USRP Based HF Spectrum Occupancy Measurements at Two Locations in Central and Western Romania

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Abstract—**In this paper, measurements of the spectral occupancy in some high frequency (HF) bands in the Western part of Romania are presented. Signals have been acquisitioned by means of an Universal Software Radio Peripheral (USRP) equipment and spectrum occupancy values have been calculated off-line for a set of frequency bands that present interest for establishing of a system for emergency communications. Calculations have been based on an energy detection criterion that is presented and discussed in the paper. Preliminary measurements performed simultaneously at two different locations, namely in Sibiu and Timişoara cities, Romania, are also reported and compared.**

Keywords—HF band; spectrum occupancy; energy threshold; USRP

I. Introduction

Electromagnetic waves from the High Frequency (HF) band (3-30 MHz) propagate over long distances by single or multiple reflections on the ionosphere and on the surface of the Earth. Propagation is affected by modifications of the ionosphere layer structure and parameters, which depend on various factors such as frequency, location, season, time of the day, solar activity, terrestrial magnetic field etc. Variability of the propagation conditions affects HF communications. However, the equipment needed for establishing a long-range communication channel in the HF frequency range is basic, so that it becomes a solution of choice when infrastructure is scarce or in emergency situations, when a communications link has to be established in a short time and over a long distance.

Ionospheric communications channels are affected by noise and perturbations arising from cosmos / atmosphere or from man-made sources. Noise levels are larger in urban, industrialized areas than in rural or remote locations with low population densities. Noise levels vary not only with space, but also with time of the day, season, frequency and other variables.

HF spectrum usage is regulated by national authorities [1] and is presently based on fixed frequency allocations. With the continuous density increase of digital systems and frequency bands that are shared by various radio services, spectrum occupancy (SO) measurements and evaluation became priorities in providing quality services. Based on information and recommendations in use [2, 3] we identified a specific need of own determinations.

Measurements of SO in various parts of the world have shown that the HF region is subject to congestion, which can be explained by the presence of many users and the long-range propagation that is specific to this part of the spectrum [4-11]. However, the same measurements have shown the presence of time gaps of signal-free frequency sub-bands that can be occupied by "frequency agile" users [10].

Measurements performed in the UK for over a decade allowed for the development of a linear regression model [4]. Similar measurements in Northern Europe have revealed similarities with the results of the UK group in the occupancy of the HF spectrum in the two regions [5]. Measurements in the USA and Canada demonstrated, among others, the dependency of the HF spectrum congestion on the geographical location [7, 8]. The problem of the range over which SO are spatially correlated is tackled, among other issues, in [6]. Results on spatial correlation are also mentioned in [11], where a time series model for the SO is developed.

In this paper, we are reporting results obtained by SO measurements performed in the towns of Timişoara and Sibiu, Romania. The work was motivated by the need to design/deploy a future communication network intended for emergency situations on the national territory. The preliminary tests of emergency data communications in the HF frequency range were performed under NVIS propagation conditions over the Romanian territory. The results obtained by [12] yield a packet error rate of 13.4% with 16 dB SNR, where OFDM waveforms were used over a standard HF channel with 3 kHz bandwidth. The analysis of the HF occupancy rate presented in this paper will give further insight into the possibility of using a larger bandwidth in order to obtain higher data rates The frequency planning will be adjusted taking into account the measured SO.

Section II of the paper will present the measurement procedure and in Section III we indicate and discuss the obtained results. Conclusions will be drawn in the last Section.

II. Measurement Procedure

The receiver has been built around a Universal Software Radio Peripheral (USRP) model NI USRP-2950R, Dual RF Transceiver equipped with LFRX (0-30MHz) daughterboard and a Diamond WD 330 J omnidirectional antenna. The equipment is located in

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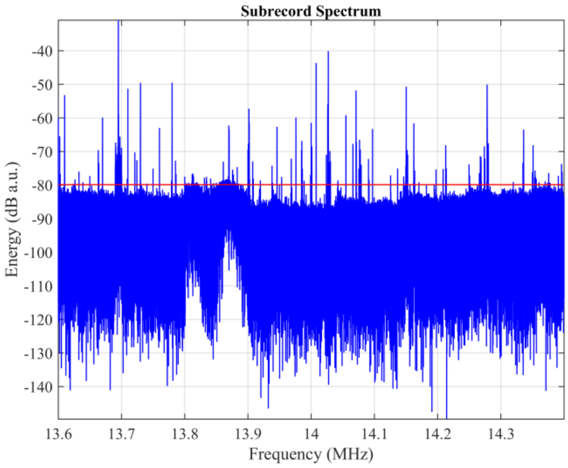

Fig. 1. Spectrum of a sub-record. The red line represents the energy threshold.

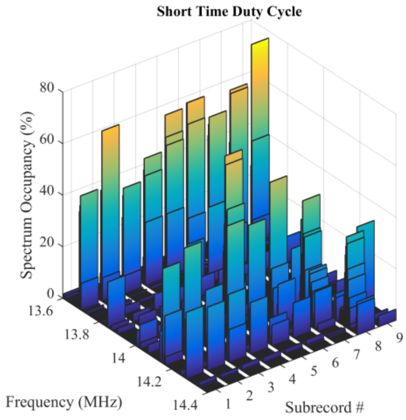

Fig. 2. Short time duty cycle of a 9-second record split in 9 1-second sub-records.

Timişoara, Romania (45.747370 N, 21.225863 E) and it is described in [13]. The receiver provides the *I* and *Q* components of the signal in the baseband, allowing the visualization of the spectrum in a frequency band around a central frequency. USRP based receiver have been chosen for this type of measurement because it has the advantages of measurement in real time the whole HF band and providing IQ data accessible at high speed (200MS/s) for custom control and interfacing from the FPGA.

Many signals have been acquisitioned and analyzed. The analysis revealed a normal structure of the signal for an urban area and a heavily occupied spectrum [14].

In the performed experiments, each signal record had a duration of 9 seconds and it has been split in 9 sequences of 1-second each, for which the Discrete Fourier Transform has been computed.

1-MHz wide spectra have been calculated from the 1-second acquisitioned (sub)signals around a set of central frequencies of interest for the considered application. The complex, low-frequency equivalents of the signals can be considered to have been sampled at a 1-MHz rate. For avoiding errors introduced by the possible roll-off at the ends of the Fourier transforms, 10% of the frequency samples (and band) have been discarded at each end of the spectrum, resulting a useful bandwidth of 800 kHz around the central frequencies.

The 800-kHz bands have been further divided into sub-bands of width B, B = 3 kHz or 4 kHz, which are intended to be used in the emergency communications network,

Energy-threshold based SO [1-3], [15] has been considered. The threshold T for the i-th 9-second record has been calculated as [15]

$$T_i = W_i + M \tag{1}$$

where Wi is the noise floor and M is a margin. In our experiments the margin was set to 15 dB. This value represents a reasonable compromise between the probability of misdetection and the probability of false alarm. The noise floor has been determined by splitting each spectrum of the 1-second sub-records into 1-kHz wide bandwidths and calculating the energy per (frequency) sample according to the Parseval theorem. The smallest of the calculated sub-band energies for all the 9-second record has been assigned to W_i.

The instantaneous spectrum occupancy $\Omega_{ij}(f)$ is defined over the energy spectrum $W_{ij}(f)$ of the sub-record *j* from record *i* at frequency *f* by

$$\Omega_{ij}(f) = \begin{cases} 1, \text{ if } W_{ij}(f) \geq T_i \\ 0, \text{ if } W_{ij}(f) < T_i \end{cases}. \tag{2}$$

The duty cycle D_{ij} is defined through

$$D_{ij} = \frac{\sum_{f \in B} \Omega_{ij}(f)}{N_j}, \tag{3}$$

where N_j is the number of samples of the sub-record *j* from record *i* contained in the sub-band of width *B*.

The D_{ij} are further averaged over *j* in order to calculate the duty cycle D_i in the sub-band *B* for the record *i* and then over *i* in order to find the duty cycle *D* in a larger interval of time. A sub-band is declared free on that interval of time if *D*=0.

In order to illustrate the above presented operations, consider the sub-record spectrum in Fig. 1, which is the energy spectrum of the signal corresponding to the third second of a 9-second record acquired on February 3, 2016, at 10:06:16 (GMT+3). The energy threshold is represented by the red line in Fig. 1. The wideband signal that is very visible is a chirp produced by the Cyprus ionosonde [14].

The short time duty cycle is obtained by applying the thresholding operation on every sub-record and the result is reported in Fig. 2 as a bar graph. The 800-kHz wide spectrum has been split in 266 3-kHz wide sub-bands and the short time duty cycle has been calculated over the sub-bands. The frequency axis in Fig. 2 displays the central frequencies of the sub-bands. As expected, the spectrum occupancy presents a high variability both in time (i.e. sub-record number) and in frequency.

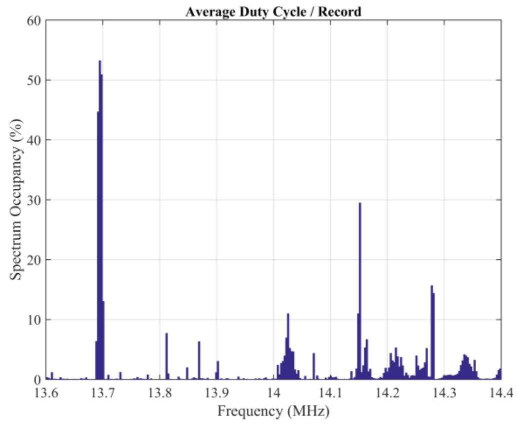

Fig. 3. Duty cycle of a 9-second record.

By averaging the short time duty cycle in time (with respect to the sub-records), the duty cycle for the 9-second record is obtained, Fig. 3. A total number of 29 free 3-kHz sub-bands can be identified in this record, i.e. 10.9% of the total number of sub-bands.

The measured SO values depend on the margin M in (1). In general, this margin is calculated in function of a chosen probability of false alarm. Finding an optimum value for M in the particular conditions given by the location of the measurement site will be subject of future work.

In the next section, we present some results obtained with the outlined procedure applied to a larger quantity of data.

III. Results of SO measurement and Joint Sensing

SO assessment at a specific location has to rely on an extensive measurement campaign. Then, statistical data and models based on neural networks or time series modeling can be inferred [11,15]. At the time of this communication, a large quantity of data has been acquired. However, measurements have to be performed for a longer period before attempting to build a SO model at one location.

We present here few representative results based on some of the measurements. Fig. 4 displays the percentage of free sub-bands over seven hours and a half (0:00-7:30 a.m. local time), for 5 different bandwidths, resulted from measurements performed on February 1st, 2017 for a center frequency of 7 MHz and a bandwidth of 1 MHz. The bandwidths listed in the legend of Fig. 4 are relevant for the emergency communication system to be built (preliminary tests have been already performed). The number of free sub-bands diminishes when the bandwidth increases, as expected, so that a trade-off between bandwidth and availability should be considered. The curves in Fig. 4 have similar shapes, which could be explained by the short-term variations in the propagation conditions.

In Table I, the percentage of 3-kHz free sub-bands are displayed along one hour, at 10-minute intervals, for typical summer and winter days, at night and daytime. Results indicate a much heavier traffic during daytime, when people are active. Also the fast fluctuation of the number of available sub-bands can be noticed, showing the importance of developing a sensing capability for the efficient use of the spectrum.

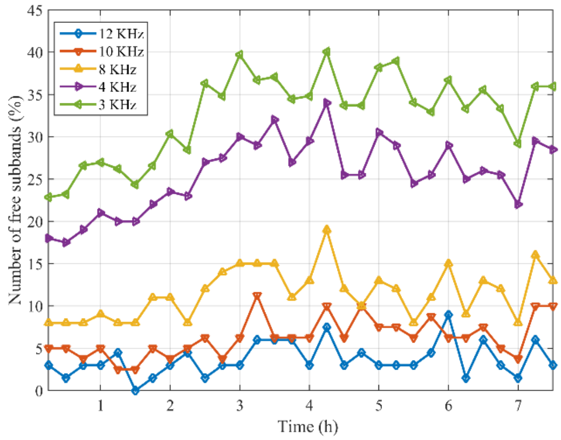

Fig. 4. Percentage of free sub-bands of various widths versus time.

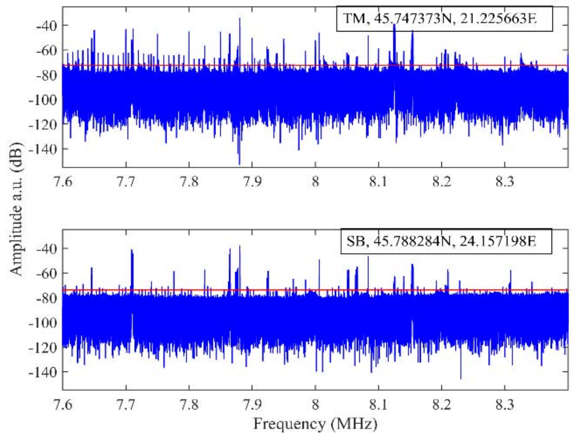

Fig. 5. The same signal spectrum simultaneously acquired in the two different towns for joint spectrum sensing. Thresholds are represented by the red lines.

It is important for the users of the communication system to share the same spectrum availability, so that a joint sensing scheme becomes relevant in this situation. Joint spectrum sensing technique [16, 17] is beneficial against multi-path fading, by taking advantage of spatial diversity and against noise uncertainty, by decreasing the probability of misdetection and false alarm.

TABLE I. Percentage of available sub-bands (%)

Summer	Day	10	40	7	20	5	18
	Night	65	60	53	67	56	47
Winter	Day	23	27	29	47	27	42
	Night	39	40	42	37	41	50

We carried out a preliminary test on joint spectrum sensing using two identical software defined radio (SDR) USRP receiving systems as described in [14], one located in Timisoara-TM (45.747373N, 21.225663E) and the other in Sibiu-SB (45.788284N, 24.157198E), at about 230 km in straight line.

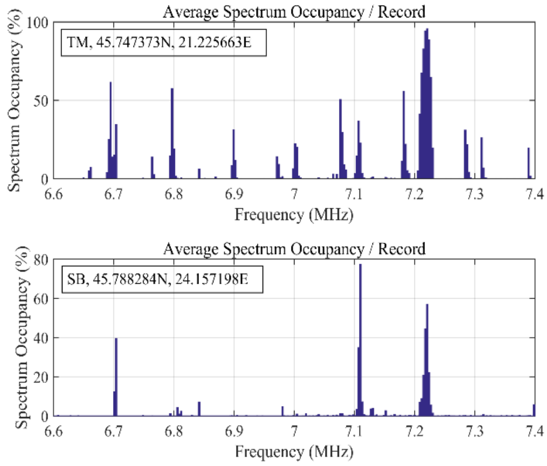

Fig. 6. Average spectrum occupancy in the joint spectrum sensing.

Both USRP devices have been equipped with GPS Disciplined Oscillators (GSPDO) that ensured time synchronization better than 50ns. Fig. 5 shows the instantaneous power spectrum of the signals captured in the two cities on a 800-kHz wide bandwidth centered around 8-MHz central frequency.

For the two received signals, we computed and plotted in Fig. 6 the average SO for a record of 10-second length. Fig. 6 shows some notable differences between the SO values for the two different receiving points (e.g. around 8.12 – 8.13MHz and 8.23 – 8.33MHz), which validates the need of cooperative spectrum sensing in order to reduce interferences as much as possible. This conclusion is confirmed by the data reported in Table II, where percentages of free sub-bands in each second of a 7-second record simultaneously acquisitioned at both locations (February 2nd 2017, 10.55 local time) at various central frequencies in the range 6-10 MHz, are reported.

TABLE II. PERCENTAGE OF FREE SUB-BANDS IN TIMIŞOARA AND SIBIU (%) AT VARIOUS FREQUENCIES

Time (s) / Frequency (MHz)		1	2	3	4	5	6	7
6	TM	31	33	34	32	31	31	24
	SB	19	29	33	28	5	26	34
7	TM	8	22	27	32	30	33	26
	SB	29	35	38	45	38	42	44
8	TM	35	29	33	57	42	62	18
	SB	50	50	52	56	45	49	51
9	TM	29	0	33	48	35	41	0
	SB	75	74	77	74	75	78	71
10	TM	24	27	30	47	28	43	20
	SB	52	56	55	55	0	60	0

IV. CONCLUSIONS

We have presented the measurement procedure and results of the SO in the Western part of Romania. SO has been determined by using an energy thresholding criterion. Joint spectrum sensing in two locations distanced at 230 km has also been approached.

The reported results indicate a high variability of the SO and notable differences between the values measured in the two locations.

Future work will focus on extensive measurements campaigns in view of finding statistical properties and modeling of the SO

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