Radio Environment Mapping with Mobile Devices in the TV White Space

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ABSTRACT

In this paper, we envision a scenario where mobile devices perform at least part-time spectrum sensing in a collaborative fashion under the control of a central server. The goal is to create an adequate 'radio environment map' for the 'white spaces' that will be useful for spectrum management decisions. We lay out the research challenges, describe a prototype implementation using a DTV receiver dongle interfaced with an Android-based mobile device, and present preliminary performance measurements.

Categories and Subject Descriptors

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

Keywords

TV Whitespace, Spectrum Sensing, Radio Environment Map.

1. INTRODUCTION

As regulators worldwide are deregulating the TV white spaces (TVWS) for unlicensed use, there is a significant interest in understanding the nature of such white spaces and the real spectrum opportunities in time and space so that they can be gainfully exploited. So far the understanding in the TVWS has been mostly driven by models that use terrain data and TV transmitter (primary) characteristics/schedule to estimate the signal strengths observed at different frequencies at a given location. There are several existing services such as Spectrum Bridge, Google Spectrum Database, MSR WhiteFi etc. that essentially use such model-based methods.

However, such model-based approaches have limited applicability in several scenarios. First, they can only model large-scale propagation characteristics and are unable to accurately describe spectrum occupancy in the urban canyons and in indoor spaces. Even in outdoor spaces, occasionally significant errors are possible. Second, such models are geared towards modeling the primary behavior that have powerful transmitters and antennas at a significant height. It is unclear whether such modeling will provide enough accuracy to estimate coverage of secondary transmitters that are of lower power and are at lower heights. Overall at best, modeling-based approaches can provide fairly conservative estimates leading to loss of spectrum use. This is more relevant in heavily populated urban regions, where the 'spectrum holes' are already limited due to relatively heavy primary occupancy [6]. This is also where the need for spectrum is the greatest.

1.1 Mobile Spectrum Sensing

We propose an alternative where model-based methods to evaluate spectrum occupancy is replaced or supplemented by actual spectrum measurements via coordinated spectrum sensors that are either add-on or integrated into mobile client devices [5, 8]. These include smartphones, tablets, e-readers, wearables such as glass or watch, or similar future platforms. While the general concept of distributed, coordinated spectrum sensing is hardly new, much of the existing work has considered lab-grade spectrum analyzers or powerful SDR-based spectrum sensing [4]. These devices are large, expensive, power-hungry and often require external computers. It is not conceivable that such systems will be widely deployed in practice to perform the task of large-scale spectrum sensing.

Modern mobile platforms provide an attractive alternative. They have multicore processors and GPUs to provide enough compute power and also provide backend network connectivity. They are also everywhere as a significant and growing fraction of humanity possesses one or more of these devices. Further, they are often idle. While they may lack appropriate radio interfaces for white spaces at this time, early prototypes have already been demonstrated [5, 8].

There are several challenges, however. Fundamentally, the challenges boil down to architectural design and accuracy versus resource use tradeoffs:

Architecture. An end-to-end framework must be developed such that spectrum data will be collected from numerous sensors and collated at the backend (a central server or cloud-based platform) to create the radio environment map (REM). The REM is essentially the power-spectral density (PSD) as a function of location. Preferably, the central server also acts as a form of 'spectrum manager' and is responsible for the actual use of the REM in making spectrum allocation decision for the secondaries.

Accuracy. It is unclear whether inexpensive radios integrated onto a phone and with small, built-in antennas can perform sensing with the needed accuracy. Also, due to re-

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source limitations, the sensing could be sparse in frequency, time and space, and also the data may be compressed. See below.

Resource. While mobile devices are often idle and may have ample processing power, they are energy poor. The radio front end can also have limitations in the sense of tunability and sampling rate. Thus, spectrum sensing must be controlled by the central server for optimally exploiting the radio capability for a given power budget. The cost of network connectivity is also an issue. The spectrum data may need to be compressed before transmission or may have to be analyzed partially (e.g., the FFT on the I/Q samples can run on the mobile).

In this poster paper, we limit ourselves to only one part of these challenges. We develop a prototype platform using commodity devices – DTV receiver dongle interfaced with an Android-based mobile device. Then, we perform preliminary experiments demonstrating that such a low-power platform can still perform adequate radio environment mapping even with measurements at a low spatial resolution.

2. MOBILE TVWS SENSOR

While current generation smartphones have several radio interfaces they do not operate in the TV band. Also, in general an interface to tune to arbitrary frequencies in the operating band and obtain I/Q samples is absent. Past work has considered developing custom, small form-factor boards with RF front ends, ADC and FPGA that can be interfaced with the phone [5]. Chip-level design of the wideband frontend of an SDR receiver has also been demonstrated [8]. However, these are research prototypes and are not widely available. Instead for our work, we rely on commodity devices to understand the potential of our techniques. We use a commodity Digital TV receiver dongle (DTV receiver with an USB interface with the form factor of a thumb drive) that has a chipset (Realtek RTL2832U demodulator) with the ability to export I/Q samples. Such dongles can be used as inexpensive software radio receivers as the demodulator (RTL2832U) supports a debugging mode where it passes the IQ samples directly from the tuner's ADC to the device. The dongle is provided with an aerial TV plug and is interfaced to a mobile device via the USB port. This forms a miniature spectrum sensor. We have connected a low gain antenna to the dongle. However, in principle such antennas can be built inside the phone.

2.1 Hardware Prototype

We have used the EzCap Digital ATSC TV dongle. The dongle uses a Rafael R820t tuner supporting the ATSC standard. The tuner works with DVB-T, ISDB-T and DTMB standards as well. Figure 1 shows our prototype spectrum sensor. The dongle has a USB 2.0 interface and can be interfaced to any mobile device that supports USB OTG (on-the-go) so that it can host a USB accessory. We have used a PiPo Smart S1 tablet, equipped with Rockchip RK3066 dual-core processor, running Android Jelly Bean (v4.1.1) operating system for the initial prototyping. Our system can easily be ported to any Android tablet or phone that has USB OTG support.

2.2 Software Implementation

The Open Source Mobile Communications (Osmocom) [1] has a community-supported project developing software support for using DTV dongles as above as functioning SDR receivers. We have ported the existing Linux libraries and drivers for these dongles to the Android platform. The overall system consists of two units: first, the mobile client (local unit) and second, a central server (remote unit) meant for logging sensing data.

Figure 1: The DTV dongle with external antenna interfaced with the Android tablet.

Mobile Client: This unit comprises of the mobile device with GPS support interfaced with the dongle. The mobile client thus acts as a mobile spectrum sensing agent. The application running in the mobile can set the center frequency and the sampling rate. Additionally, the mobile device runs a TCP server that streams I/Q data (geo-location tagged) to the central server. The latter can also send requests to the mobile client to start, stop change the center frequency or sampling rate of the scan.

Central Server: The server receives I/Q data from the mobile client and computes the power spectral density (PSD) by employing standard FFT techniques on the stream of incoming I/Q samples. This unit forms the central repository of the sensing data and is responsible for computing the Radio Environment Map (REM) from the data. The server can also start, stop and/or schedule scans on specific clients depending on the needs. The central server also responds to queries regarding spectrum availability from secondary devices given its location and makes or helps in spectrum allocation decisions. A set of APIs are being developed for interfacing the client with the server for smooth interfacing and for promoting independent software developments.

Our initial work in creating and evaluating REM is presented in Section 3. Energy optimization issues, scheduling of spectrum scans and spectrum allocation issues are part of our ongoing work and are not directly addressed in this poster.

3. CREATING RADIO ENVIRONMENT MAP

The goal in this section is to demonstrate that even with low resolution spatial sampling commodity platforms as our prototype can map the radio environment with a fairly good accuracy. To demonstrate this we use an industry-standard portable RF signal and spectrum analysis platform, ThinkRF WSA4000 [2], that provides the baseline spectrum measurements. For the purpose of our work, ThinkRF measurements form the ground truth dataset. ThinkRF provides a sampling rate of 125 Ms/s. A 16K bin FFT is used at the backend to create the power spectral density with each FFT bin corresponding to roughly a 7.6 KHz bandwidth. The dongle runs at a substantially slower rate of 1 Ms/s. Here, a 1K bin FFT is used providing a bin size of 1 KHz.

Concurrent but independent measurements are done in a continuous fashion in both the dongle-based prototype as

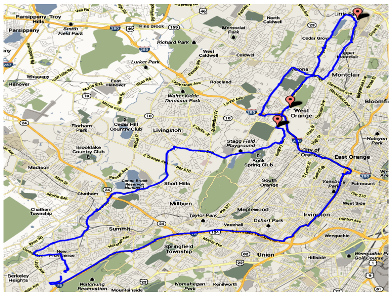
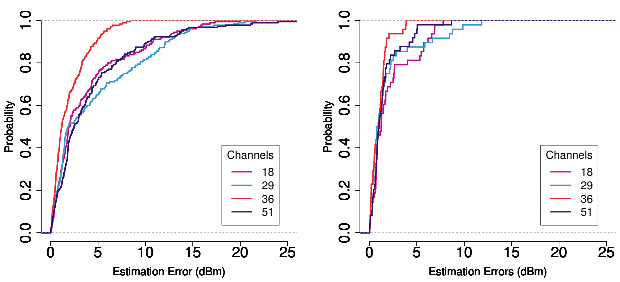


Figure 2: Measurement route (roughly 60 miles) and locations of 3 TV towers. Two of the towers transmit on 1 channel each and the other transmits on 2 channels. These 4 channels are studied.



(a) 6 miles (b) 1.5 miles

Figure 3: CDF of absolute estimation error by using subsets of the dongle data set for the 4 TV channels studied. Two cases are evaluated where the chosen subset of measurement samples has average measurement distance of 6 miles and 1.5 miles.

well as the ThinkRF platform from a mobile van driven along a 60 mile loop in and around Essex county in New Jersey (see Figure 2). The measurements are done in a continuous fashion. They are geo-tagged using a separate external GPS receiver and stored in a database. Since the dongle is substantially slower than the ThinkRF (by more than an order of magnitude), the dongle is used to scan only 4 specific TV channels that are reasonably prominent in the area (see Figure 2). This way reasonably frequent measurements can be collected. At the end of the experimental runs, our database has collected roughly 1100 ThinkRF measurements and roughly 200 dongle measurements for each of the 4 channels. Before the map creation, the dongle has been calibrated against the ThinkRF platform using a signal generator. The signal generator generates a tone at the frequency of interest at specific transmit power levels. Both devices are placed at a specific location (one at a time) near the signal generator and the average received power is computed for each frequency bin after the FFT. The differences are recorded and are used as bin-specific corrections for the dongle measurements for the analysis we present here.

3.1 Interpolation

Recently, there has been several works in employing standard methods of spatial statistics in mapping the radio environment (see, e.g., [9]). Empirical measurement-based work has also been done [7]. We take the same basic approach by assuming the radio signal strength at each frequency to be a random field in 2D that is sampled at some random (spatial) intervals. The samples are presented by our data set. We use different randomly chosen subsets of dongle measurements we have collected (roughly with average measurement distance of 1.5 miles and 6 miles for two cases studied) and use these to interpolate the 2D field of signal strength separately for each 7.6 KHz frequency bin. We use Ordinary Kriging [3, 7] as the interpolation method as also used in prior work.

To validate the results, we compare the interpolated values at each frequency bin from the actual measured ground truth (ThinkRF measurements) for each location where ground truth measurement is available (roughly 1100 locations). The absolute error (in dBm) is plotted in the form of a CDF separately for each of the 4 channels. See Figure 3. Note the error statistics is excellent. The median error is $1-3$ dBm for the 6 mile case and less than 1 dBm for the 1.5 mile case. This shows that very sparse measurement density can be tolerated. Mobile phone density in urban areas will be certainly one to two orders of magnitude relative to these values, though scheduling issues may lessen the actual measurement density. We also anticipate error performance to improve further by using more sophisticated interpolation.

4. CONCLUSION AND FUTURE WORK

Mobile spectrum sensing present several research challenges, but when addressed right, such systems enable adequate radio environment maps for the white spaces with very little infrastructure cost. In this work, we have laid out the vision of such systems, presented a prototype implementation and performed preliminary validation experiments. The entire gamut of challenges mentioned in the paper forms parts of our ongoing and future works.

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