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Automated bandwidth measurements using ITU-R SM.443 and GNU radio devices

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Abstract

Recommendation ITU-R SM.1392 defines the minimum requirements for monitoring tasks in developing countries and is currently being updated by the ITU-R Working Party 1C. To fulfill the technical tasks defined in the new SM.1392 draft recommendation, we developed a set of compliant procedures using open GNU Radio devices such as USRP and bladeRF. In this paper we show the automated spectrum bandwidth measurement tasks implemented in a GNU radio device, according to the ITU Spectrum Monitoring Handbook and ITU Reports and Recommendations referenced in the ITU-R SM.1392 draft.

1. Introduction

Recently, the evolution of the dynamic spectrum access concept and cognitive radio has challenged radio regulators and traditional spectrum-assignment processes. Similarly, the digitization of most radio services has challenged the way in which the regulators verify compliance with spectrum assignments using spectrum monitoring stations. New regulations concerning white spaces and dynamic spectrum access issued by administrations in different countries (FCC, Ofcom, and CEPT, to mention a few), as well as some pilot trials of TV white spaces, have challenged the regulators to develop reliable methods for guaranteeing access to the spectrum without any harmful interference to primary users in a dynamic spectrum environment.
Considering that WRC-15 stipulates that no change in the radio regulations is necessary regarding the use of dynamic spectrum access techniques or cognitive radio, better spectrum monitoring systems and spectrum occupancy procedures are required to guarantee spectrum access to different types of users in this new, currently evolving paradigm. This challenge is huge for developing countries that have limited budgets and different priorities for using those budgets.

Currently, ITU-R SM.1392 [1] specifies the minimum requirements of a spectrum monitoring system for developing countries, and ITU-R SM.1537 [2] proposes the automation and integration of monitoring systems with spectrum management software. Monitoring units based on digital signal processing are also included to increase efficiency and execute more specialized monitoring tasks. These devices can be part of spectrum management networks and are useful for extending coverage in remote zones with limited infrastructure [3].

The implementation of each measurement procedure for a digital or analog receiver is detailed in the ITU-R Recommendations and Reports, and in the Spectrum Monitoring Handbook. However, most of the procedures described in the current ITU-R Recommendations require the presence, in place or remotely, of a human operator to set up the device, calibrate it, and perform the procedure.
To respond to these new challenges, during the last three years, the ITU study group 1 in the Working Party 1C has been working on the evolution of the spectrum monitoring concept, resulting in the recommendation ITU-R SM.2039 and the report ITU-R SM.2355, which includes new techniques and concepts for evolving spectrum monitoring networks. Two of those new concepts are the grid monitoring network or spectrum monitoring sensor network concept proposed in ITU-R SM.2355 and the hierarchical monitoring network concept proposed in the same report by the authors of this paper. These concepts propose the use of a sensor network employing low-cost devices and user devices (e.g., cognitive devices) as part of a spectrum monitoring network that can conduct automated measurements and data management in the cloud.
As part of updating the ITU-R Recommendations, Working Party 1C is also revising some of the existing recommendations about spectrum monitoring, including ITU-R SM.1392 and SM.1880 about spectrum occupancy, according to ITU-R question 233-1/1.
ITU-R Recommendations describe the use of different types of equipment required to perform the spectrum monitoring tasks, including radio receivers, swept spectrum analyzers (SSA), and FFT-based receivers. However, although FFT-based devices are mentioned in the most recent ITU-R Recommendations and in the Spectrum Monitoring Handbook, methods to fully exploit these devices are not described. Furthermore, a spectrum analyzer can be used for measurements of parameters such as frequency and bandwidth as well as those of digitally modulated signals or for the detection of unknown sources of interference.
The new draft of ITU-R SM.1392 mentions that "…FFT analysis in both receivers and spectrum analyzers has become affordable and should be preferred. This is not necessarily more costly than conventional sweeping analysis." Recommendation ITU-R SM.443, as well as sections 4.2 and 4.5 of the Spectrum Monitoring Handbook, describe the measurement of bandwidth in detail, mainly using SSA.
The recent evolution of software-defined radio devices, based on GNU Radio and low-cost hardware, opens new opportunities to develop flexible and low-cost automated

spectrum monitoring systems for developing countries as well as other countries. These could also be used to develop automated techniques for spectrum monitoring and the connection with spectrum management systems.

We have implemented the bandwidth measurement defined in ITU-R SM.1392 in a low-cost unattended monitoring unit based on software-defined radio, which is described in 4. For this measurement, we use algorithms based on FFT and modern signal processing techniques available in GNU Radio and Python. In the present paper, we analyze the results of measurements in FM radio broadcasting and terrestrial mobile UMTS services. We also present some ideas to improve unattended monitoring tasks and some of the tasks described in current ITU-R Recommendations mentioned in ITU-R SM.1392.

2. Spectrum Monitoring in Developing Countries

The draft recommendation ITU-R SM.1392 5 clearly establishes that the radio monitoring stations and networks in developing and developed countries have the same tasks, and hence, the same requirements. However, the differences concerning available budget and manpower between the developing and developed countries might be substantial. Therefore, thorough planning and careful designing of systems and networks are essential to minimize these differences.

Limited budgets generally result in a lack of staff or staff with inadequate training. Consequently, a flat hierarchy occurs and the existing staff is required to perform tasks that they have not been trained for. In some administrations, the spectrum monitoring staff also has to fulfill spectrum management and inspection tasks [5].

Some developing countries have vast unpopulated territories as well as populations spread over large areas. The lack of staff mentioned above imposes some constraints such as the impossibility of having monitoring staff working 24 hours a day to attend to various interference issues in such areas. A combination of such economic and technical constraints requires innovative approaches to fulfill the regulator's responsibilities with cost-effective investment.

3. Spectrum Monitoring Bandwidth Measurements of SIMON

SIMON (an acronym for "Monitoring System" in Spanish) is an SDR monitoring unit built with an SDR device (USRP B200 or Nuand's bladeRF) and an embedded control system such as Raspberry Pi or CubieBoard.

USRP and bladeRF are part of a family of SDR devices that use GNU Radio, an open-source SDR developer framework with a growing family of supporting hardware. These devices are relatively cheap, with adequate hardware specifications suited for spectrum monitoring tasks and other RF applications. Some applications of these devices are for 5G prototypes using the USRP Rio Model.

The frequency range of SIMON depends on the features of the SDR device. With bladeRF and the XB-200 transverter board (an additional module that expands the low-frequency range of bladeRF), SIMON has an RF frequency range of 50 kHz to 3.8 GHz for monitoring HF/VHF applications. The range with USRP B200 is between 70 MHz and 6 GHz. With other USRP models, the range depends on the daughter board.

SIMON is an FFT-based spectrum analyzer that executes the bandwidth measurement mentioned in ITU-R SM.1392-2 [3] using the received FFT trace. These procedures are implemented in GNU Radio and Python following the recommendations mentioned in ITU-R SM.1392-2, as will be described in the following paragraphs.

This reports the occupied bandwidth during a transmission, which can be measured using a spectrum analyzer or a digital monitoring receiver, allowing the recorded trace to be stored in memory for later graphical processing. The occupied bandwidth can also be measured using FFT techniques, according to the ITU Spectrum Monitoring Handbook [7]. ITU recommends two methods for use at monitoring stations: using a directional antenna with high directivity (to improve the signal-to-noise ratio (SNR)) and avoiding any impulse interference during the measurement.

3.1 β% method

This method calculates the occupied bandwidth by considering the power spectral density of the signal and an estimated bandwidth. The occupied bandwidth for this method is defined as "the width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage β/2 of the total mean power of a given emission" [6]. The value of β/2 should be 0.5% unless the class of emission specifies another value in an ITU-R recommendation.

According to the occupied bandwidth calculation given in [6], the power spectral density (PSD) is added throughout the estimated bandwidth to give 100% as the reference. Then, starting from the lower frequency, the power spectral density of each frequency is again added up until the sum reaches 0.5% of the reference. At this point, a marker is set. The same calculation is then performed starting from the highest frequency until again 0.5% of the reference is reached and a second marker is set. The occupied bandwidth is the frequency difference between the two markers.

For services with analog modulation, PSD should be calculated with the Maxhold trace because the behavior of the signal is constant. Regarding services with digital modulation, there is a fluctuation due to the non-constant modulation. In that case, the measurement should be made 400 times using the instance trace (Clear Write trace) to obtain the average occupied bandwidth.

3.2. x-dB method.

This takes the maximum power level of the Maxhold trace and defines it as the 0-dB reference level. The occupied bandwidth is the width of a frequency band between the lower and upper frequencies, where the power level is less than x dB with respect to the 0-dB reference level. Typically, $x = -26$, but this can be adjusted depending on the class of emission, as given in 6. 0 shows the relationship between the 0-dB reference level and the x-dB value.

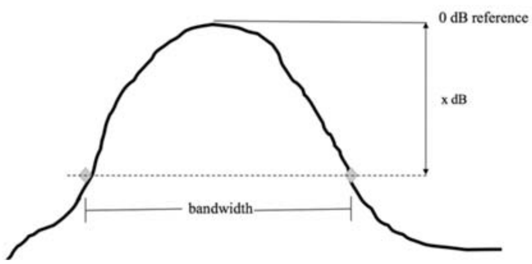

Figure 1 *x*-dB method

3.3 Remarks about Bandwidth Measurement

Note that the procedures described in ITU-R SM.443 for bandwidth measurements are not well suited for an unattended remote monitoring station. First, the mention of the use of a directional antenna supposes the availability of a servo system that can rotate the antenna, and therefore, the presence of an operator manipulating it. Second, the *x*-dB method requires an SNR that is sufficiently high to take values of -26 dB or more that are required by the procedure. A similar problem arises with the *β*% method; however, it is easier to deal with. The high SNR requirement creates problems with low-level signals, which is one of the challenges mentioned in the new recommendation ITU-R SM.2039 [4]. For an unattended system, it is better to use omnidirectional antennas to reduce the complexity and improve maintainability, as well as simplify the procedures. However, this approach requires some improvements in bandwidth measurement algorithms.

4. Validation and Results

Previous studies compared software-defined radio devices and commercial spectrum analyzers, with satisfactory results for spectrum management tasks [4]. We present results for the tasks established in the Spectrum Monitoring Handbook and ITU-R SM.1392.

Measurements were executed in frequency bands corresponding to an analog broadcasting service and a digital terrestrial mobile service (IMT) in order to validate the reliability of the system. A nearby radio station at 107.5 MHz FM was selected and 10-s samples were taken every 5 min over 24 h with a bandwidth and sample rate of 1.5 MHz (which can be equal because IQ-demodulated complex samples are used), an FFT length of 4,096 points, and a channel size of 200 kHz.

The channel size is used to filter neighboring radio stations because the radio device, Nuand's bladeRF, cannot reach a lower bandwidth. However, it can measure from 50 kHz to 3.8 GHz with a hardware extension and can be synchronized using a 1PPS signal.

For each 10-s sample of maximum values, the following measurements were performed:

- Frequency and bandwidth using the frequency sweept and *x*-dB algorithms
- Frequency and bandwidth using the frequency swept and *β*/2 algorithms
- Frequency and bandwidth using the FFT and *x*-dB algorithms
- Frequency and bandwidth using the FFT and *β*/2 algorithms
- Power spectral density

The frequency results using the *x*-dB algorithm are shown in TABLE I. and those using the *β*/2 algorithm are shown in Table II.

TABLE I. FM FREQUENCY RESULTS I

	Results in Hz	
	Swept and x-dB	***FFT and x-dB***
Bandwidth Average	225627.940188	
BW. Std. Deviation	15240.4963711	

Using *x*-dB to calculate the bandwidth, the result is close to the channel size, as expected, with a standard deviation of 15.2 kHz. However, on using *β*/2, a more stable result is obtained, with a standard deviation of 9.4 kHz. This is due to the nature of the algorithms: *x*-dB is based on a threshold, whereas *β*/2 is based on the power of the signal. The behavior of both algorithms is reflected in the frequency values obtained using both Frequency Swept and FFT methods.

TABLE II. FM FREQUENCY RESULTS II

	Results in Hz	
	Swept and β/2	***FFT and β/2***
Bandwidth Average	179780.693464	
BW. Std. Deviation	9454.51571215	

Figure 2 shows bandwidth and frequency values against time for all the above mentioned combinations of algorithms. The plots show comparable results; however, we found an abnormal peak between 5 pm and 8 pm that could be attributed to an error in the oscillator of the transmitter, a modification in the emission parameters, or a change in the radio programming (such as the broadcasting of news instead of music). As the bandwidth of emissions from FM broadcasting transmitters is closely linked to frequency deviation, a possible malfunction was detected by our monitoring system.

For measurements in the digital band, a UMTS carrier at 882.5 MHz in an area of high population density was selected, with a bandwidth and sample rate of 5.5 MHz. The results are given in TABLE III. and TABLE IV. From the results and the plots shown in Figure 3, we can conclude that the *x*-dB algorithm is unreliable for digital technologies, because it is not possible to establish a valid threshold. We conclude that this is the reason why the ITU-R Spectrum Monitoring Handbook recommends the use of $\beta/2$, instead of the x-dB method, for digitally modulated signals.

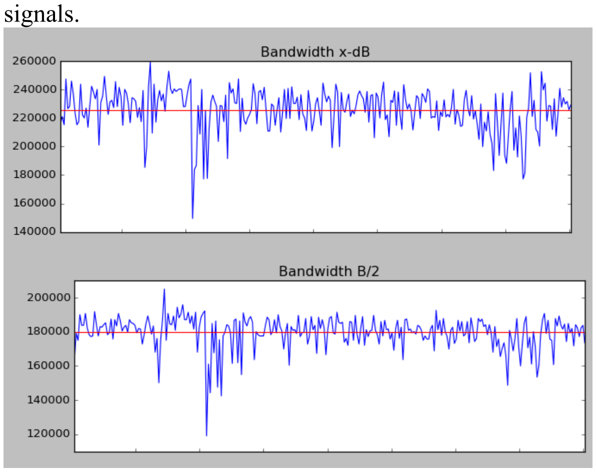

Figure 2 Results of an FM radio station, starting at 11:00 am

TABLE III. UMTS FREQUENCY RESULTS I

	Results in Hz	
	Swept and x-dB	***FFT and x-dB***
Bandwidth Average	5444657.52058	
BW. Std. Deviation	35335.5761731	

TABLE IV. UMTS FREQUENCY RESULTS II

	Results in Hz	
	Swept and β/2	***FFT and β/2***
Bandwidth Average	4284308.75826	
BW. Std. Deviation	66649.7467836	

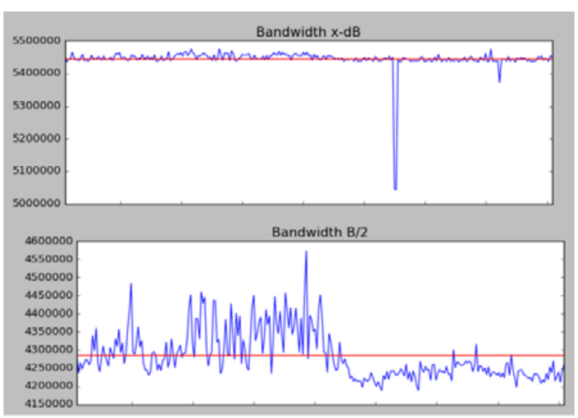

Figure 3 Results of a UMTS carrier, starting at 5:00 pm

However, $\beta/2$ also exhibits special behavior when the traffic is low in UMTS, i.e., when the power of the signal decreases. The SNR is higher, a power-density sparse occurs, and the bandwidth boundaries tend to the ends, resulting in a fake increase.

5. Conclusions

We have demonstrated the implementation of ITU-R SM.1392 bandwidth measurements using affordable SDR devices and the automation of the measurement procedure using a sensor network approach. However, to identify and fix special behaviors of the algorithms and to obtain a holistic view of the spectrum for each radio service, the results should be analyzed as a whole, not individually.

Open-source SDR devices allow the development of improved algorithms for unattended small monitoring stations, according to the requirements of the current technology trends such as dynamic spectrum access or white spaces.

The use of FFT-based signal processing techniques allows the development of new and improved algorithms to execute the bandwidth measurement task described in ITU-R SM.1392. It also allows new methods and algorithms to be proposed to update the corresponding recommendations referenced in SM.1392.

6. References

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7 International Telecommunication Union - Radiocommunication Sector [ITU-R], “Measurements,” in Spectrum Monitoring Handbook, ITU, Geneva, 2011, pp. 207–418.