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Measurements of Short-Time Spectrum Occupancy for Ionospheric Propagation

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***Abstract* – Results concerning short time spectrum occupancy in the 3-15 MHz spectrum range of the High Frequency band (3-30MHz) for a 24-hour period are reported. Measurements have been completed using an USRP equipment and a broadband HF antenna in February – March 2017. Results indicate that convenient free bandwidths exist for short time intervals. These free frequency intervals can be used for opportunistic transmissions in an emergency communications system. Spectrum occupancy measurements can also be considered by authorities when deciding on spectrum allocation.**

***Keywords* – Short time spectrum occupancy, duty cycle, congestion, USRP**

I. INTRODUCTION

Ionospheric propagation of electromagnetic waves provides the opportunity to implement long-range communication links with basic equipment. The large covering area is due to consecutive reflections of waves on ionosphere and ground or on different layers of the ionosphere itself [1].

Ionospheric propagation is influenced by the degree of ionization of the gas layers from the atmosphere. Therefore, Sun cycles, cosmic radiation, solar and terrestrial movements and meteorological conditions create not only multiannual, annual, seasonal, weekly and daily trends, but also random variations of the propagation conditions [2].

Electromagnetic waves from the High Frequency (HF) spectral region (3-30 MHz) travel through the ionospheric channel. This spectral range is regulated and allocated by national authorities, like all usable regions of the radiofrequency spectrum [3]. Nevertheless, large portions of the spectrum are not continuously occupied, leaving space for opportunistic use [4]. This includes cognitive radio and communication in emergency situations [5,6].

A clever planning of medium access, spectrum sensing and spectrum management in a communication network requires knowledge of the spectrum occupancy (SO) [5]. Depending on the requirements of a specific application, the SO can be assessed for longer or shorter periods of time. Since we are targeting the deployment of a HF communications network to be used in emergency situations, we are interested in all kinds of results on SO. In this paper, we report results on short-time SO measurements obtained at the location of Timişoara, Romania (45.747370 N, 21.225863 E). The reported results can be used also by national authorities for further decisions on spectrum allocation.

II. RELATED RESULTS IN THE LITERATURE

SO measurements in the HF range have been performed starting from the eighties of the last century in various parts of the world: UK, USA, Canada, Northern Europe, Germany, Australia, the Eastern Mediterranean region, various other countries of Europe etc (see e.g. [4], [7-9] and the references therein). The motivation for this work was similar to ours: deploying point-to-point communication networks for emergency situations or for regions lacking infrastructure on one hand and assessing frequency allocation on the other hand. The goal is to use in a planned or opportunistic way temporarily free bands of the frequency spectrum. Recommendations on performing SO measurements have been issued [10].

Results on SO measurements can be expressed in terms of statistics or models [5]. A linear regression model has been developed [11]. Other models rely on neural networks [12] and time series [7]. Both ways of reporting results can be found in the HF SO measurement related literature. Models allow to express in a compact way the SO pattern at a location and can be readily incorporated in a model or simulator of the communications channel.

SO is dependent on location, time and frequency band. As expected, large urban areas are more occupied than rural, remote ones. Measurement of daily variations indicated a smaller SO during night time, when lack of solar radiation lowers the degree of ionization. Higher SO occurs at lower frequencies, since the maximum usable frequency (MUF) decreases at night fall. SO quickly increases in the morning, when people start daily activities and signals from remote regions are propagated by the newly built-up ionosphere. The occupied frequency range also increases during daytime. Following variations of solar radiation and Sun spot cycles (approx. 11 years), SO exhibits seasonal and yearly trends.

The variability of the SO implies that statistics and models are necessary on different time scales. In this paper, we are reporting measurement results of SO on a small-time scale, which assess daily variations. Larger time scales are considered elsewhere [13].

III. DESCRIPTION OF THE METHOD

SO measurement requires an antenna and a receiver. According to [5], the effect of the equipment on measured SO statistics is minor if it works "reasonably well". We have used a Diamond WD 330 J omnidirectional broadband antenna and a Universal Software Radio Peripheral (USRP) model NI USRP-2950R, Dual RF Transceiver equipped with LFRX (0-30MHz) daughterboard [14]. A spectrum analyzer could also be used as a receiver. However, the USRP allowed for the acquisition of the sampled version of the signal captured by the antenna so that several signal processing procedures could be conveniently applied. Furthermore, the communications network [6] will be built around USRP receivers.

The acquisitioned signal (records) had a duration t_r(e.g. t_r=5 seconds) and a bandwidth B_r (e.g. B_r =1 MHz) centered on a frequency f_c from the HF band. The central frequencies were chosen having in view the necessities of the communications network. Every record has been split off-line in sub-records of duration τ (e.g. 1 second), $t_r=M\tau$.Records have been repeated N times with a period T(e.g. T= 10seconds) for a certain duration, e.g. 1 hour.

The power spectrum of each sub-record has been numerically calculated, based on the Discrete Fourier Transform and the Parseval theorem. Therefore, when counting from the start of the record, time of sub-records is indexed as

$$t_{mn} = m \times t_r + n\,T,\; m = 0..M-1,\; n = 0..N-1 \qquad (1)$$

Each sub-record has been split into several sub-bands of bandwidth B = 3 kHz (the remaining frequencies at the edges have been discarded). The value of B has been selected for convenience, as required by the communications network [6, 8, 9]. We calculated the SO on each cell having a duration τ and a bandwidth B, i.e. $SO(t_{mn}, f_k)$, where f_k denotes the center frequencies of the sub-bands, k=1..333.

The calculation of the SO has been based on an energy detection criterion [5], which relies on a threshold depending on frequency $T(f)$. A cell has been declared occupied (i.e. SO=1) if at least one sample in the power spectrum was greater than the threshold and free (i.e. SO=0) in the opposite case.

The threshold can be written as [5]:

$$T(f) = W(f) + M \qquad (2)$$

where $W(f)$ is the noise floor and M is a fixed margin.

Ionosphere communications are affected by cosmic, atmospheric and man-made frequency-dependent noise. The last component depends also on time, making the noise floor difficult to estimate. Therefore, we have considered a median filtering of the power spectrum of the sub-records instead. The procedure is illustrated in the next Section. By relying on median filtering, both time and frequency variations of the floor can be traced. A value M=8 dB has been chosen as a convenient compromise between misdetection and false alarm.

The average over time of the spectrum occupancy yields the *duty cycle* of a sub-band:

$$DC(f_k) = \langle SO(t, f_k) \rangle_t \qquad (3)$$

The average over frequency of SO gives the *congestion* of the 1-MHz channel

$$CC(t_{mn}) = \langle SO(t_{mn}, f_k) \rangle_f \qquad (4)$$

Measurement results of the above introduced quantities are reported in the next Section.

IV. RESULTS AND DISCUSSIONS

An example of the power spectrum of a 1 second record covering a bandwidth of 0.4 MHz around a 3.5-MHz center frequency is plotted in Fig. 1. Moving average of the signal power spectra and the detection threshold are also shown.

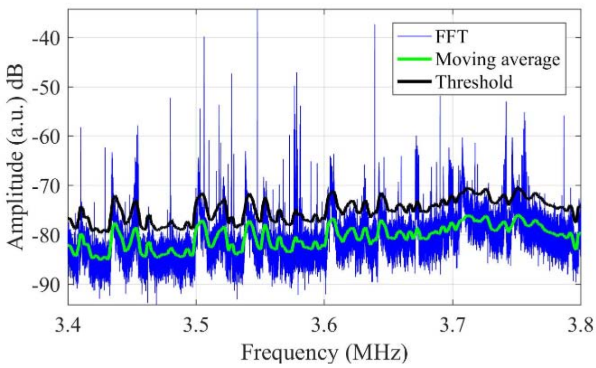

Fig. 1. Power spectrum of asignal around 3.6 MHz(blue), moving average value (green) and detection threshold (black).

Fig. 1 reveals a relative high spectrum occupancy, usual for the lower range of the HF spectrum. Fig. 1 also reveals a nonuniformity of the background noise power spectrum, justifying the use of the moving average for threshold computing.

Fig. 2 displays the short time SO for a 100 sec time interval, starting at 20:15:00 (local time). For clarity, only 100 KHz from the total bandwidth of 1 MHz is plotted.

Short time SO in in Fig. 2 shows the existence of free regions of the spectrum having time duration and frequency bandwidth that are adequate for burst transmissions on an opportunistic radio link.

Fig. 3 plots the congestion as defined in (4), for a time interval of 1000 sec starting at 20:00:00 (local time). The central frequency is 14 MHz and the bandwidth is 1 MHz.A very low activity was detected in this frequency band at the considered time, except for some spikes and a constant activity between seconds 300 and 850.

The duty cycle calculated according to (3) for the same signal is plotted in Fig. 4, for 1 hour, staring at 19:30:00 local time. Duty cycle allows to find small bandwidths that are free for almost the entire time interval (e.g. in the first part of the spectrum, between 13.5 and 13.6 MHz).

Fig. 5 plots the duty cycle as defined in (3) for a very large part of the HF band (3 – 25MHz), for a 10-minute time interval, starting at February 28, 10:00:00 local time. There is an intense activity at lower frequencies and a very low occupancy above 18 MHz motivated by propagation characteristics. The detail in Fig. 5 shows that, even in the region with high occupancy, small free sub-bands suitable for an opportunistic link can be found.

For a signal centered at 14 MHz and a bandwidth of 500 kHz, we made over 7600 1-second recordings, with a 2-second interval between successive recordings. Fig. 6 plots the empirical cumulative density function (CDF) of the number of free 3KHz sub-bands in the 500 KHz bandwidth at two-time instant spaced by 300 sec. CDF reveals a very high probability (around 0.85) to find at least one free sub-band in the considered bandwidth. With a probability of 0.5 we find more than 7 free 3 KHz sub-bands. Fig. 5 shows a small variation of the number of free sub-bands in a short time interval.

For the same signal, Fig. 7 plots the CDF of the number of free successive 1 KHz and 3KHz free sub-bands at 14.1 MHz for the entire observation time.

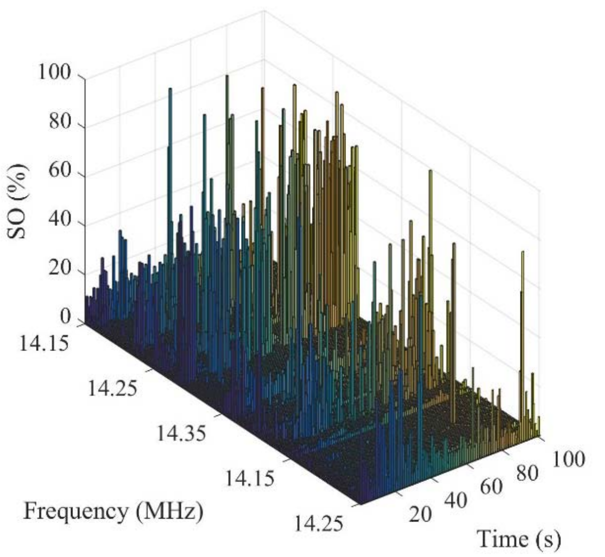

Fig. 2. Short time spectrum occupancy details for 14.15 – 14.25 MHz and 100 s.Time count start at 20:15:00.

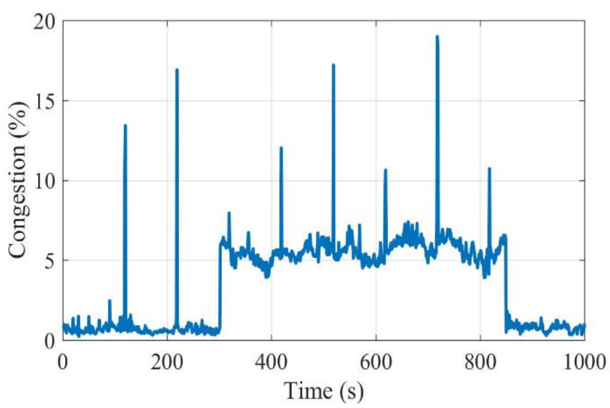

Fig. 3. Congestion plot for 1000 sec for 1 MHz bandwidth around 14 MHz central frequency. Time count start at 20:00:00.

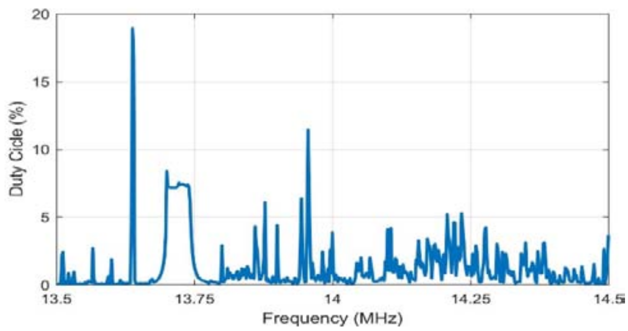

Fig. 4. Duty Cycle for the 1 MHz banwidth at 14 MHz central frequency for 1 hour starting at 19:30:00.

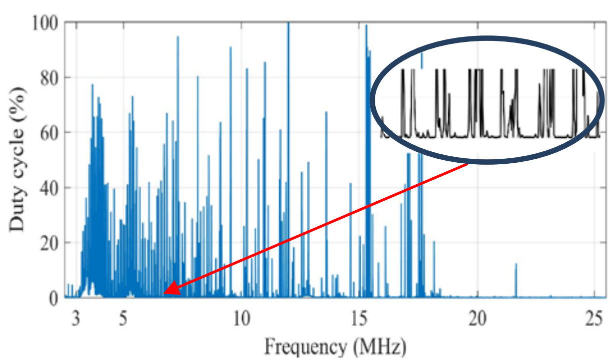

Fig. 5. Duty cycle for 3 – 25 Mhzbandwidth for 10 min, starting at 10:00:00

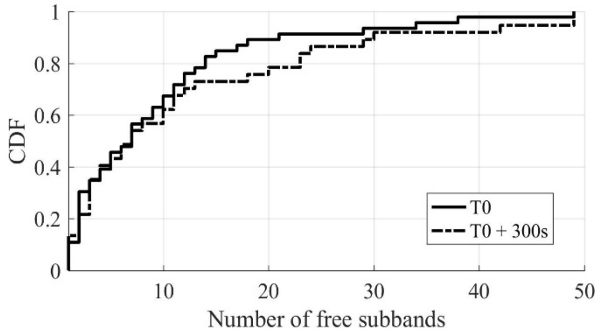

Fig. 6. Empirical CDF of the number of free 3KHz sub-bands in 500KHz bandwidth at two time moments

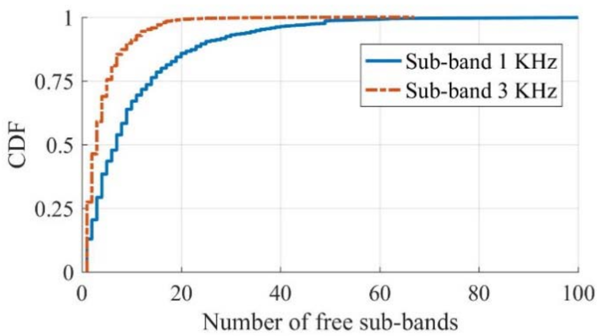

Fig. 7. Empirical CDF of the number of free 1 KHz and 3KHz sub-bands at 14.1 MHz for 6 hours

Fig. 6 and 7 show that both in frequency and time the probability to find free sub-bands is relative high. As expected, the higher the desired free bandwidth, the lower the probability to find.

V. CONCLUSIONS

In this paper, we report results on short time SO in the 3-15 MHz spectrum range of the HF band.

Measurements have been completed by using an USRP equipment and a broadband HF antenna. SO has been calculated by means of an energy detection thresholding criterion. The threshold has been computed using a moving average of the signal power spectrum and a suitable noise margin.

Congestion and duty cycle have been defined and computed in order to find small bandwidth slices of the spectrum that are free of signals. The slices can be used for opportunistic transmissions in an emergency communications network.

Knowledge of SO may support spectrum allocation decisions taken by regulating authorities.

VI. ACKNOWLEDGMENT

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