Demonstration Abstract: A Low-cost Sensor Platform for Large-scale Wideband Spectrum Monitoring

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ABSTRACT

Today's radio frequency (RF) spectrum measurements are mainly performed by governmental agencies which drive around using bulky and expensive specialized hardware. This approach does not scale well, providing us with only a poor situational awareness of the actual RF spectrum usage around us. We have developed a wideband spectrum monitoring sensor for remote operation that builds upon portable and low-cost commercial off-the-shelf (COTS) hardware components with a total cost per sensor device below $100. This results in a stunning cost reduction factor of 50 to 500 comparing to professional equipment. Our sensor platform adopts the software-defined radio paradigm and performs all signal processing steps on the CPU and GPU of a low-cost single-board computer. We address the challenges of large frequency errors and long scanning times due to the hardware constraints by proposing new correction and optimization methods, providing a satisfactory level of accuracy in indoor and outdoor environments. Our remote sensing platform is envisioned to be used at larger scale for various applications such as dynamic spectrum access in cognitive radios, detecting regions with elevated electro-smog, or for policy enforcement in the electromagnetic space.

Categories and Subject Descriptors

C2.3 [**Network Operations**]: Network monitoring

Keywords

Spectrum monitoring, Crowdsourcing, Wideband, Distributed

1. INTRODUCTION

The electromagnetic (EM) spectrum is well regulated but the actual usage of the spectrum at different locations is poorly understood. The problem is that today's spectrum measurements are primarily performed by governmental agencies which drive around using expensive and bulky specialized hardware [2, 5]. This monitoring approach does not scale well and is not able to cover the pervasive deployment of wireless networks as well as the increasing range of spectrum frequencies being used. Recent suggestions to enable wide-scale and real-time spectrum monitoring have therefore been to build a networked and distributed infrastructure using remote spectrum analyzers [1, 2, 4], or leverage the masses to crowdsource the measurement stations by trading-off radio device sensitivity with cooperation [3, 5].

To support this vision, we have developed a low-cost sensor platform that allows to perform continuous RF spectrum measurements in the frequency band between 24 and 1766 MHz and to collect the results over the Internet. Our sensor platform is unique in the field of spectrum monitoring solutions. Compared to specialized spectrum analyzers [7] or more advanced software-radio platforms like the Universal Software Radio Peripherals (USRPs), our sensor is a factor 50 to 500 times cheaper. In contrast to existing spectrum analysis software projects for RTL-SDR based USB dongles[1], our architecture is designed for distributed operation on single-board computers and incorporates various scanning strategies, spectrum analysis and error/noise correction techniques as well techniques for flexible and configurable remote wide-spectrum monitoring.

Figure 1: Low-cost wideband spectrum monitoring hardware sensor platform.

2. SENSOR PLATFORM

2.1 Hardware

Our sensor platform is shown in Figure 1. It builds upon three COTS hardware components – a *single-board computer (SBC)* platform, a *USB dongle* and an *antenna*. The USB dongle, together with the antenna connected to it, is used as RF receiving device outputting a digital I/Q signal. The SBC platform serves as the host computing device for processing the I/Q samples from the RF device. For the demonstration, we use a Raspberry PI B+ as SBC

[1]`http://sdr.osmocom.org/trac/wiki/rtl-sdr#KnownApps`

IPSN '15, Apr 14-16, 2015, Seattle, WA, USA

http://dx.doi.org/10.1145/2737095.2737124.

which has a CPU of 700 MHz, 512 MB RAM and an on-board GPU as well as a RTL-SDR compatible USB dongle with a Realtek RTL2832U chipset. The dongle supports a continuous tuning range between 24 and 1766 MHz. The maximum complex sampling rate over USB is 2.4 MS/s, resulting in a spectrum bandwidth of 2.4 MHz with 8 bit resolution that can be sensed at a time. A temperature sensor is further attached to the single-board computer to correct the large frequency error of the RF device.

2.2 Software

To monitor the spectrum, the tuner of the USB dongle is swept over a configurable frequency range in steps of 2.4 MHz. The SBC receives a series of I/Q samples which are then processed in several steps for segmentation, DC removal, windowing, FFT, envelope detection and averaging. These spectrum analysis techniques are standard techniques as found on modern hardware-based digital spectrum analyzers [7]. The difference is that we implement those techniques in software on the CPU and GPU (only the FFT) of the SBC and expose all parameters to a controller for remote configuration over the Internet.

In contrast to specialized spectrum analyzers, we have to address two main challenges when using a limited hardware platform for spectrum monitoring: large *frequency errors* and large *scanning times*. The frequency error comes from the low-quality crystal oscillator as being used for the clock reference of the USB dongle which has inaccuracies in the order of 50 ppm. This is reflected as a temperature-dependent frequency error in the order of a few kHz. To correct this frequency error, we propose to rely on GSM signals of nearby base stations as received by the USB dongle itself. Since this process is time-consuming (up to 6 minutes for the initial synchronization and roughly 10 seconds for re-synchronization) and blocking the usage of the dongle for spectrum monitoring, we further rely on the local temperature of the sensor to adjust the error offset when the temperature changes after synchronization with the GSM base stations. In combination, these techniques allow us to decrease the frequency error by a factor of $10 - 40$X.

The large scanning time comes from the high delay to change the tuning frequency of the USB dongle from the operating system of the SBC and/or the signal processing delays when using large frequency resolutions. Even for low frequency resolutions of 10 kHz, a sequential scan from 24 to 1766 MHz can take up to one minute to complete. This may lead to signals that are not captured when they appear on specific frequencies while the USB dongle is tuned to others. To address this challenge, we propose a similarity-based hopping strategy which visits bands of high variability more often than bands which have high similarity in consecutive visits. This technique allows us to significantly improve the overall quality of the monitored spectrum since many bands are either not utilized or contain signals whose spectra do not change significantly over time. Our software architecture as well as the techniques to correct frequency errors and improve scanning times are describe in more details in [6].

3. DEMONSTRATION

The demo session will consist in showing how well our low-cost sensor platform is able to monitor the spectrum. We will show our distributed sensor platform from the following two aspects:

- A few sensors will be placed in the demo room for people to play with. People can change the configuration of the sensors through a controller in the same room and observe the results in real-time. To show the benefits of our frequency error correction technique and the similarity-based scanning strategy, we will place sensors side-by-side for direct comparison.

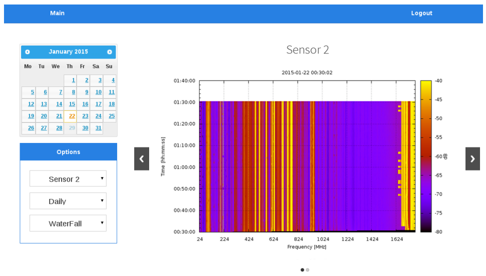

Figure 2: Distributed sensors and its spectrum scanned as shown in the website.

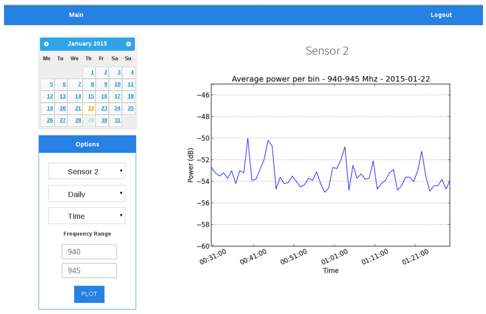

Figure 3: Evolution of the average power per bin over time (calculated in the range $940 - 945$ MHz).

- The web application will provide live measurements from remote sensors that we have deployed in Europe. Waterfall daily (Figure 2) and evolution of the received power (Figure 3) for selected ranges of frequencies are also included in the website. As use case, we will show that TV broadcasting frequencies in the range of $791.5 - 860$ MHz are disappearing in Madrid because of the advent of LTE base stations.

Acknowledgement

This article has been partially supported by the Madrid Regional Government through the TIGRE5-CM program (S2013/ICE-2919)

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