

# Broadband Spectrum Survey Measurements for Cognitive Radio Applications

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**Abstract.** *It is well known that the existing spectrum licensing system results in a gross under-utilization of the frequency spectrum. Spectrum background measurements – spectrum surveys – provide useful data for spectrum regulation, planning or finding frequency niches for spectrum sharing. Dynamic spectrum sharing as a main goal of cognitive radio (CR) is the modern option on how to optimize usage of the frequency spectrum. A spectrum survey measurement system is introduced with results obtained from a variety of markedly different scenarios allowing us, unlike other studies, to focus on wideband and fast spectrum scans. The sensitivity of the receiver is no worse than -113 dBm in the whole band. The utilization of the frequency spectrum is analyzed to prove its under-utilization and to show spectrum sharing opportunities. This was shown to be true in the frequency band higher than 2.5 GHz. A comparison with other spectrum survey campaigns is provided.*

## Keywords

Spectrum survey, spectral measurement, cognitive radio, spectrum allocation.

## 1 Introduction

Spectrum surveys are important from several perspectives. Spectrum regulators need to know which frequencies are used at measured locations, and which power limitations have to be complied to. Our actual topic of interest for wireless developments is Cognitive Radio (CR) [1]-[3] which is primarily based on spectral sensing to help manage dynamic spectral access [4]-[7]. There are defined primary and secondary users [1] in cognitive systems. The primary users have the privilege of exploiting their part of the spectrum while the secondary users (or cognitive users) use the primary user's spectrum only when it is not occupied, that is to say in a white space. White spaces (the part of the spectrum which is not used at a current location or time [8], [9]) are unique opportunities for overlay spectral sharing. It is necessary to mention that spectrum sensing should be done in real time to provide the actual information required for the cognitive cycle, or, by

cooperative sensing where information is provided by cognitive nodes [10]. Moreover, cognitive radio needs to deal with hidden terminal phenomena [11]. This problem is caused when the primary user is not detected (due to low energy levels) and the cognitive engine uses an occupied frequency for secondary users.

Sometimes it is not possible to make a spectrum sensing operation and the CR should communicate with another cognitive node, or, it is possible to prepare an empirical model which provides the typical behavior of the spectrum at the current location and time. We distinguish between spectral sensing and a spectral survey as spectral sensing is used primarily in the cognitive systems (full – Mitola's – CR) [2]. However, a spectral survey generally focuses on spectral data collection. These data are used "offline" in many ways such as in cognitive engine training or collision management.

In fact, frequency spectrum background measurement is not a novelty in the field. In a cognitive radio system spectrum sensing is mostly performed by the techniques listed [12] (or by a combination of them):

- **Energy detection** – Does not need knowledge of the detected signal and has low costs, but cannot work with low SNR and cannot distinguish users sharing the same channel.
- **Matched filter** – Optimal detection performance, low computation costs, but requires knowledge of the primary users.
- **Cyclostationary detection** – Robust to interference and low SNR, but also requires partial information of detected users.

It should be mentioned that there are several working cognitive test-beds using matched filters for specific frequency bands [13]. The simulation of cognitive radio processes is based on spectrum survey data, which is the reason why this type of measurement is important.

The spectral survey system presented is, for its complexity, based on energy detection – no knowledge about detected signals is necessary. Moreover, in contrast to other measurement campaigns, the system presented focuses on both fast changes in wideband systems and

overview spectrum measurement. The presented measurement system enables the user to scan more than 2 GHz per 1 s with sufficient sensitivity to measure all data in a row which means that there is no interruption in broadband measurements due to switching the antenna or changing the system parameters. One antenna enables you to measure a wide range of frequency samples (300 kHz – 10 GHz) and the portability of the system is another advantage. The measurement system focuses on the output of two main results. Firstly, the fast snapshots of the spectrum are used to calculate utilization in the particular bands (channel usage). Secondly, spectral data, from the overview, calculates not only utilization of the spectrum but also the dependence of spectrum utilization during the daytime. Both of these measurement outputs should be used for cognitive system training [1], [14].

This paper is organized as follows. In the next chapter, the measurement system, measured scenarios, calibration and post-processing procedure are described. The third chapter introduces the measurement results at several different locations. Finally, conclusions are drawn in the last section.

## 2 Measurement Survey

The spectrum survey was defined as an offline spectrum background measurement for future analysis. The measurement campaigns were conducted in completely different locations to obtain general data with rural, suburban, urban and special case scenarios. To reach maximal credibility of the measurement, data were collected at the same place at different times of day.

### 2.1 Measurement Setup

The presented system (Fig. 1 and Fig. 4) measures data in a row so that the whole band is measured without interruption (antenna changes, gain control, etc.). A fast, wideband receiver (Rohde & Schwarz PR100 [15]), a specially designed double-dish antenna for wideband measurements (30:1 bandwidth) [16], 2m SMA cable with maximal insert attenuation 2.5 dB on measured frequencies and specially designed software to set up the receiver and manage data storing are used for the measurement.

The controlling software uses PR100 [17] native commands to manage measurements allowing us to set various types of parameters such as resolution bandwidth (gap between two spectral lines) and measurement bandwidth. The other key parameters used in our measurement system are duration of the measurement ( $t_{duration}$ ), which described how long the measurement was performed, and measure time ( $t_{measure}$ ), which defines the duration of collecting data for each measured frequency point. The worst noise floor of the receiver for the whole band was calculated as -123 dBm for RBW 1.25 kHz and -113 dBm for RBW 12.5 kHz). The sensitivity calculated from the receiver data sheet [17] was the worst case for the

whole band. Data from the receiver were sent through an Ethernet interface to the controlling PC, where they were stored for further analysis.

The main advantages of our measured system are its portability (the system could work without electricity for more than 4 hours), speed and resolution.



Fig. 1. Measurement system.

### 2.2 Scenario Definitions

The purpose of the spectrum survey was to determine spectrum utilization. Under-utilized sections of the frequency spectrum could be evaluated as white spaces and used by a cognitive engine for spectrum sharing [2]. There were several measured campaigns for outdoor scenarios [18]-[20], but it was more important to have indoor data as well as this is a target area for cognitive radio systems. Moreover, fast and wideband results are important for spectrum sharing simulations and these aspects justify the presented measurement. Generally, measurements were divided into two groups according to the data which we are interested in:

**Fast spectrum scanning (FS)** – designed to detect fast changes in the frequency spectrum in time. In this type of measurement, we focused on specific frequency bandwidth (GSM, UMTS and Wi-Fi) with limited sensitivity (the higher the sensitivity, the lower the speed) for a shorter period of time (an hour) in order to study white spaces in a limited frequency bandwidth or the changes in a particular wireless system.

**Overall spectrum scanning (OS)** – it was designed for optional sensitivity scans through a wide band. Changes in time were not so important and were not the crucial parameter as we were focused on the overall spectrum situation. It was necessary to make long-term measurements (lasting several hours) to achieve a sufficient number of cycles. For this type of measurement, we were not able to use the full capacity of the scanning speed because when using an optimal setup, files with measured data exceed the storage size available. The longer time frames were performed to study time dependence on a large scale.

The measurements were further divided according to duration:

**Short-term (ST) measurement** – this measurement is performed for a limited time. Both fast spectrum sensing and overall spectrum sensing are possible in this mode. The typical duration is several hours (maximum duration of the measurement without electricity was 4 hours).

**Long-term (LT) measurement** – is designed for a very long time period (days). It is physically impossible to store an unlimited amount of data so measured data reduction is necessary. This reduction should be done for example by increasing  $t_{measure}$ . This type of measurement is mainly used for overall spectrum sensing, because by increasing  $t_{measure}$  the time information is lost.

The measuring antenna was placed in an open space (roof/balcony for urban, sub-urban and rural locations) and a tripod was used for measurements which positioned the antenna at a height of 1.6 meters over the terrain thus guaranteeing maximum fidelity of measurement.

The list of measured scenarios can be seen in Tab. 1. The Lecture hall scenario was selected to measure the influence of people on the wireless traffic. The measurements were also conducted in the same scenario during public holidays to ascertain the influence of people. Another outdoor measurement was performed to study the utilization of the spectrum based on different building densities. In the urban location, the antenna was positioned on the roof of the building as well as in an open place in the urban area. The same measurement principle was also chosen for suburban locations. In the open field scenario (rural) there were no nearby buildings or other sources of wireless traffic (Fig. 1).

Location	Description	Measurement Type
<b>Full Lecture Hall</b>	<i>Lecture hall occupied by 150 students during the lecture</i>	Fast spectrum sensing Short-term
<b>Empty Lecture Hall</b>	<i>Empty lecture hall during a public holiday</i>	Fast spectrum sensing Short-term
<b>Urban Location</b>	<i>Several locations on roofs near CTU in Prague.</i>	Both FS and OS Both ST and LT
<b>Suburban Location</b>	<i>Village location. The observing point was on the roof.</i>	Both FS and OS Both ST and LT
<b>Rural Area</b>	<i>No nearby transmitters and houses at this location.</i>	Both FS and OS Only Short-term

Tab. 1. Measured locations with description and types.

### 2.3 Data Post-Processing

Generally, one of the most important parts of this system is post-processing and data management as described further in detail. The measured data has to be post-processed (Fig. 2) so final data calculations were processed in Matlab environment to be divided into several steps.

Firstly (Fig. 2, 1.), a consistency check was necessary because some information could have been lost during the measurement process (UDP transmission of the packets is

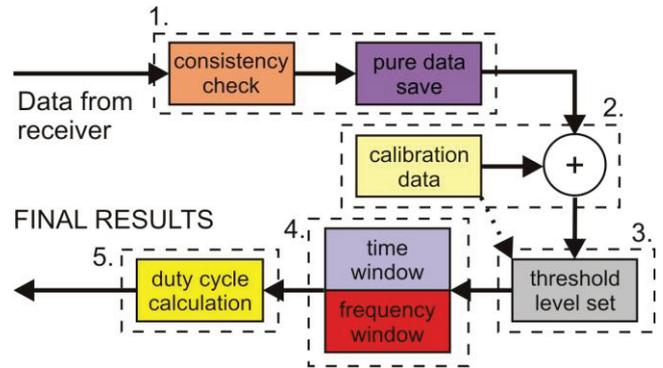


Fig. 2. Flow chart of post-processing.

not a reliable TCP/IP protocol). Measurement information such as  $f_{starts}$ ,  $f_{end}$  and frequency step ( $RBW$ ) were loaded from the measurement information file. These values were also checked directly from the measured data. After this, the specific measured values corresponding to one cycle were loaded from the file containing measured data. If a mistake was detected, data from a previously completed cycle could be used to fix this row. The typical error rate in the presented measurement was less than 1%. The consistent data were saved as a binary data file for future analysis. This type of file consumed less space and was easy to operate with.

Following this (Fig. 2, 2.), calibration data (see section 2.5), measured in an anechoic chamber, were used to minimize noise and frequency dependence of the antenna and receiver. The calibration data ( $S_{calibration}$ ) were loaded to the measured data ( $S_{measured}$ ) according to (1) to achieve the final processed data  $S_{final}$ .

$$S_{final} = S_{measured} - S_{calibration} \cdot [dB\mu V] \quad (1)$$

This type of calibration loses absolute information about the energy/power level, but the effects of the frequency dependent part of the measured system (such as cable, antenna) are minimized and noise level fluctuates around 0 dB. This was extremely important because we were not interested in the exact level of measured values, rather we wanted to determine utilization of the frequency spectrum. Another possibility was to calibrate measurement system by exact frequency dependency values of each part of the measurement system (cable, antenna and receiver).

At this point (Fig. 2, 3.), the threshold level value ( $L_{threshold}$ ) was set. The measured values for frequency points above this level were marked as “occupied” by another service (primary user). If the calibration data were included, the threshold level was estimated from the calibration data as a value to minimize the probability of false detection (5 dB over the calibrated data). Otherwise, the threshold was essentially estimated as 10 dB over the mean level of the signal which guaranteed that the decision level was above the noise. Calibration data were needed for all measurements presented.

At this point (Fig. 2, 4.), measured data were collected with a higher resolution and repetition rate than could be

displayed. This is why the reduction of the measured time was applied in both domains (time and frequency) by sliding windows. The frequency domain window ( $W_{frequency}$ ) was changed according to the evaluated data range. Resolution of the system enabled us to take more than 2 data points for each channel of the particular service into account with the time domain window ( $W_{time}$ ) taking the same parts of the frequency points for several data rows into account.

Finally (Fig. 2, 5.), the quantifying parameters were evaluated. The most common parameter describing utilization of the frequency spectrum is the *Duty Cycle* (2) [18], [20], [21] which is defined as the number of detected peaks  $N_{detected}$  divided by total frequency and time points in the measurement  $N_{total}$ . It is more clearly presented in (Fig. 3).

$$Duty\ Cycle = \frac{N_{detected}}{N_{total}}. \quad (2)$$

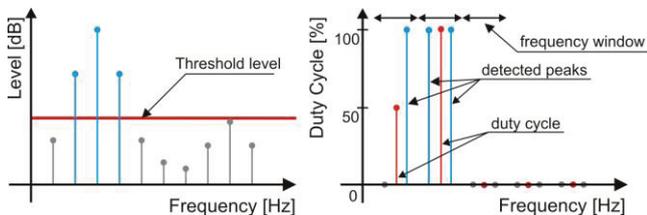


Fig. 3. *Duty Cycle* definition.

Another important feature of the spectrum survey is “whitespace” detection. An example of this are the calculations made for Wi-Fi service. In this case, a band  $\pm 25$  kHz around the central frequency was evaluated according to  $L_{threshold}$ . When there was no significant energy within the specified band the whole channel was marked as a whitespace and it was available for spectrum sharing at that time. This was the “optimistic case” in terms of spectrum sharing. On the other hand, the pessimistic case is calculated in the same way, but the whole channel is compared with  $L_{threshold}$ .

## 2.4 Optimistic vs. Pessimistic

Cognitive radio requires actual data of the frequency spectrum for spectral sharing. Other spectrum survey measurements demonstrated huge underutilization [18]-[20], [22] in most typically used frequency bands. To obtain more realistic data we defined two different cases when quantifying spectrum utilization. We defined an optimistic case where the average values were calculated for both filtering windows making it possible to determine many opportunities for spectrum sharing despite the probability of interference with primary users of the spectrum. A pessimistic case was also defined where the maximal values from each window were used during the averaging process.

These two cases allowed us to determine real spectrum opportunities and minimize interference problems with primary users.

## 2.5 Calibration Measurement

Generally, some characteristics (noise, gain, transfer function, etc.) of the antenna and the receiver are dependent on frequency. The minimization of this influence was done by the calibration measurement in the anechoic chamber. The measurement setup is depicted in Fig. 4.

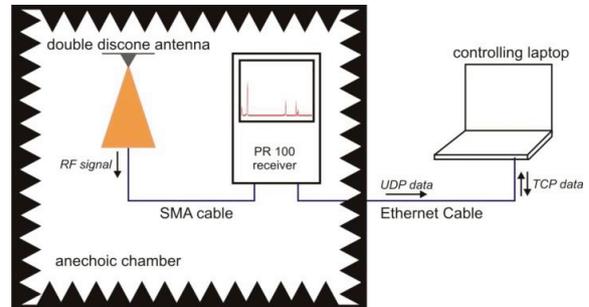


Fig. 4. Measurement setup for calibration.

The anechoic chamber provided satisfactory isolation from RF services and pertinent information about the noise of the complete measurement setup. Hundreds of cycles were measured to obtain a sufficient data sample.

One measured cycle is depicted in Fig. 5 as a blue curve, together with the mean value of all measured cycles as shown by the red curve. The average was calculated from 400 measured cycles to eliminate non-periodic noise from raw data. This data row contained a large number of lines – comb lines, which were raised from the noise.

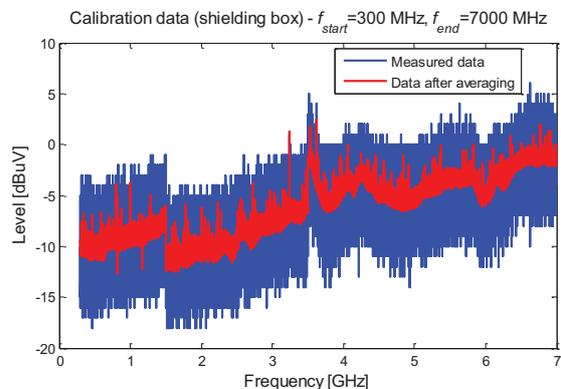


Fig. 5. Calibration data  $f_{start} = 300$  MHz,  $f_{end} = 7000$  MHz,  $RBW = 12.5$  kHz.

It was experimentally proved that some of these lines were caused by internal noise from the receiver (e.g. CPU – 1 GHz, etc.) as these lines were clearer in the calibration measurement than in the real scenario. On the lower frequencies (752 MHz), the DVB-T signal penetrated the anechoic chamber from 2 TV transmitters located nearby (2.5 km – Prague Strahov and 5 km – Žižkov tower). Also some small peaks can be detected near the GSM/UMTS frequencies (1.8 GHz or 2.1 GHz).

For post-processing we decided to use a red curve from Fig. 5 as the calibration data with all artifacts having been detected in the anechoic chamber.

### 3 Measurement Results

#### 3.1 Short-Term Measurements

The short-term measurements were focused on detecting changes in particular services. The performed measurements focused on the band from 700 MHz to 2.7 GHz. A mainstream of mobility services (GSM, UMTS, Wi-Fi) is located in this band. The parameters of these measurements are summarized in Tab. 2.

Parameter	Value
$f_{start}$	700 MHz
$f_{end}$	2700 MHz
$RBW$	12500 Hz
$t_{measure}$	500 $\mu$ s
$t_{duration}$	3600 s
Threshold	5 dB

Tab. 2. Short-term measurement parameters.

The time and frequency window varied according to the examined service to reach a minimum of 2 samples per channel bandwidth.

Firstly, we examined the rural area (Fig. 6), where similar spectrum utilization as in an urban or indoor location is assumed. The measurements in this rural area were conducted during different seasons (summer and winter) and there were no significant differences in these measurements. It was proved that GSM in both bands (900 MHz and 1800 MHz) is heavily used. Different distribution of services can be determined by comparing rural measurements (Fig. 6) and indoor urban measurements (Fig. 7). For example, in the rural location the utilization of the DVB-T band was higher than in the occupied lecture hall.

The next examined scenario was indoors in the lecture hall. This scenario was measured with students both during a lecture and during public holidays. The results from the full lecture hall are presented in (Fig. 7).

This measurement was compared with values obtained from a measurement at the same location and at the same time of day but during public holidays (when the lecture hall and surrounding areas were empty). This comparison was made to study the effect of people occupying that location. The difference of the calculated duty cycle values between the full lecture hall and empty lecture hall is depicted in (Fig. 8). The *Duty Cycle* was decreased from the value of 5.205 % to the value 3.5 %.

In the situations presented, the duration had taken 1.7 s until the starting frequency was scanned again which enabled a study of channel performance not only in frequency but also in time. Better insight of the measured data could be performed by an evaluation limited bandwidth. The utilization results were depreciated by the pilot signals of services such as Wi-Fi and GSM, which were transmitted the entire time. For example, the UMTS frequency plan allowed us to distinguish mobile service providers as depicted in Fig. 9.

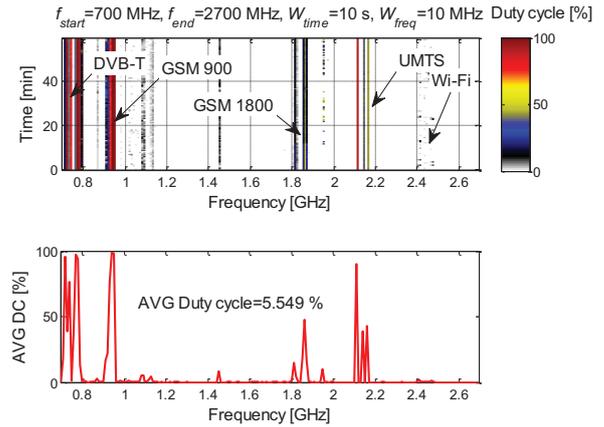


Fig. 6. Measurement results from the rural area.

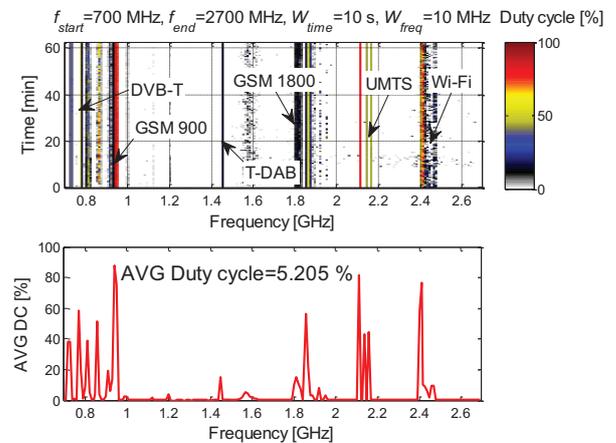


Fig. 7. Spectrum overview for occupied lecture hall.

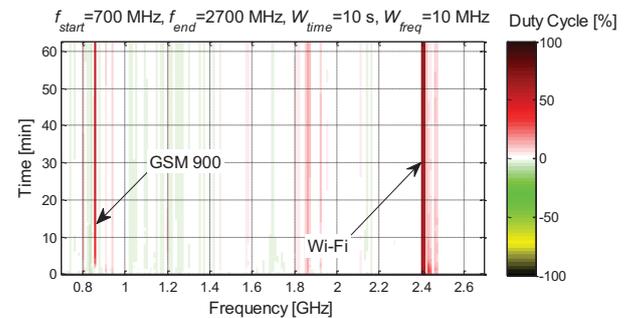


Fig. 8. Difference between occupied and unoccupied lecture hall.

Finally, the Wi-Fi band was examined in detail where the main differences between a full and empty lecture hall were measured. According to the measured data (frequency widths of the channels), we assume that Wi-Fi is working under IEEE 802.11g [23]. Two Wi-Fi channels, which were found to be time dependent of the *Duty Cycle*, are also presented in Fig. 10. The international Wi-Fi network “Eduroam” was located in Wi-Fi channel #1 (CH 1) and another Wi-Fi network occupied channel #12 (CH 12). Another network could be found in Fig. 10, which does not allow being distinguished.

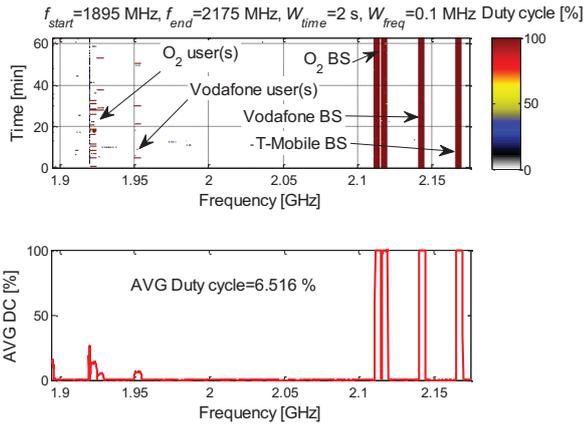


Fig. 9. UMTS band measured in lecture hall with students.

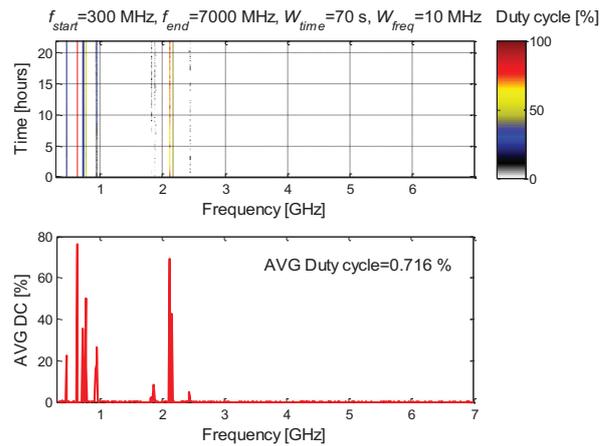


Fig. 11. Spectrum overview for the suburban scenario.

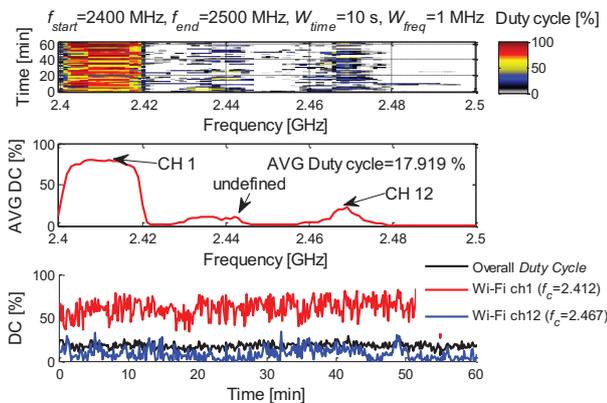


Fig. 10. Utilization of Wi-Fi band in lecture hall with students.

In the “empty” lecture hall the *Duty Cycle* of the Wi-Fi band was calculated as 1.84 % (the difference between a full and empty lecture hall is 17.08 %). This proved that the occupied lecture hall generates more wireless traffic. Channel #1 was triggered in 80 % of the measured rows.

### 3.2 Long-Term Measurement

On the whole, there were more challenges in the long-term measurement process. The amount of data needed to be reduced for this type of measurement because it is not possible to store such a huge amount of data (21 MB for 1 GHz). Moreover, an electrical connection was necessary for these measurements. The parameters of this measurement are presented in Tab. 3.

Parameter	Value
$f_{start}$	300 MHz
$f_{end}$	7000 MHz
$RBW$	1250 Hz
$t_{measure}$	500 $\mu$ s
$t_{duration}$	not set
$Threshold$	5 dB

Tab. 3. Long-term measurement parameters.

The presented measurement (Fig. 11) was performed in a suburban area. The low utilization values are given by

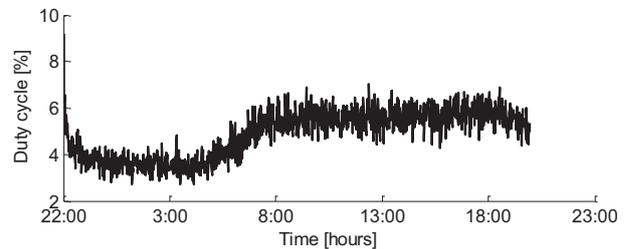


Fig. 12. GSM 900 band utilization (860 – 980 MHz).

a large, scanned bandwidth with a very small frequency step. The *Duty cycle* calculation depended on the number of measured frequencies. On the higher frequencies the communication is based on point-to-point phenomena and for this reason it is more difficult to detect these services.

The time dependence is illustrated in Fig. 12. The utilization of the GSM 900 MHz band varies with time according to daily time. The minimal value was between 23:00 till 6:00.

### 3.3 Measurement Result Comparison

The measured locations were compared in Fig. 13 for the optimistic and pessimistic situations. It is possible to see that in the optimistic case it is easy to find spectrum sharing opportunities due to low spectrum utilization. On the other hand, in the pessimistic case it is nearly impossible to find sharing opportunities in some frequency bands. The overall results of the spectrum utilization are listed in Tab. 4.

The long-term measurements (more than 24 hours) prove that the spectrum occupancy is dependent on time (e.g. the *Duty cycle* of the GSM 900 MHz band varied from 6 % during the day and 4 % at night. We do not observe any significant wireless traffic in the band from 3 up to 7 GHz because point-to-point services are mainly used on these frequencies and it is hard to detect these services by spectrum survey measurements.

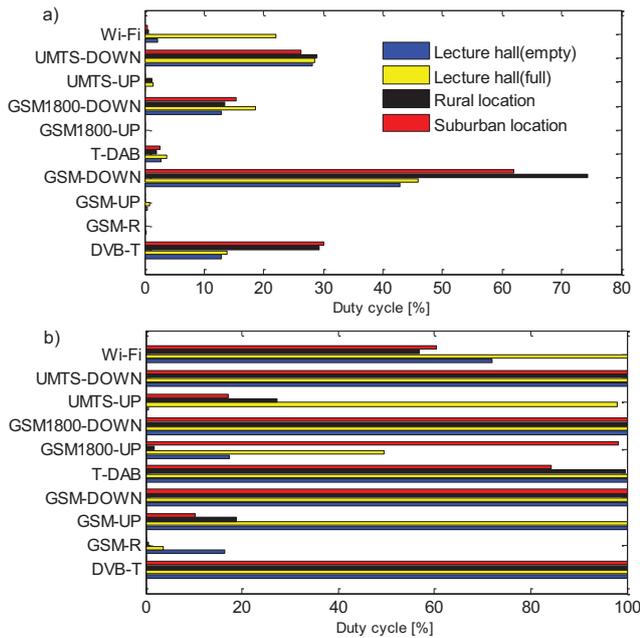


Fig. 13. Utilization of the selected services for selected scenarios for a) optimistic scenario and b) pessimistic scenario.

Measurement Description	DC [%] whole band	DC [%] GSM 900	DC [%] Wi-Fi
Full lecture hall (0.7 – 2.7 GHz)	5.21	23.29	17.92
Empty lecture hall (0.7 – 2.7 GHz)	3.5	20.73	1.84
Rural area (0.7 – 2.7 GHz)	5.55	34.92	0.54
Suburban area (0.3 – 7 GHz)	2.19 5.07 (0.7-2.7 GHz)	31.2	3.852
Urban area (0.3 – 7 GHz)	2.18 3.77 (0.7-2.7 GHz)	22.38	3.48

Tab. 4. Summary of the utilization (Duty cycle - DC) in different measured scenarios.

Wi-Fi, as an open band under ISM regulation, was examined in more detail (Tab. 5). The number of white spaces, white space duration and number of gaps was calculated from measured data. The calculations were also made for an optimistic and pessimistic case.

In the previous chapter it was shown that in the “full” lecture hall Wi-Fi channel #1 was mostly occupied. According to the IEEE 802.11 definition we calculated *Duty Cycle* of this channel to be 77.2 % with the maximal white space duration of 8.94 s for the optimistic situation and 1.79 s for the pessimistic situation. Channel #1 overlapped with several other Wi-Fi channels (according to the modulation) and the situation was very similar for nearby channels. On the other hand, it was possible to find a totally free channel in the “empty” lecture hall or in the rural area. These unoccupied parts of the frequency spectrum could be used by a cognitive engine to increase data throughput [13].

From these results, it was possible to establish sharing possibilities (the number and duration of the whitespaces)

Scenario \ Channel #	# 1	# 2	# 3	# 6
<b>Full lecture hall</b>				
Optimistic DC [%]	77.2	76.8	5.1	9.8
Avg. gap duration [s]	2.35	2.41	36.24	20.03
Number of gaps [-]	366	363	99	170
Pessimistic DC [%]	99.4	99.5	98.1	56.8
Avg. gap duration [s]	1.79	1.79	1.83	3.71
Number of gaps [-]	12	10	39	440
<b>Empty lecture hall</b>				
Optimistic DC [%]	4.81	2.96	0	1.3
Avg. gap duration [s]	35.92	57.29	whole	124.51
Number of gaps [-]	97	62	1	29
Pessimistic DC [%]	48.5	48.5	41.4	18.5
Avg. gap duration [s]	3.87	3.86	4.54	9.65
Number of gaps [-]	487	488	472	309
<b>Rural area</b>				
Optimistic DC [%]	1.4	1.3	0	0
Avg. gap duration [s]	126.102	121.75	whole	whole
Number of gaps [-]	28	29	1	1
Pessimistic DC [%]	14.9	18.5	16.9	21.8
Avg. gap duration [s]	11.99	9.85	10.7	8.56
Number of gaps [-]	254	296	278	327

Tab. 5. Wi-Fi band white space results for selected Wi-Fi channels and locations.

	Campaign	Frequency Band [GHz]	RBW [kHz]	Sampling distance [kHz]	Sweeps per hour
	Presented Short-term	0.7 – 2.7	12.5	12.5	1800
	Presented Long-term	0.3 – 7	1.25	1.25	60
A	Valenta V. et al. [19] - Reg. 1	0.1 – 3	3	160	6
	Valenta V. et al. [19] - Reg. 2	0.4 – 6	55	125	9
B	Patil K. et al. [20]	1.5-3	200	200	3600
C	SSC [18]	1-3	30	30	NA

Tab. 6. List of different measurement campaigns.

based on the utilization of the channels. From Tab. 5 it is obvious that the results of the white spaces for the similar *Duty Cycle* are the same. For example, channel #1 in the full lecture hall can be used for approximately 860 s (23 % of measured time) by another service in the optimistic case, and 21 s (0.006 % of measured time) in the pessimistic case. At this time it was possible to apply an overlay sharing mechanism to achieve maximal utilization of this channel. On the other hand, there was plenty of sharing time in channel #6. 3400 s (94 % of time) was available in the optimistic case and 1632 s (45 % of measurement duration) in the pessimistic scenario. In this example, some traffic from channel #1 should be shifted to channel #6 to maximize data throughput. It was not necessary to investigate a rural area or an empty lecture hall in a similar way because the Wi-Fi service was rarely used or the transmitter is too far in these types of scenarios.

As a result of the low utilization of the whole bandwidth, it is logical to use a dynamic spectrum allocation to increase system parameters, such as SNR or transmission speed. The optimal bands for dynamic spectrum access are TV bands where utilization is decreased due to digitization and Wi-Fi bands.

As mentioned above, other measurement campaigns can be found in the literature. Those selected are listed in Tab. 6.

It is a difficult task to compare the results from these measurement campaigns since the measurement conditions and parameters are completely different (Tab. 6). Nevertheless, the reported results are similar to the values introduced in this paper. For example, the overall utilization in our measurement was determined as spectrum utilization around 5 % and the stated value of campaign A from 6.5 % up to 10.5 % according to the measured region. However, campaign B calculated utilization values as high as 22.72 % in a similar band near Barcelona. This difference could be caused by the rough frequency scale. Also the GSM 900 band and Wi-Fi ISM band could be easily compared. We obtained a utilization value of 23 % at urban location and 34 % in the rural area. In the Wi-Fi band we measured spectrum utilization to be 3.48 % at the urban location and 0.54 % for the rural area. Campaign A measured utilization values from 38 % up to 48 % according to the measured region and utilization. The Wi-Fi ISM band was utilized to a value around 10 % in this location. The GSM band utilization was measured to be over 40 % and Wi-Fi less than 2 % for by campaign C.

## 4 Conclusions

The measurement system for utilization of the frequency spectrum measurement – spectrum survey – was introduced. Two main types of the measurement were performed in different locations with utilization parameters being calculated not only for the whole band, but also for a specific group of services. Firstly, a short-term spectrum survey was designed to present utilization of the frequency spectrum using *Duty Cycle*. Measurements were performed in limited bandwidths but with a high rate of repetition to find spectrum sharing opportunities (usage of the frequency spectrum was typically around 5 %), which could be used by cognitive radio. It was experimentally proved that frequency spectrum is heavily underutilized in most of the frequency bands. The measured values were also compared to existing results from similar scenarios.

A deep analysis of Wi-Fi (ISM) was performed and the possibility of channel switching to optimize wireless traffic was found to increase data throughput. One of the measured channels was available 94 % of the measured time.

The main advantages of the presented systems are portability, speed, sensitivity and resolution. In contrast to similar measurements of the frequency background, our results were collected with a higher repetition rate and with more frequency points. The unique set of measured data was created for cognitive radio simulations, cognitive radio testing and further analysis.

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