A Cognitive Radio Prototype Operating in UHF TV Bands

Monisha Ghosh, Vasanth Gaddam, Gene Turkenich & Kiran Challapali
Wireless Communications & Networking Dept.
Philips Research North America
Briarcliff Manor, NY 10510
{monisha.ghosh, vasanth.gaddam, gene.turkenich, kiran.challapali}@philips.com

***Abstract*—With the switch-over to digital television in February 2009, the UHF band will become available for unlicensed use, pending the final FCC rule and order. The incumbents that need to be protected are digital television and wireless microphone signals. Some of the key requirements for an unlicensed radio to operate successfully in this band are (i) the ability to quickly and robustly sense spectrum availability, (ii) MAC protocols that allow seamless multichannel operation, without any user intervention, and (iii) QoS guarantees in the face of channels becoming unavailable due to the appearance of incumbents. The Philips prototype demonstrates these features in a fully Cognitive Radio (CR) platform operating in the UHF television bands (Channels 21-51). The prototype senses, transmits and receives in the UHF band. The sensing algorithms detect television and wireless microphone signals down to -114 dBm. The MAC protocol is based on distributed beaconing and coordinated "quiet periods".**

Keywords-Cognitive radio, sensing, MAC, beaconing, quiet periods, DTV, NTSC, wireless microphoness

I. INTRODUCTION

The proliferation of wireless applications/devices has created a big demand for prime (i.e. with good propagation characteristics) radio frequency (RF) spectrum. Though most of this spectrum is allocated, the usage of this spectrum varies significantly with time and space. In order to increase the efficiency, one would require a device that continuously scans the radio environment for vacant spectrum and uses it for its communication needs. These new class of devices, referred to as Cognitive Radios (CRs),[1][2] will efficiently use the spectrum while avoiding interference to the primary occupants of the spectrum.

While individual pieces of a cognitive radio platform in the UHF band have been demonstrated before, this demonstration will span all of the principal requirements of a cognitive radio: sensing at low levels, distributed coordination of channel availability via beaconing and quiet periods while maintaining QoS of the application. It will conclusively show that these technologies are mature and can be transitioned into real products in a very short time.

II. UHF CR PROTOTYPE USING WIFI CARDS

The CR prototype is build using a combination of custom algorithms implemented on a Field Programmable Gate Array (FPGA) and commercial off-the-shelf components. Figure 1 shows the top-level block diagram of the CR prototype. A standard WIFI card is used to realize the Medium Access & Control (MAC) and Physical (PHY) layer functionality. The PHY is operated in 5 MHz mode and the MAC is extended to include ad-hoc distributed architecture and cognitive features.

A frequency conversion module is used to down/up convert the wifi signals to the desired channel in the UHF band. Figure 2 shows a detailed block diagram of the CR node. The sensing module consists of a standard TV tuner and an FPGA evaluation board. The TV tuner is used to down-convert the signals to an IF, which are then sampled by ADC on the FPGA board at 100 MHz. The digitized signals are processed in real-time in the FPGA to sense for digital and analog TV signals and wireless microphone signals.

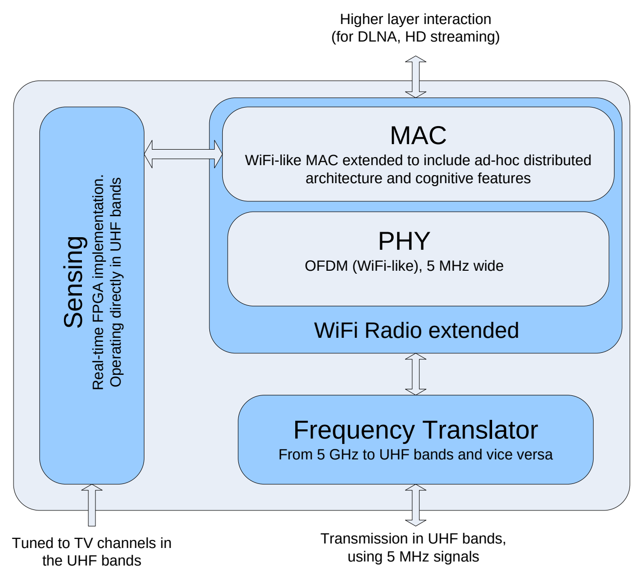

Figure 1. Top-level block diagram of the CR prototype

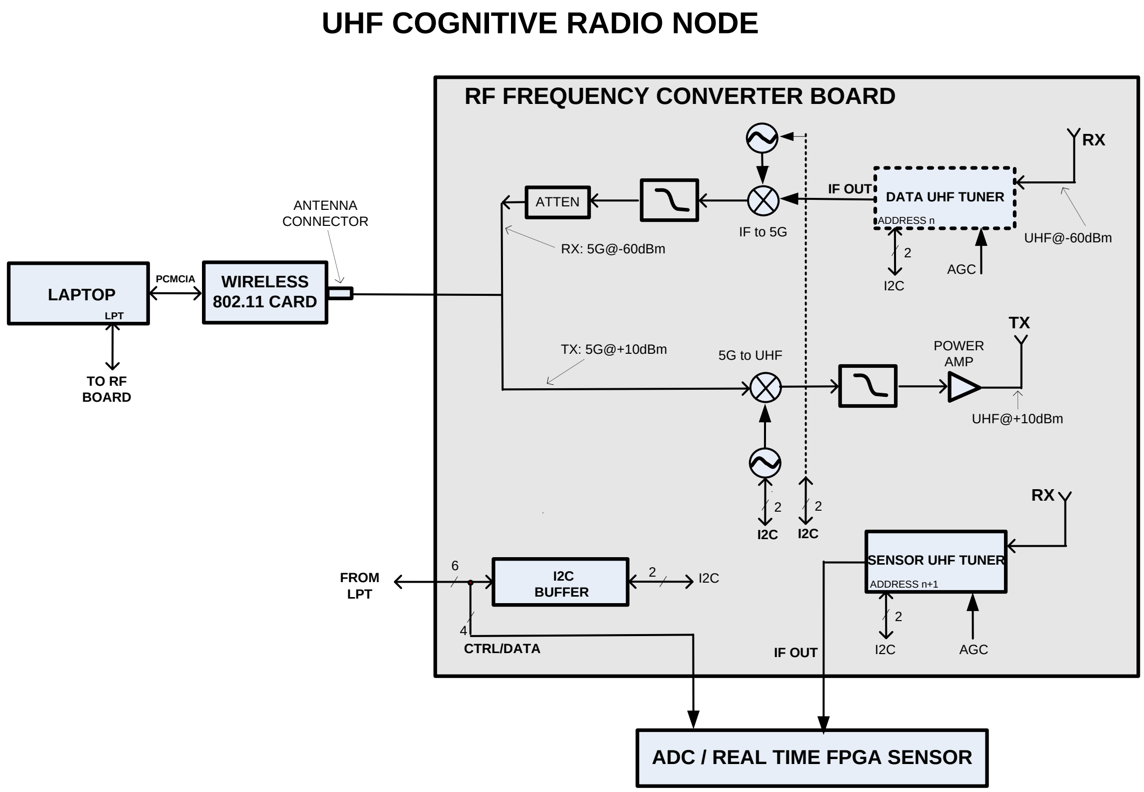

Figure 3. Block diagram of a UHF cognitive radio node

III. PROTOTYPE FEATURES

This prototype demonstrates the following:

(1) Robust sensing of television (ATSC and NTSC) signals and wireless microphone signals, which is a necessary first step for implementation of cognitive radio in the television bands.

(2) Distributed MAC protocol implementation demonstrating distributed beaconing and quiet periods scheduling for sensing.

A. Sensing of Radio Environment

The sensing module detects for the presence/absence of the primary licensed users (DTV and analog TV) and the secondary licensed users (Part 74 devices, e.g.: wireless microphone transmitters). The sensing algorithms are based on a combination of energy detection and feature detection and are able to reliably detect signals down to -114 dBm levels [3]. A unique benefit of the proposed sensing algorithms is the short dwell time (40 ms) on each UHF channel. This feature enables the CR device: a) to support applications that have strict QoS requirements, and b) to quickly vacate a channel when an incumbent appears thus minimizing the interference to the incumbents. Some additional post-processing steps are also implemented to reduce the probability of false alarms. Additional details about the sensing algorithms and their performance are discussed in [3].

B. Cognitive MAC Protocols

In order to support the spectrum sensing functions provided by the PHY and to meet the DFS parameters [4][5], a cognitive MAC has to provide the following new features in addition to the functions of a standard MAC.

- Set-up of home channel and backup channels – The CR device performs an initial scan of all UHF channels and identifies vacant channels during the boot-up process. It then selects a home channel and a backup channel (or multiple back-up channels) from this list of available channels.
- Set-up of quiet periods – The MAC schedules periodic and on-demand quiet periods and also ensures that the quiet periods are synchronized within a network and across multiple networks.
- Sensing during quiet periods – Depending on the DFS parameters and application requirements, the MAC can request sensing of current home channel, backup channels and/or adjacent channels during the quiet periods.
- Incumbent detection and channel vacation – The MAC includes mechanisms to determine channel occupancy based on the information available from its node and also from the other nodes in the network. The MAC also provides protocols to move to the backup channel when an incumbent is detected on the home channel without

causing interference to the incumbent while maintaining QoS for the application that it is supporting.

IV. DESCRIPTION OF THE DEMO

The demo includes three CR nodes and will demonstrate a real-time streaming video application. The demo set-up is shown in Fig. 3. A picture of a CR node is shown in Fig. 4.

The video is transmitted on a vacant TV channel, which has been identified as an available channel (i.e. free of incumbents) by all the CR nodes within that network. The home channel and the backup channels are determined by the nodes when they power up (known as bootstrapping process). All the nodes within the network exchange the home channel and backup channel information through the beacons and arrive at a common list. In addition, all the nodes perform sensing during the regularly scheduled quiet periods while serving the application. The nodes scan the home channel and backup channel for incumbents and update the information accordingly. For example, if an incumbent suddenly appears on the backup channel then the device selects another backup channel from its list of available channels and conveys this information in its beacon.

We use an ATSC DTV generator and/or a wireless microphone transmitter to introduce an incumbent on the channel being used by the CR nodes for the video transmission and demonstrate that the CR nodes seamlessly switches to the backup channel (or the next available free channel) without causing any degradation to the video quality. The CR nodes also update the backup channel information by choosing the next channel from the list of available channels. In case an incumbent appears on the new home channel then the CR switches to this new backup channel. The home channel and backup channel information is continuously updated as the incumbents start and stop their transmissions. Fig 5. shows a snapshot of a node in communication mode.

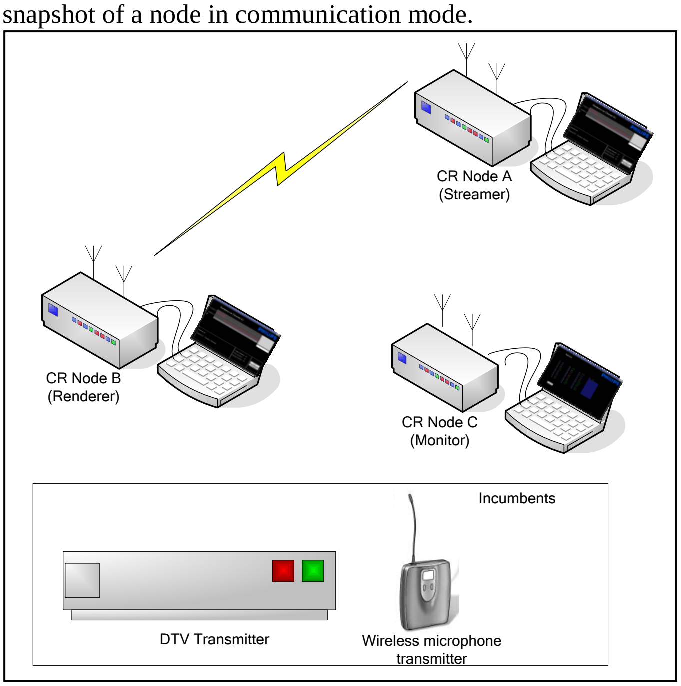

Figure 4. Demo set-up

In parallel with the demonstration of this application, we have another CR node that is configured as a monitor. This node continuously scans the UHF TV channels and identifies if the channel is occupied or vacant. The GUI on this node (see Fig. 6) shows the real-time sensing information by identifying the over-the-air (OTA) television (ATSC and NTSC) signals, wireless microphone signals and secondary (unlicensed) signals on each of the channels. While the video streaming application is running, this node shows all the activity (in terms of occupants) occurring in the channels of interest.

Figure 5. Picture of a cognitive radio node

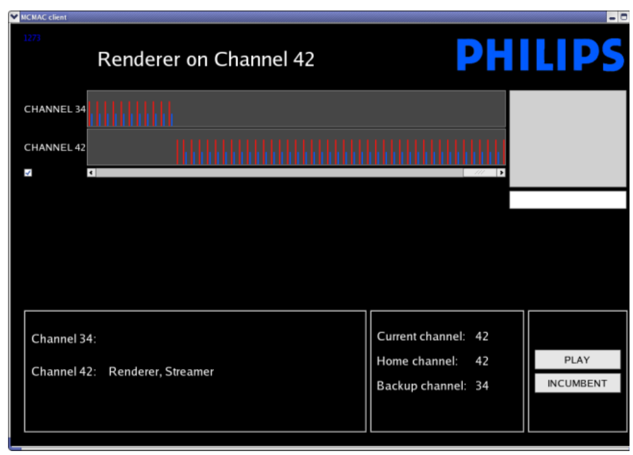

Figure 6. Snapshot of the CR node in communication mode

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Figure 7. Snapshot of the CR node in sensing mode

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