Level: An Open Platform for Sensor Network Development in TV Whitespace

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***Abstract*—The rapid proliferation of wireless sensors will require new techniques to handle the corresponding growth in traffic. One of the ways this growth may be addressed is with technology like TV Whitespace. This paper presents a new open source hardware platform to allow students and researchers to cheaply and easily experiment with sensor networks in the TV Whitespace bands as well as other frequency bands. It is hoped that the availability of such a platform will spur innovation in mesh networking, security, dynamic spectrum access, and related areas of research.**

Keywords*—*Whitespace, Cognitive Radio, Security, Sensor Networks

I. INTRODUCTION

TV Whitespace has the potential to be used for a variety of purposes. Most commonly, the viability of delivering internet to rural areas using TV Whitespace as a backhaul is investigated [1]. The excellent signal propagation characteristics of TV Whitespace also make it ideal for long range wireless sensors. Sensors typically need very little bandwidth and can take advantage of "holes" in the spectrum that would otherwise go unused [2]. Relatively little work has been done in using TV Whitespace in a sensor network. The lack of a suitable hardware platform with which to experiment that is optimized for sensor networks and that can operate in TV Whitespace may be contributing to this phenomenon.

The current generation of hardware solutions for developing and testing sensor networks has several limitations. Most testbeds rely on Zigbee compliant radios like the XBee in conjunction with a microcontroller [3], or a similar integrated mote. The problem with these kinds of devices is that they often do not have significant computing or digital signal processing abilities, and they are restricted in their frequency range to only a few dozen megahertz and are unable to tune to TV band frequencies. Alternatively, some researchers use radios like the Ettus USRP [4, 5] which offers a much larger frequency range that includes the TV band and has the capability of performing intensive computational operations on the data from the radio. The downside of this approach is the cost of the radio, as well as its size and power consumption.

An embedded platform that is capable of transmitting and receiving in TV Whitespace frequencies is needed to allow researchers to begin developing and testing sensor networks in the field. It must be small and power efficient while retaining a large frequency range and must have adequate processing capability. Because no such device existed, the Level platform was developed. A prototype has been built based on the CC430 microcontroller from TI and the ADF4351 wideband synthesizer with integrated VCO from Analog Devices. This paper discusses the design principles of this device in Section 2 as well as the hardware architecture, current capabilities of this device, and possible future improvement in both hardware and software.

II. THE LEVEL PLATFORM

A. Design Principles

A mote for a sensor network that operates in TV Whitespace must be capable of transmitting and receiving from 470 MHz to 700 MHz. It must also be small and power efficient, and must have a suitable processor to handle basic digital signal processing. Because many consumer devices do not have the ability to communicate over TV Whitespace, a way to shift traffic from TV Whitespace to another popular band like Bluetooth or WiFi would also be beneficial. Finally, the mote should be easy to debug, as its firmware will likely change often during the course of research. To achieve these design principals, the device should also incorporate publicly available components rather than custom ASICs so that parts can be replaced easily and modifications to the design are easy to make.

B. Hardware Architecture

The Level platform is based on a 16 bit CC430F5137 microcontroller. This microcontroller utilizes a von Neumann architecture and incorporates an RF transceiver core from the sub-GHz CC1101. The CC430F5137 contains a 12 bit ADC, a critical component for sensors to capture data from their environment at an acceptable resolution, and a hardware implementation of AES-128, meaning the CPU can be saved for other operations while still ensuring that all traffic across the network is encrypted.

The CC1101 RF transceiver core is only capable of operating in the 315/433/868/915 MHz bands. To be capable of operating in TV Whitespace across 470-700 MHz, a transverter

was implemented. The ADF4351 wideband synthesizer with integrated VCO is used as a local oscillator and, after being filtered, is mixed through an ADEX-10L passive mixer. The CC430F5137 RF output is sent through a SAW filter before going into the mixer. The output of the mixer is then sent through a series of filters, amplifiers, and RF switches. Since only a single antenna is used, the microcontroller switches the signal path from the antenna to the transmitting or receiving path when appropriate.

C. *Current Capabilities*

Currently, the Level platform is able to transmit and receive from 35 MHz to 1500 GHz. It consumes a maximum of approximately 356 mA, although it is able to go into several power saving modes that can reduce this by a great deal. The Level platform has two "taps" in the form of directional couplers, one on the output of the CC430F5137 and one on the output of the ADF4351. These can be used to assist in debugging during development by allowing the user to observe the local oscillator or RF transceiver outputs independent of the mixer, filters, and amplifiers.

The mechanical design of the Level platform was designed to fit into the "shields", or daughterboards, that attach to a popular hobbyist microcontroller called the Arduino. Rather than include a WiFi or Bluetooth IC directly on the Level platform, the ability to use existing daughterboards allows the user to add whichever additional communication device they would like and change them with ease. Examples of daughterboards that are available include Ethernet, WiFi, Bluetooth, GSM, and Zigbee. Because these daughterboards all communicate over SPI on common pins, the Level platform is compatible with all of them and can act as a bridge between TV Whitespace and any of those protocol stacks. The Level platform can also use the same set of pins to potentially interact with another processor if it is necessary to offload some of the processing requirements. A photograph of the Level platform is shown in figure 1.

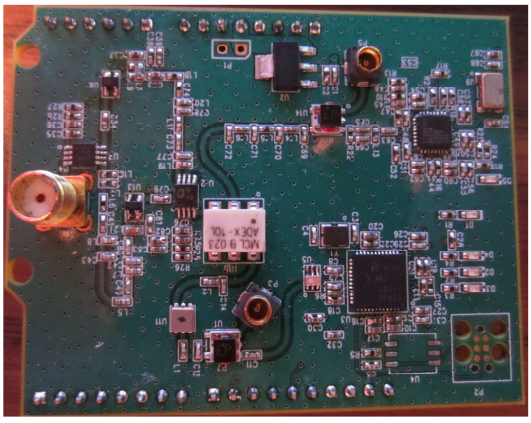

Fig. 1. *The Level hardware platform.*

D. *Future Work*

The Level platform hardware and software is open source, and others are encouraged to improve and expand the capabilities of the device. Several improvements are possible in the current design. For example, the ADF4351 is capable of outputting from 35 MHz to 4.4 GHz, but the mixer can only handle up to 1.5 GHz. By changing the mixer, it should be possible to increase the frequency range of the Level platform. The filters offer another avenue for improvement. All the filters on the device are high order Chebyshev filters. This makes them have a very sharp and precise cutoff, but it also means they have a lower Q than a lower order filter. Further analysis on the tradeoff between good cutoff and high Q could be performed using experimental data from a test deployment to optimize the filters.

The software offers many opportunities for optimization as well. The Level platform is designed to comply with the FCC rules for a mobile device in TV Whitespace wherein the base station commands the mobile device with what frequency and bandwidth to use. However, spectrum sensing using Fourier analysis can be implemented to help inform the base station about the spectral environment [6].

Security in TV Whitespace and other similar cognitive radio protocols is an important research area in determining if and how cognitive radio can be used commercially outside of research [7]. The Level platform can be used to not only test security in sensor networks based on TV Whitespace, but it can also be used to test backhaul links and other applications of TV Whitespace. Additionally, because the Level platform is capable of transmitting on ISM band frequencies, it can be used to test and attack other ISM band devices.

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