Survey on Spectrum Utilization in Europe: Measurements, Analyses and Observations

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***Abstract*—This paper presents major results and comparisons of radio spectrum utilization measurements that have been carried out in three different locations in Europe, namely in the suburb of the city of Brno in the Czech Republic and in the suburb and the city of Paris in France during years 2008 and 2009 respectively. The analyzed radio bandwidth extends from 400 MHz to 3 GHz. The measurement method is based on the energy detection principle. Utilization performance and behaviors of major wireless communication systems and primary wireless system within different regions and different environments are investigated here. Our analyses pick out correlations between spectrum utilization within different regions and summarize common observations and physical aspects that will have to be considered in the future radio spectrum management to assure efficient spectrum utilization.**

Keywords-cognitive radio, dynamic spectrum access, spectrum utilization measurements.

I. Introduction

THE radio spectrum is a particular natural resource, as it is non-exhaustible, however considered as a scarce resource due to the way we use it. Therefore, to ensure the rational, fair and economical use of the spectrum, relevant authorities such as ITU (International Telecommunication Union), ČTÚ (Czech Telecommunication Union), FCC (Federal Communications Commission), etc. have been established. Their mission is to ensure interference-free operations of wireless systems by means of applying Radio Regulations and Regional Agreements in the whole world. Actual wireless communication systems are mainly based on the fixed radio resource allocation. This means that a certain portion of the radio spectrum is assigned or licensed to other parties on long term basis and covering large regions like whole countries. This approach provides ultimate protection from harmful interference in an allocated radio band, but on the other hand, as many measurement studies reveal [1], [2], the fixed radio frequency allocation may lead into significant underutilization of the radio spectrum due to very sporadic usage across different geographical regions as well as in different periods of time. These results lead us to reconsider the traditional centralized administrative approach to spectrum management and moreover, it opens space for novel and more efficient wireless communication systems based on the dynamic spectrum access, such as cognitive radios.

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An old management adage that is still accurate today says "*you can't manage what you don't measure"*. Therefore, to estimate the degree of the radio spectrum utilization in various geographical regions and hence to reconsider principles of actual radio spectrum management, a campaign of experimental measurements has been conducted. The main objective of these measurements has been to determine the typical behavior of the radio spectrum usage and to find out correlation and usage patterns within different radio bands and different regions. Based on such knowledge, appropriate measures should be taken in the process of the radio spectrum reallocation. In total, three different locations in two countries have been analyzed, namely in the Czech Republic and in France. The Section II briefly presents measurement locations, measurement equipment as well as the measurement method and processing of measured data. The Section III reveals results of individual measurement campaigns. The last section summarizes and compares observations and future plans.

II. Measurement Conditions

A. *Measurement Locations*

The degree of the spectrum usage has been investigated in following regions:

- Region no.1: northern suburb of Brno, Czech Republic.
- Region no.2: eastern suburb of Paris (ESIEE Paris), France.
- Region no.3: city of Paris, near "Place de la Nation".

The first set of measurements was conducted in the northern suburb of Brno (medium industry town with 380,000 inhabitants) in the Czech Republic in July 2008. The second and the third set of measurements were carried out in France, namely in the eastern suburb of Paris, and in the city of Paris near "Place de la Nation" in February and December 2009 respectively. In the first two regions, the measurement equipment has been installed on the rooftop of a seven and five-storey stand-alone departmental buildings with a clear 360° view. In the last case, the measurement equipment has been installed on the top floor of a five-storey house-building.

B. Measurement Equipment and Measurement Method

The measurement method is based on the energy detection principle. The RF signal has been captured by a wideband log-periodical antenna and continuously scanned by a spectrum analyzer. Since the measurement log-periodic antenna exhibits relatively high directivity (half power beam-width at 3 GHz is about 60°), the omni-direction effect in the horizontal plane has been achieved by means of rotation where a single set of continuous 24-hours measurements corresponds to a single direction. Then, the antenna is turned through a relevant angle and a new direction is analyzed. In total, six directions have been analyzed in individual regions and then, six-day maximum values have been taken for further processing. Spectrum analyzers (Rohde&Schwarz FSP and Tektronix RSA3408A) have been controlled remotely using Matlab Instrument Control Toolbox through the USB/GPIB interface. The whole analyzed band has been divided into 20-MHz sub-bands and analyzed using a given RBW. Each sub-band is represented by a given number of samples spaced by 160 kHz and 125 kHz (see measurement set-up summary in the Table I).

TABLE I. MEASUREMENT SET-UP

Region	Analyzed band [GHz]	No. of 20-MHz sub-bands	RBW [kHz]	Sample spacing [kHz]	Sweeps per day
No.1	0.1 – 3	145	3	160	144
No.2	0.4 – 6	280	55	125	215
No.3	0.1 – 3	145	55	125	645

III. PRINCIPLES OF ANALYSES

The overall plot of spectrum occupancy in the suburb of Brno is depicted in Fig. 1. The upper plot presents the maximum power obtained during the six-day campaign of measurements. The second plot shows the power profile that corresponds to the average power of the upper plot. This figure shows the overall performance of spectrum occupancy with notably different activity in different time periods, however, it doesn't provide any concrete information for further evaluation. To get more detailed information about the spectrum usage, the whole frequency band has been divided into narrower sub-bands and analyzed independently. The utilization of selected bands has been defined by the *duty cycle* parameter, which specifies the fraction of time the band is used. The duty cycle has been calculated as a ratio of the number of samples with power level superior to the power threshold $N_{P>threshold}$ and the total number of samples N_{Total} as indicated in Eq. 1. This method has been applied in all regions.

$$\text{Duty cycle} = N_{P>threshold} / N_{Total} \quad (1)$$

Determination of the decision power threshold is a critical issue. An excessive threshold may lead to overlooking potential activity within the band, but on the other hand, too low values may result in false alarm due to the background noise. In order to overcome this problem, different thresholds for different frequency bands have been defined, depending on the level of the background noise. The power threshold that determines the occupancy of a frequency sample has been set in most cases to 7 dB above the average value of the background noise measured within the band of interest. 7 dB has been chosen as the optimal value based on long term observation of the background noise. However, in some cases, the threshold has been deliberately decreased in order to pick out very weak signals otherwise considered as background noise (e.g. wireless systems in the 2 GHz frequency band, see Fig.2 *e)* and *f)*).

IV. MEASUREMENT RESULTS

Following figures present analytical results for individual frequency bands. Due to space constraints imposed on this paper, only limited results from the region no.3 are presented here (a complementary comparative summary from other locations is presented afterwards). Each trio of plots represents respectively the power profile, frequency samples considered as occupied and the corresponding duty cycle. The decision threshold is given in individual plots of the power profile.

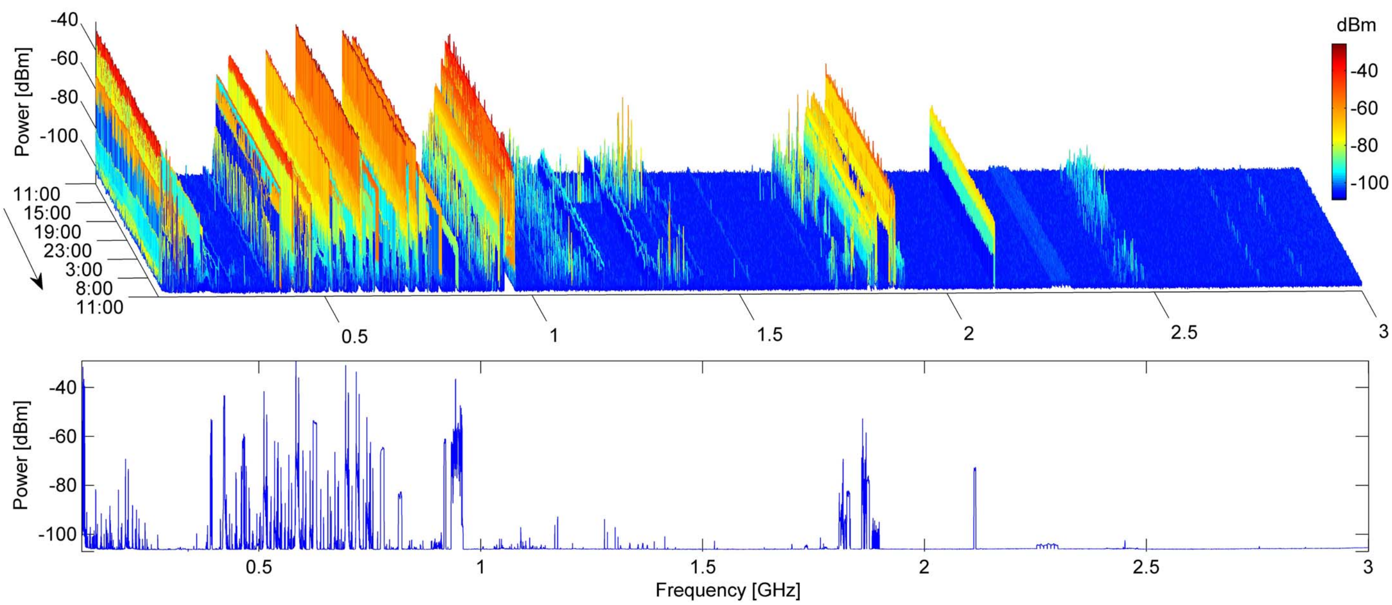

Figure 1. Overall plot of the 24-hour maximum spectrum usage measured over six days in the suburb of Brno, Czech Republic.

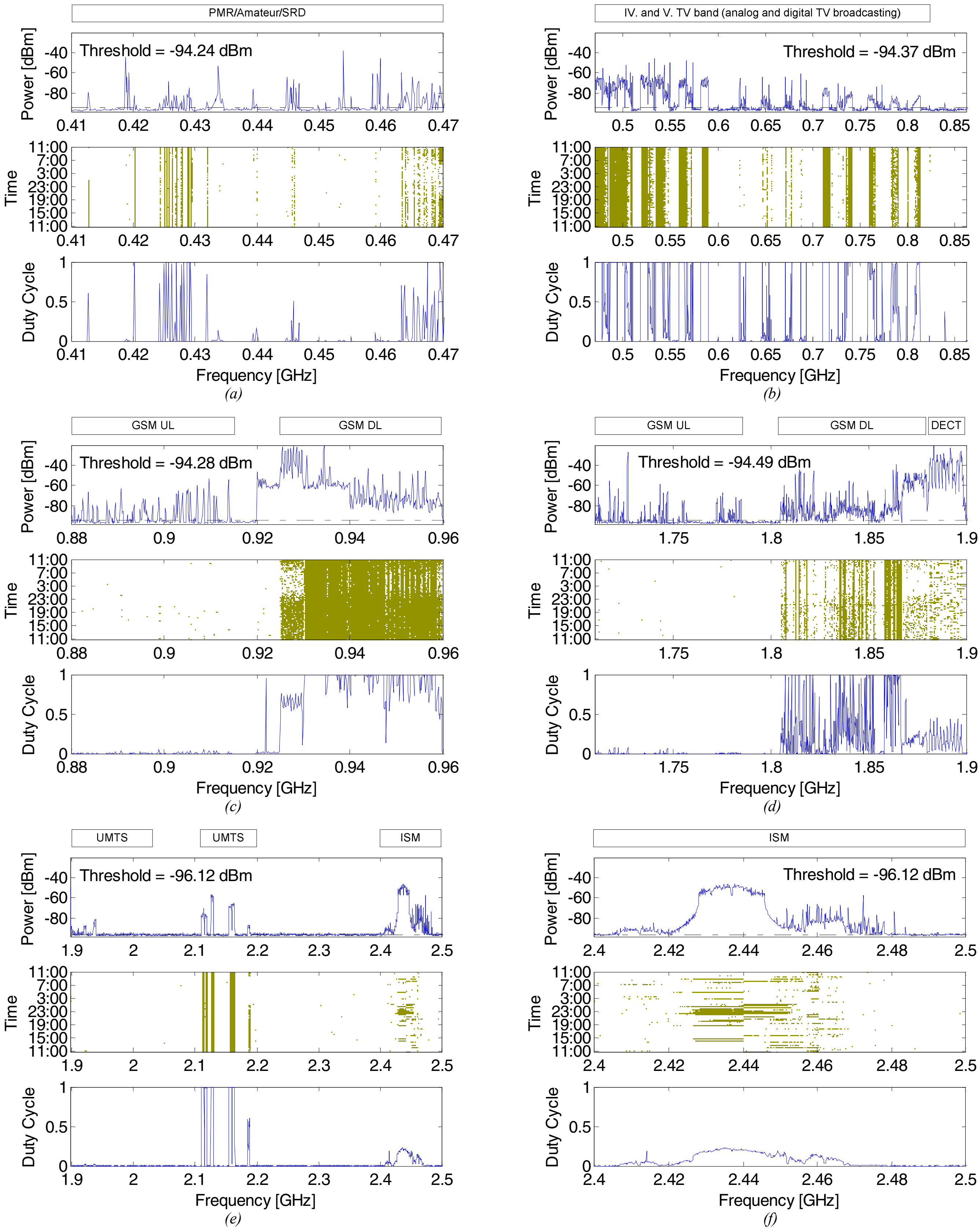

Figure 2. Spectrum utilization analyses based on a continuous, six-day monitoring campaign in Paris, near "Place de la Nation" (N 48°50'44", E 2°23'42"). Individual radio bands cover PMR/Amateur/SRD band *(a)*, 4th and 5th UHF TV band *(b)*, (E-)GSM 900/1800 and DECT *(c)* and *(d)* - note the drop of activity within downlink (DL) and uplink (UL) channels during the night. Last two plots *(e)* and *(f)* depict spectrum usage in the 2GHz band that accommodates among others the UMTS TDD/FDD/Satellite and wireless application in the unlicensed ISM band.

Fig. 2 *a)* depicts spectrum usage in frequency band from 410 to 470 MHz. This band exhibits very diverse spectrum usage in individual regions. Namely in the Czech Republic, this radio band accommodates two CDMA2000 systems in duplex bands 410-413 MHz (UL)/420-423 MHz (DL) and 451.5-455.54 MHz (UL)/461.5-465.54 MHz (DL), which in turn increases the overall usage of this frequency band compared to other regions (19.7%, 9.83% and 6.37% in regions 1, 2 and 3 respectively). A comparative plot is depicted in Fig. 3.

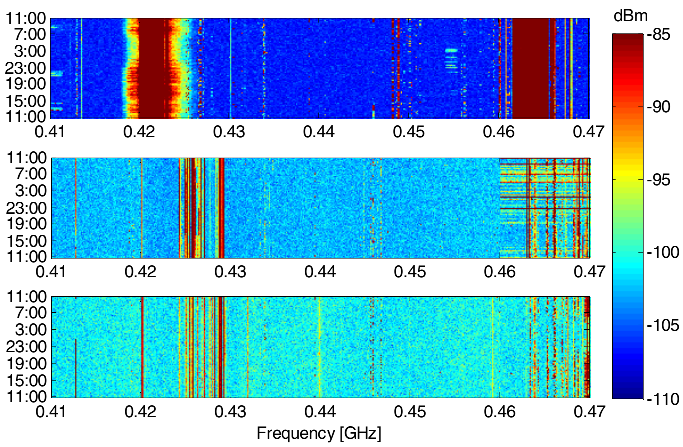

Figure 3. Usage of the 400 MHz band in regions 1, 2 and 3 respectively.

Usage of the UHF TV band in Paris is depicted in Fig. 2 *b)*. A comparative plot is shown in Fig. 4. Allocation of the 4th and 5th TV band differs in both countries. In the Czech Republic, the allocation extends from 470 MHz to 862 MHz (49 x 8-MHz channels), while in France, the upper limit of the 5th TV band is 830 MHz (45 x 8-MHz channels). The resulting TV spectrum utilization has been defined in two following ways:

1) As a ratio of the number of samples superior to the threshold level to the total number of samples in a given radio band. This value corresponds to the average duty cycle.

2) As a ratio of the number of TV channels considered as occupied to the number of available channels. In the case of the analog TV signal, the whole 8-MHz TV channel has been considered as occupied when both, the main carrier and the audio sub-carrier exceeded the threshold.

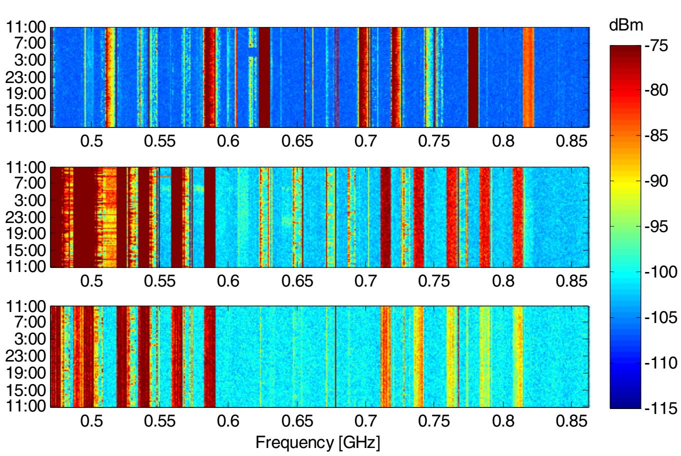

Figure 4. Usage of the UHF TV band in regions 1, 2 and 3 respectively.

A summary of the utilization in the TV band is presented in Tab. II. The difference between that two calculation methods shows that the first general method may lead to underestimation of the spectrum usage even though distinct TV signal features are present. Hence, to provide a higher degree of protection to the TV broadcasting, the second method should be considered for more appropriate spectrum sensing.

TABLE II. SUMMARY OF SPECTRUM USAGE IN THE UHF TV BAND

Region	Allocation [MHz]	No. of "occupied" channels	Utilization [%] *(method 1)*	Utilization [%] *(method 2)*
No.1	470 – 862	20	21.2	40.8
No.2	470 – 830	28	44.9	62.2
No.3		23	29.9	51.1

It can be seen that the precious UHF TV band presents a great reuse opportunity in both countries. Namely in Paris, only 23 8-MHz channels have been considered as occupied, which in turn results in 176 MHz of unused or underutilized frequency spectrum. In the Czech Republic, our analysis has revealed that a band of 232 MHz within the TV band is unused.

Figures 2 *c)* and *d)* show utilization of the (E-) GSM 900, GSM 1800 and the DECT system. Regional results of the (E-) GSM 900 are depicted in Fig. 5 along with corresponding average power plots that clearly indicate the drop of activity during the night (23:00-7:00 in Brno, 00:00-8:00 in France). This does not concern DL signaling channels that are transmitted continuously. Same trends have been observed in the GSM 1800 system. DL channels of both systems exhibit much higher degree of utilization compared to UL channels. This is explained as a result of the position of the measurement antenna and the fact that the power transmitted by base stations is significantly higher compared to user terminals that are not located in the line-of-sight to the measurement antenna. Even though the UL bands appear as underutilized, the activity of DL channels dedicated to voice transmission indicates that paired UL channels in a given cell are occupied as well. Therefore, to estimate the global usage within a given cell, an UL band associated to the occupied DL paired band should be considered as occupied. On the other hand, the apparently underutilized UL radio band may present a reuse opportunity for low range CR devices operating in a specific area and under

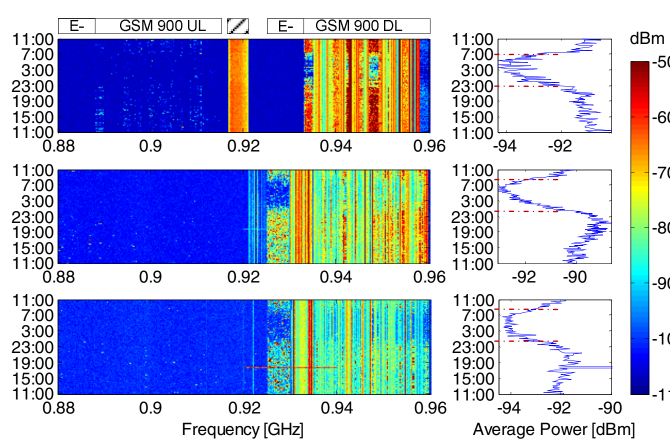

Figure 5. Utilization of the (E-) GSM 900 in all regions. Right-hand plots present corresponding variation of the average power as a function of time.

specific power constraints (e.g. indoor environment, underground, opposite side of the cell, etc.). Summary of the spectrum usage in individual regions based on the latter is presented in Tab.III. Besides the GSM, Fig. 5 shows UMTS DL channel that is employed in the Czech Republic in the band 917-920.8 MHz (pair band to the UL band in 872-875.8 MHz).

TABLE III. SUMMARY OF SPECTRUM USAGE IN BOTH GSM BANDS

Region	System	Utilization [%]
No.1	(E-) GSM900 / GSM1800	38.0/22.0
No.2		47.9/29.3
No.3		44.4/15.6

Figures 2 *e)* and 2 *f)* present utilization performance in the 2 GHz radio band. Regional results are shown in Fig.6 and summarized in Tab. IV. This band accommodates UMTS TDD/FDD/Satellite, IMS applications and moreover, MMDS (only in the Czech Republic). The reason for very low utilization namely in the UMTS TDD and the FDD UL band is attributed to the measurement method itself. The energy detection method cannot efficiently detect wideband signals such as UMTS. To detect noise-like wideband signals, more sophisticated methods have to be employed (e.g. feature detection [3]). As in the previous case where the active GSM DL voice channels indicated the "unseen" activity in the UL band, similar considerations can be adduced here. Very low usage has also been detected in the unlicensed ISM band even though the threshold has been shifted down to 5 dB above the average background noise level. The reason may be seen in the specific measurement location: most of wireless applications in this band use directional antennas pointing downward to cover defined hot-spots and hence, the measurement antenna located on the roof and pointing only horizontally can hardly detect the ground activity. Moreover, propagation properties of radio waves in this band are worse compared to lower frequencies.

TABLE IV. SUMMARY OF SPECTRUM USAGE IN UMTS AND ISM BANDS

Region	System	Utilization [%]
No.1	UMTS/ISM	2.1/0.2
No.2		10.8/4.5
No.3		11.1/7.63

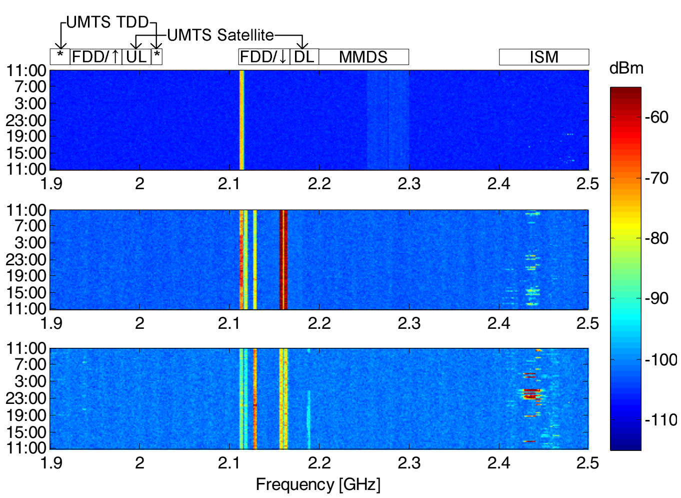

Figure 6. Usage of the 2 GHz radio band in regions 1, 2 and 3 respectively.

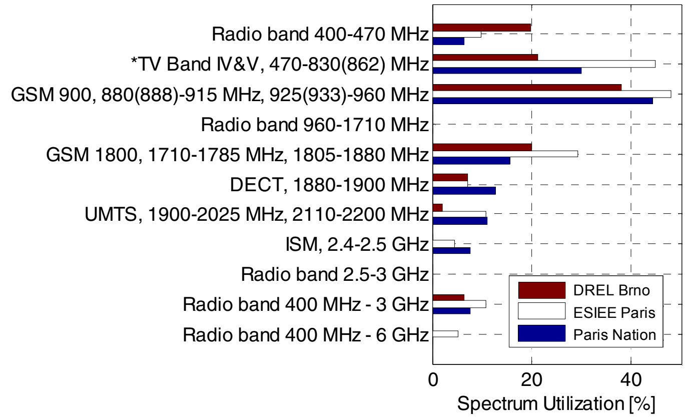

Figure 7. Comparative summary on regional spectrum utilization.

V. CONCLUSION

It has been demonstrated that significant reuse opportunities do exist in the analyzed radio spectrum. Even though our analyses do not offer an accurate estimation of the spectrum usage for certain communication systems (wideband CDMA, fast time-varying signals) and are limited to very specific environments, several general observations have been obtained. It has been found that although the urban density in individual regions is very diverse (2.2-million city vs. suburb of a 400-thousand town), the resulting global spectrum usage in the analyzed frequency band is very similar (the overall utilization in the band 400 MHz-3 GHz in regions no.1, 2 and 3 is 6.5%, 10.7% and 7.7% respectively). One reason is that in the Czech Republic, additional wireless systems are employed in less usual frequency bands (namely two CDMA2000 systems in the 400 MHz band, UMTS in the 900 MHz band or the MMDS), which in turn compensates the expected lower utilization of e.g. TV, ISM or UMTS bands. Our measurements in the ISM band confirm that spectrum sharing under defined power restrictions offers significant frequency reuse opportunities and may go smoothly without creating spectrum interference and congestions. This approach to the spectrum management is therefore suggested as a candidate solution to certain underutilized frequency bands.

This paper has introduced a comparative study of the short-term spectrum usage in different regions however, this work remains preliminary. To determine more objective spectrum utilization, additional and more sophisticated methods will have to be employed and other locations will have to be analyzed. This includes for example detection of wideband signals (feature detection, noise analyses etc.), detection of fast-varying signals, long-term measurements to determine activity trends in different time periods and periodical trends (day/night, periodical activity of satellite radio links and radars etc.) or parallel indoor vs. outdoor measurements.

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