

Initial Results of a New Mobile Spectrum Occupancy Monitoring Network

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Abstract—In this paper we present results of the new monitoring network for spectrum governance. The network is based on the RFeye system of CRFS where the data is collected employing mobile monitoring vehicles. The measurement data, obtained from a frequency sweep between 10 MHz and 6 GHz, is further analyzed. For this purpose a tool is made, tailored for the needs of the spectrum regulator. Initial results are presented based on the measurement data showing the spectrum occupancy of various Dutch operators in the GSM downlink bands for different geographical areas. In addition, the statistics are provided with respect to the in-band power variation.

I. INTRODUCTION

Traditional tasks of the spectrum regulator include minimizing interference and locating (illegal) interferers, such as FM radio pirate transmissions [1]. In many countries a fixed network infrastructure of monitoring sites is used to monitor the spectrum. In the Netherlands, the fixed network consists of 12 monitoring sites that measure the received power from 100 kHz to 1.3 GHz in a 25 kHz raster. However, modern communications require smaller service area per base station and also higher frequencies up to 6 GHz. The traditional methods for spectrum monitoring cannot meet these requirements and are therefore not fully qualified anymore. Hence, new tasks for the spectrum regulator arise to determine the spectrum usage in higher frequency bands. More about present-day spectrum governance can be found in [2]–[5] where economical aspect are treated in [6]–[8].

To meet these new tasks, we propose a new method to efficiently monitor the spectrum usage using a mobile monitoring network. This network

consists of mobile vehicles, equipped with the RF-eye system of CRFS [9] which is able to measure the frequency spectrum up to 6 GHz. The RFeye measurement equipment is designed to provide a cost-effective system that can provide continuous, 24/7 monitoring of the radio spectrum. The measurement data is stored and can be used for offline spectrum analysis.

The advantages of using mobile spectrum monitoring compared to the traditional approach are:

- The spectral usage in a particular geographical area and frequency band can be assessed. Areas of interest can be investigated in more depth by assigning monitoring vehicles to these areas.
- The (spatial) resolution of the monitoring network increases.
- The regulator can, according to the requirements, dynamically change the size of the geographical area for spectrum monitoring.
- In general the standard deviation of radio signals in place is much higher than in time. Using a fixed network would require a very high density of fixed monitoring sites. This suggests the use of mobile spectrum monitoring.

II. SPECTRUM USAGE ANALYSIS

Many days of spectrum measurements do induce a huge amount of collected data. In this section we describe how to access and use the huge amount of collected data from the mobile monitoring vehicles (see figure 1).

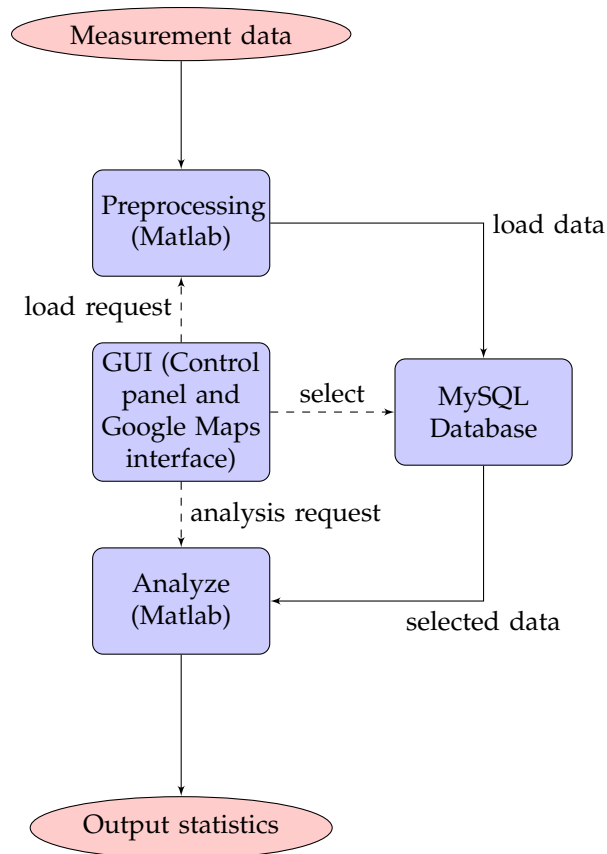


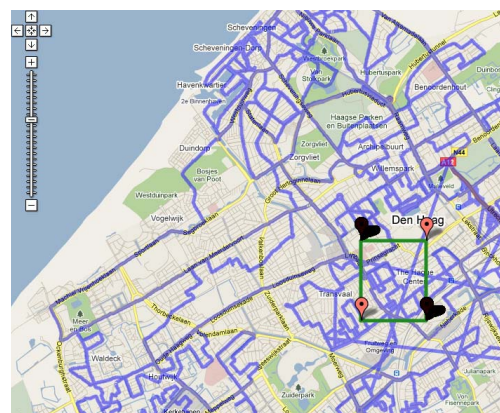
Fig. 1. The process of loading, accessing and analyzing data from a MySQL database using Matlab. Dashed lines represent request commands.

To start with, the data is measured and collected in the following way. The RFeye system measurement equipment mounted on the mobile vehicle yields the measurement data while driving through rural and urban areas in the Netherlands. The spectrum between 10 and 500 MHz is sampled using a step size of 19.5312 kHz, while a reduced sample rate is used for the spectrum between 500 - 2000 MHz and 2000 - 6000 MHz using respectively step-sizes of 78.125 kHz and 156.25 kHz. The measurements take place at a 1 second time interval and yields the frequency response data for the specified spectrum. These values were chosen by the Dutch radio communication agency who performed the measurements.

As a next step, the CRFS measurement data is loaded to a local computer for further offline processing. Subsequently, the data is transferred from the local system to an external server so that a huge amount of data of many measurement days can be

stored. At the server system a MySQL database is maintained in order to analyze and access the data efficiently.

In Matlab, on a local machine, we access the MySQL database using a graphical user interface (GUI) tailored and built to meet the spectrum regulator's essential needs. Using this GUI, the geographical area and frequency band of interest can be selected. By using the Google maps API, the area selection takes place graphically which is shown in figure 2. This provides us the spectrum traces for a selected geographical area, where each trace corresponds to a particular measurement time instant. Furthermore for each trace, the location information is retrieved and available by using GPS.



(a) The selection tool: the area inside the green rectangle is selected. In this case an urban area.



(b) The measurement points in the selected area.

Fig. 2. The selection tool using Google Maps, in order to select the area of interest graphically.

Note that the data stored in the database is accessed through a MySQL interface in Matlab. This enables us to efficiently access and select data from the database using MySQL commands in a Matlab

environment. The selected data in the database is downloaded to the local machine and is loaded to the Matlab workspace for further processing. For the measured data in the specified frequency band and geographical area, the accompanying histogram is computed leading to the probability density function (PDF). In a similar way, the cumulative density function (CDF) can be derived which is often more appropriate in spectrum usage analysis.

III. RESULTS

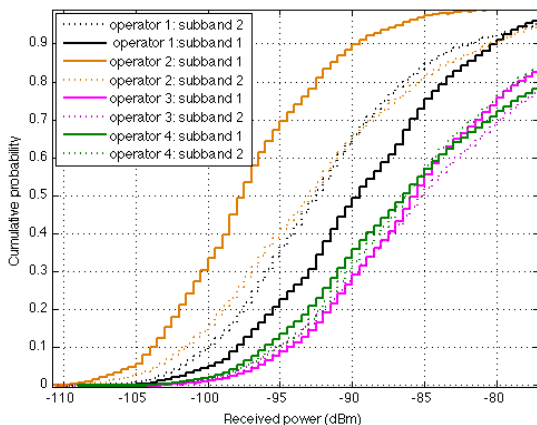


Fig. 3. The cumulative probability density functions per sub-band in the GSM900 band for each operator active in the Netherlands, in a geographical rural area.

In this section the results are shown for the GSM900 and GSM1800 downlink band. To start with, the frequency sub-bands in the GSM900 are investigated. Table I lists for Dutch operators¹ (KPN, Orange, Telfort, Vodafone) in the GSM900 band the associated frequency sub-bands. The spectrum is analyzed per operator and per frequency sub-band. The outcome is shown in figure 3.

Based on the results in figure 3 it turns out that, for a specific operator, the spectrum occupancy differs significantly between distinct sub-bands. However, we merge the sub-bands per operator for

¹The list with mobile network operators is based on the situation in the year 2006. At that time five operators were active in the GSM bands. Note, T-Mobile was at that time only active in the GSM1800 band. The situation is different now, due to the acquisition of respectively Orange by T-Mobile and Telfort by KPN. Hence, nowadays three mobile network operators are left in the Netherlands. This means that operator 1 and 2 are owned by the same operator. For that reason it is likely that the measured received power of these networks are less compared to the networks of operator 3 and 4.

respectively GSM900 and GSM1800. This in order to analyze the overall performance per operator. Besides, the spectrum occupancy for respectively the whole GSM900 and GSM1800 band is analyzed for two different geographical areas. The results are shown in figure 4. The overall performance for GSM900 and GSM1800 shows the following outcome: the spectrum occupancy is significantly higher in urban areas compared to rural areas for each operator. Moreover, the cumulative density functions reveal higher activity, and thus higher transmit power, in the GSM900 band compared to the GSM1800 band. This corresponds with the results mentioned in the Singapore spectrum survey [10]. In addition, the performance of the operators are compared using the criteria stated in table II. Based on these field strength values, it follows that operator 3 provides the highest spectrum occupancy in both GSM bands.

	Operator 1	Operator 2	Operator 3	Operator 4
band 1 (MHz)	925.1 - 925.9	925.9 - 927.3	935.1 - 939.1	939.1 - 948.1
band 2 (MHz)	927.3 - 931.5	931.5 - 935.1	948.1 - 956.5	956.5 - 958.9

TABLE I

THE SUB-BANDS ALLOCATED TO THE VARIOUS DUTCH MOBILE TELEPHONE OPERATORS IN THE GSM900 BAND. NOTE THAT THE OPERATORS, MENTIONED IN THIS PAPER, ARE LABELED IN THIS TABLE IN A DIFFERENT ORDER.

To visualize the occupation results, figure 5 shows the spectrum usage in the frequency band 948.1-956.5 MHz for many traces, respectively for a rural and urban geographic area. Note that the operator, assigned to the frequency band of interest, is operator 3. The selected frequency band consists of several GSM downlink channels, each having an allocated bandwidth of 200 kHz. As expected, the activity in this band, according to GSM communication, is larger in the urban area. The data analysis yields respectively the mean, median, maximum and minimum field strength over time per frequency. The results, associated with the selected geographical area, are depicted in figure 5.

The statistics were based on measurements taken on many locations in a particular geographical area, which is different from what is reported in other papers regarding spectrum occupancy surveys. There the spectrum usage is measured at a fixed point [10]–[15]. As a comparison, we compute the devi-

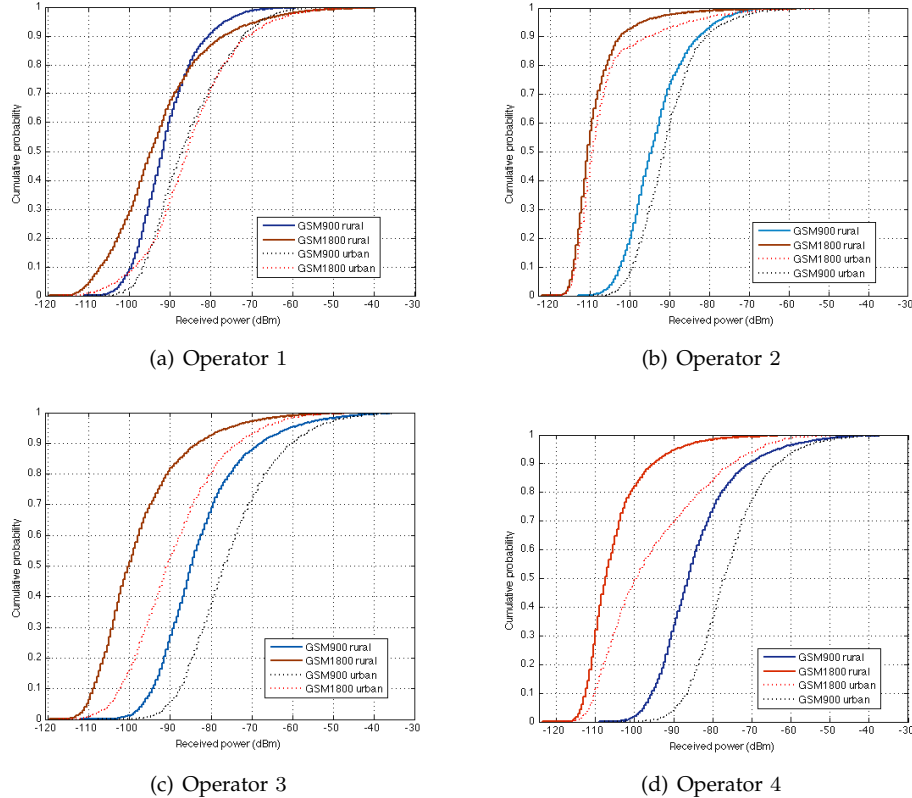


Fig. 4. The cumulative density functions per operator in a rural and an urban area for respectively GSM900 and GSM1800.

Operator	GSM1800 rural (dBm)	GSM1800 urban (dBm)	GSM900 rural (dBm)	GSM900 urban (dBm)
1	-107.0	-98.5	-99.5	-96.5
2	-114.0	-113.5	-102.5	-99.0
3	-109.0	-102.5	-94.0	-87.5
4	-112.0	-110.0	-95.5	-86.5

TABLE II
AS A QUANTITATIVE PERFORMANCE MEASURE, FOR EACH OPERATOR THE FIELD STRENGTH VALUE IS DERIVED WHICH SEPARATES THE LOWER 10 PERCENT OF THE FREQUENCY SPECTRUM FROM THE HIGHER 90 PERCENT FOR EITHER THE GSM900 OR THE GSM1800 BAND.

ation of the in-band spatial field strength variation of both GSM bands with the results from the fixed measurement set-up in the Singapore occupancy survey [10]. For this purpose we compare the received power variation per band in different geographical areas for an arbitrarily chosen operator (in this case operator 4). The corresponding results are shown in figure 6. Here the power variation on logarithmic scale, i.e. V_{dBm} , is computed based on

the actual received in-band power for a particular trace. The latter is modeled as a random variable X , from which it follows that

$$V_{\text{dBm}} = 10 \log X - 10 \log p \quad (1)$$

where p stands for the derived mean power over time. The power variation results are shown in figure 6. Based on these results it turns out that the in-band power in urban areas has a larger variation than in rural areas. Furthermore, the power variation for GSM900 surpasses GSM1800. We explain this as due to the higher GSM900 transmit power. Another thing that emerges from the power variation plots in figure 6 is the shape of the distribution function. In the urban setting of GSM900, which happens to possess the highest signal to noise ratio (SNR), the probability density function exposes two peaks. One peak represents the in-band noise power whereas the second peak arises due to the received signal power. These two peaks are also present in the GSM900 distribution function for the rural area, however, the second peak is less strong

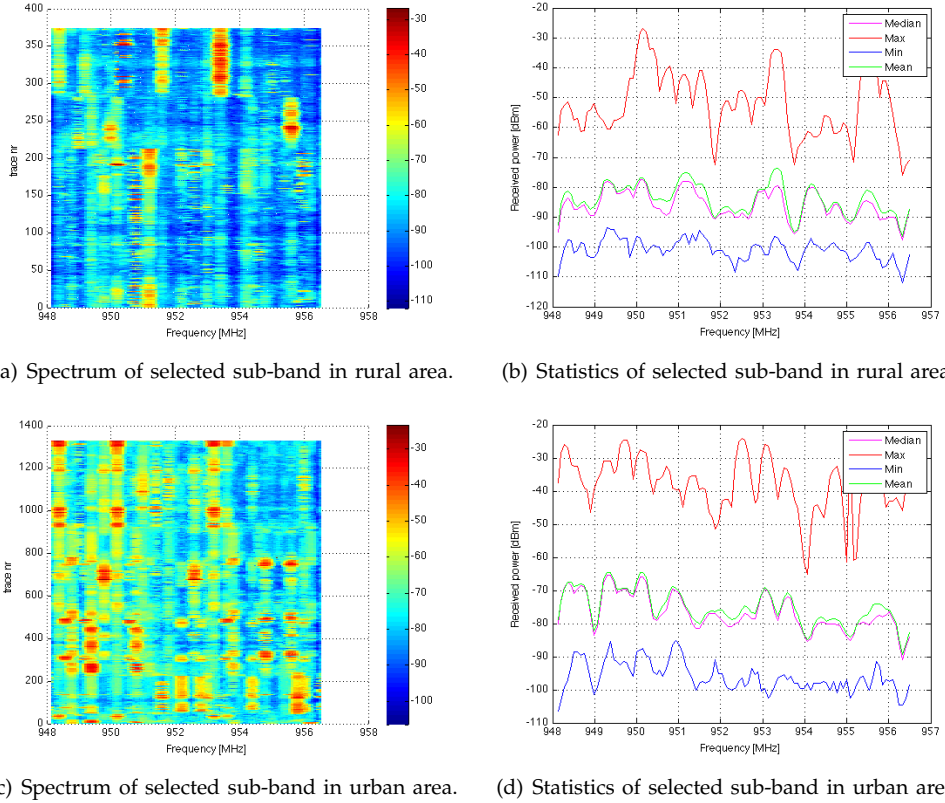


Fig. 5. Frequency spectrum and statistics of operator 3 in the selected GSM900 sub-band.

compared to the peak in the urban environment's plot. Similarly for GSM1800, two peaks are displayed in the urban probability density function plot. This plot differs from the GSM900 case since the first peak, once again explained as the received noise power, exceeds the second signal power peak. Moreover, due to the lower transmit power of GSM1800, the signal peak is hardly visible in the power variation plot from the rural measurement data. To analyze the distribution on a decimal scale, the following conversion takes place:

$$V_{\text{decimal}} = 10^{\frac{10 \log X - 10 \log p}{10}} = \frac{X}{p} \quad (2)$$

The results, plotted in figure 7, show a relation between the SNR and the variation of the distribution function. As an example, the probability density function for the rural GSM1800 situation is more widely spread on this interval compared to urban GSM900. Note that the histogram of these points tends to have a log-normal distribution. We consider it interesting to investigate this in more detail using a curve fitting approach.

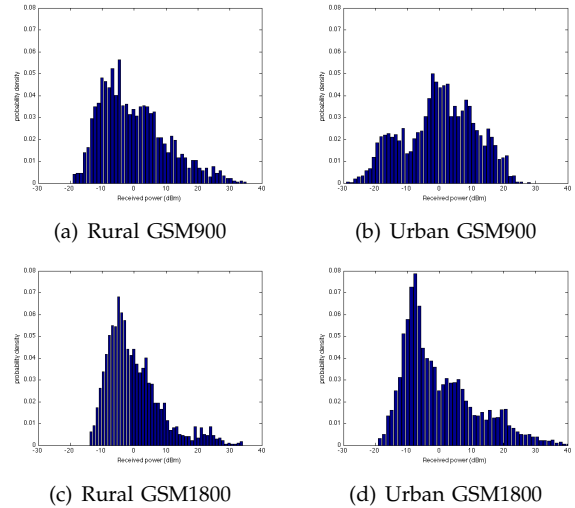


Fig. 6. The RSS statistics of the selected operator 4.

IV. CONCLUSION

In this paper we present a new monitoring network for spectrum governance based on the RFeye

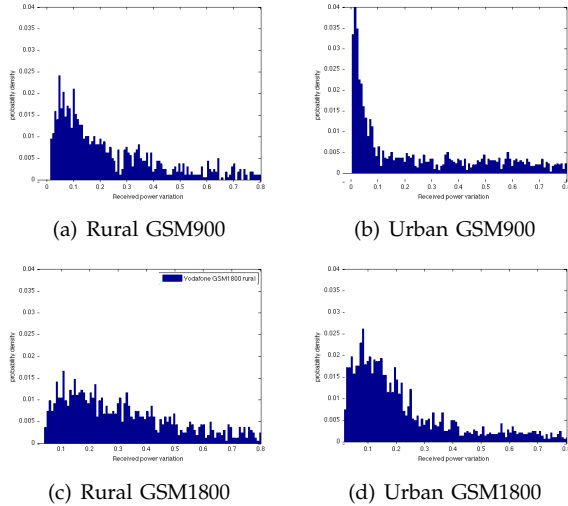


Fig. 7. The RSS statistics of the selected operator 4 on a decimal scale.

system of CRFS [9]. A tool is built to effectively store and access the measured data on an external server system in order to determine the usage in a particular frequency band and geographic area. In addition, a method is described to analyze the data, and sample results are presented. The data analysis shows that sub-band usage varies per operator, where at the same time, spectrum occupancy is significantly larger in urban areas compared to rural areas. In our set-up spatial field strength measurements are considered which we compared with the time varying field strength measurements performed in the referred Singapore survey. There average occupancies for the GSM900 and GSM1800 frequency band are assumed. However, our measurements did show that the spectrum occupancy varies significantly in different geographical areas, which shows the importance of including spatial power variations. The distribution of the in-band spatial power variation tends to be a log-normal. It would be interesting for future research to investigate this in more depth using curve-fitting methods in order to see which distribution, and scale parameters, fits best.

As expected, it appears from our measurements that the spectrum is more heavily used in urban areas compared to rural areas. Hence problems arise regarding the economical viability of opportunistic radio, i.e., you have more opportunity in rural, but most demand for spectrum in urban areas.

V. ACKNOWLEDGMENTS

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