Enabling Cognitive-Radio paradigm on commercial off-the-shelf 802.11 hardware

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ABSTRACT

Cognitive Radio paradigm (CR) has been recognized as key enabler for next generation wireless networking: the possibility to access 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.

1. INTRODUCTION

In recent years, dynamic spectrum access and cognitive technologies are suggesting a new networking paradigm, with devices able to sense the environment and reprogram themselves in reaction to mutating spectrum conditions and application requirements. Several Cognitive Radio platforms have been proposed so far, especially for testing PHY related parameters [1, 2]. In this context, the GNU Radio front-ends displayed high potentials for handling complex de/modulation schemes on general purpose PC backends [3]: unfortunately the high communication latencies preclude experiments involving even basic MAC schemes. Tough technical solutions for extending cognitive reconfiguration above the PHY layer do exist [4], they are usually built on dedicated hardware powered by expensive FPGAs (e.g. WARP boards with Xilinx Virtex 6): if on the one hand they enable full customization of the channel access, on the other one their 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 inside the EU-FP7 project FLAVIA, to support the CR paradigm. The WMP is a flexible programmable 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 (from TDMA, to CSMA, to 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 is a MAC-agnostic engine that executes the MAClet that encodes a specific MAC program: as the WMP enables real-time MAClet switching, the channel access strategy can be opportunistically adapted to network conditions. Switching MAC policies on WMP-enabled nodes, however, must be coordinated and orchestrated by 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-local loop provides high-speed node-level cognition, reactions driven by the MAClet Controller 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 depicted 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. As standard DCF is running at

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

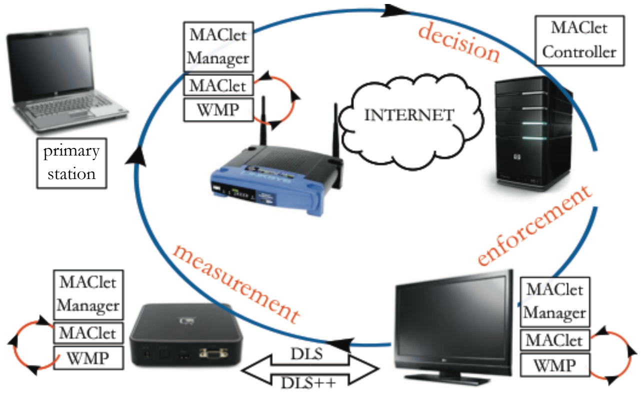

Figure 1: Interaction between the two cognitive loops lead secondary users to Direct Link Setup

the beginning, packets transmitted by the streaming server 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). Thanks to the DLS, packets of the TV stream are directly transmitted to the TV set, relieving network resources, and the two secondary stations maintain connection to the BSS given they periodical run standard DCF. If collisions do not decrease, or show up again because of more primary station transmissions, the MAClet Controller may send new configuration data for the DL-DCF MAClet that in addition to direct-linking packets, transmits the video stream on a different channel: in this case 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, providing ability to the secondary nodes to either exchange packet directly (DL-DCF, possibly on a different channel) or communicate with other primary users (DCF), according to the configuration policy decided by the MAClet Controller and enforced by the MAClet Manager. The decision taken by the MAClet Controller depends on the collision ratio estimated at the AP by the node-local loop itself which monitors the retry-bit in received packets and sends collected data to the controller. After decision, the controller eventually sends to all 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 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.

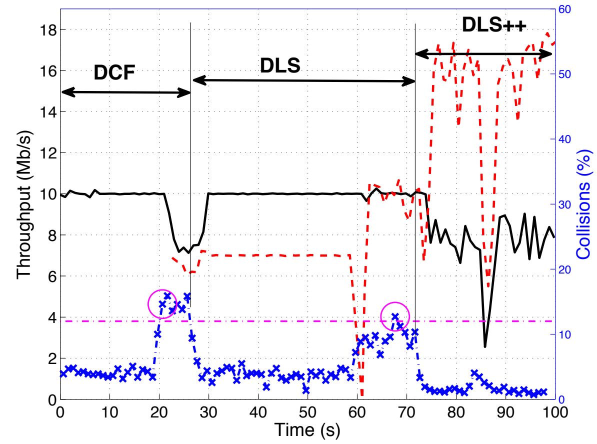

Figure 2: Throughputs evolution and collision ratio estimated at the AP

4. CONCLUSIONS AND FUTURE WORKS

In this demo we add cognitive features to the WMP platform, using a double cognitive loop: the local and the network-wide one. This allows secondary users to successfully adapt their MAC to the requirements of the primary users. As future work we plan to investigate how to reduce the network reaction latency with better usage of the local loop.

Acknowledgment

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5. REFERENCES

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6. DEMO REQUIREMENTS

In order to run the demo the following hw/sw configuration is required: (i) four Alix nodes (one AP and three WMP-enabled stations), (ii) one laptop, (iii) one ethernet switch and five ethernet cables for the control network.