardware", IEEE INFOCOM'12, Orlando (FL), USA, Mar. 25-30, 2012.

[6] G. Bianchi, P. Gallo, D. Garlisi, F. Giuliano, F. Gringoli, I. Tinnirello, "MAClets: Active MAC Protocols over hard-coded devices", ACM CoNEXT 2012, Nice, France, Dec. 10-13, 2012.

[7] P. Gallo, D. Garlisi, F. Giuliano, F. Gringoli, I. Tinnirello, G. Bianchi, "A Control Architecture for Wireless MAC Processor Networking", Future Network and MobileSummit'13, Lisbon, Portugal, Jul. 3-5, 2013.