A Monitoring Network for Spectrum Governance Applications

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Abstract—**Dynamic Spectrum Access (DSA) is an exciting new technology, which introduced a paradigm shift in spectrum access. As a result it also changes the role of the regulator. On one hand the scarce radio spectrum should be used in an optimal way, so that the society is best served. On the other hand interference between users and networks should be avoided. For that reason rules have to be defined for spectrum use. This topic is called spectrum governance. For evaluation and to check whether devices obey the rules, a monitoring network is needed. In this paper, we propose to use a fleet of mobile monitoring vehicles for this purpose.**

I. INTRODUCTION

The radio spectrum is a relatively scarce resource and only frequencies between 200 MHz and 3 GHz are best qualified for wireless mobile communication. For that reason, rules have to be defined for spectrum usage, which should have two goals:

- Minimize interference between users
- Optimize the spectrum usage

Of course, both goals are conflicting to some extent. A more efficient use of the radio spectrum can lead to more interference. Rules are not only determined by technical parameters, also economical, legal, political and social constraints play an important role in these rules. The topic of this research is called spectrum governance[1]. The output of spectrum governance is a set of rules, which are the input to existing and Dynamic Spectrum Access (DSA) enabled radio equipment. One should note that DSA and spectrum governance are not independent research areas. The paradigm shift in spectrum access and its impact caused by DSA also require to change the traditional spectrum governance approach. Feedback to the current spectrum governance rules are, among others, given by the output of the monitoring network. This monitoring network has several goals. First, it evaluates the performance of the current set of rules, by measuring the spectrum usage and interference levels. Moreover, it can be used to check whether existing radio equipment complies with the rules. Also, the vast amount of measurement data can be used as input for DSA enabled radio to facilitate the search for the appropriate white space.

There exists already some literature that describes how to allocate [2], [3], [4], [5], [6], [7], manage [8], [9], [10], [11], standardize [12], [13], [14], [15], and use the spectrum as secondary user [16], [17], [18], [19] (e.g. Spectrum
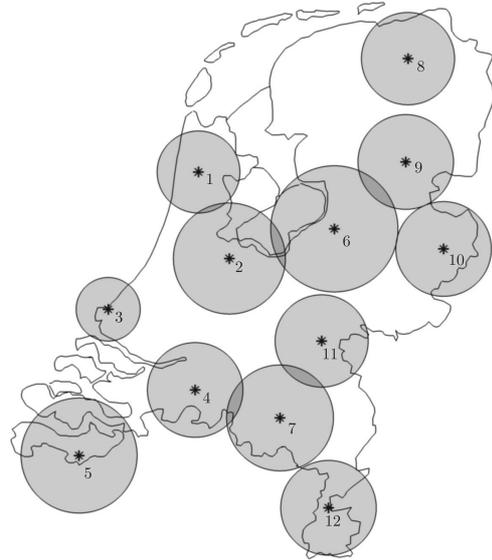
Fig. 1. Monitoring sites in the Netherlands, the size of the circle shows the radio horizon.

User Rights (SUR), Dynamic Spectrum Access (DSA), Dynamic Spectrum Management (DSM)) in an efficient way. Moreover, how it affects current regulation [20], [21], [22], [23], [24], [25], [26], [27] that argue the need for a monitoring network to assure compliance of (DSA) radio equipment with regulatory rules [20], [23].

On the other hand, not much literature can be found how to design such a monitoring network. The design of this network and measurement methodologies are the topics of this paper.

Traditional spectrum governance is focused on minimizing interference and locate (illegal) interferers, such as illegal FM radio transmissions. Radio propagation is another topic of interest. To fulfill these tasks, every nation has set up a network of monitoring sites to monitor the spectrum. As an example, the monitoring network in the Netherlands has been depicted in Figure 1. The network consists of 12 monitoring sites that measure the received power from 100 kHz to 1.3 GHz in a 25-KHz raster.

However, the current monitoring network is not sufficient for the new tasks of spectrum governance, because modern communication uses a smaller service area per base station and also higher frequencies up to 6 GHz are used.

The paper is organized as followed. First, spectrum governance is briefly addressed and its requirements on the monitoring network. This is followed by an overview of this technical platform. With this network a vast amount of data is collected which needs to be processed efficiently. In the section modeling spectrum usage we discuss how to process this data and how to assess spectrum usage. The paper is ended by conclusions and future work.

II. SPECTRUM GOVERNANCE

In the introduction we have briefly described the goals of spectrum governance. In this section we elaborate on the tasks of spectrum governance and its relevance for society.

There are several social topics that have impact on spectrum governance:

- **Freedom of knowledge and innovation**. During the start of the European union, four freedoms were defined. Freedom of goods, services, people and money. Recently the freedom of knowledge and innovation was added [28]. For spectrum governance this means that it should remove constraints to allow new services and start of new companies.
- **Security**. ICT technology has become a very important technology for society and the society expects that wireless communication is secure. Therefore, it should be resistant against hacking, eavesdropping and jamming.
- **Quality of Service (QoS)**. Wireless communication should function reliably. The rise of spectrum usage makes this more challenging. Moreover, each electronic device radiates and receives electromagnetic waves. So, Electromagnetic compatibility (EMC) is important for spectrum governance.
- **Health**. Consumers are concerned about health and the influence of electromagnetic waves on the human body. A good understanding of the electromagnetic properties of the human body is for that reason essential.
- **Construction of buildings**. New buildings are designed to serve mankind. However, construction materials are not selected for their radio propagation conditions. So, modern buildings attenuate radio waves more than old buildings. As a result, mobile operators need to place more base stations in newly developed urban areas to obtain good coverage.
- **International radio communication meetings**. Radio waves do not stop at the border of a country. So, there are international meetings in which the spectrum is divided between countries. There is a lead time of several years in these meetings before new applications can be accommodated in the spectrum. The society and economy of a country is served best, if the government can assess the future spectrum needs.

A. Requirements

To serve these social topics, spectrum governance requires a technical platform that can address these topics.

Below we have listed important (technical) tasks of spectrum governance:

- Measure the spectrum usage.
- Measure and locate interferers.
- Verify that frequency bands are 'empty' before they will be used for a new technology.
- Measure the radio propagation conditions.
- Identify trends in telecommunication.
- Develop policies to stimulate efficient spectrum usage.
- Assess the impact of new technologies on the spectrum usage.
- Assess to what extent current networks/frequency bands can be used more efficiently.

The first four requirements have to be taken care of by a monitoring network. Each application requires a different approach of monitoring. For 'mission critical' applications like military, public safety and broadcasting services, interferers needs to be detected as soon as possible. For these kind of applications, a network of monitoring sites is required that measure real-time these bands "24/7". These services use frequency bands below 1 GHz and are mostly infrastructure-based. So, the current network in the Netherlands is suitable to perform these tasks.

For other services like mobile communication, sensor networks and mobile internet such a network is not sufficient. Therefore, we present in this paper to use mobile monitoring vehicles for these applications: a spectrum monitor mounted on a vehicle. For instance, they can be mounted on taxis or buses to get a good coverage in urban areas.

Benefits of mobile monitoring vehicles are:

- More mobile monitoring vehicles result in a better resolution.
- More mobile monitoring vehicles can be assigned to interesting areas.
- A mobile monitoring vehicle is very close to the actual users. Therefore it experiences the same spectrum as the users. Fixed monitoring sites measure a spectrum at a typical height of 50 m.
- The standard deviation of radio signals in place is much larger than the standard deviation in time. So, to get a good overview of the spectrum, one would like to have as many monitoring sites as possible.

In collaboration with the Dutch Radio communication agency, we have initiated such a network of mobile monitoring vehicles in the Netherlands. The system is based on the RFeye system of CRFS [29]. The RFeye system can be mounted on a normal vehicle and continuously measures the frequency spectrum to 6 GHz (see Fig 2). All the data is stored on an storage USB key and the collected data is used for offline analysis. At the moment of writing, 10 RFeye systems are built into vehicles. In [30] a similar setup is described for the British radio communication agency, OFCOM.

Fig. 2. RFeye system of CRFS

III. MODELING SPECTRUM USAGE

One of the most important questions for the regulator is to assess the spectrum usage. In this section we describe how to use the collected data of the mobile monitoring fleet. To assess the spectrum usage, we propose to put a grid on the geographic area under investigation. A typical size of a square would be 10 by 10 km, but its size depends on the application. In dense urban areas, the grid size can be chosen smaller and on the other hand in rural areas this size is too small. In each square, the measurements of all mobile monitoring vehicles are collected and we propose to pick N random measurement points. In addition, the minimum distance between each point should be at least M meters. In this way we get independent measurement points and we prevent biasing of measurements points, when for instance a mobile monitoring vehicle is stuck in a traffic jam.

In Figure 3, the measured radio spectrum between 100 MHz and 500 MHz is depicted, during one measurement day. It contains about 300 spectrum traces that are measured with our measurement vehicle (Rhode & Schwarz FSH) [31], while driving through Amsterdam. We use this data as initial results for our proposed method. Of course, in a real network of monitoring vehicles, more frequencies and also much more measurement data would be available. For that reason, we show only the output for the city of Amsterdam. In future publications we will present the results based on the RFeye system.

Figure 3 shows the measured spectrum in Amsterdam and four lines are depicted: the mean, median, minimal and maximum value of each frequency bin. Several conclusions can be drawn from this figure. First, the noise floor of our measurement equipment is around -140 dBm/Hz. Second, the spectrum between 230 MHz and 390 MHz is used for military purposes. As expected there is almost no activity in this band. Outside this band, several frequency bands are in use. In these bands there is a huge difference up to 45 dB between the minimum and maximum values. This difference is much more than reported in papers, which measure the spectrum at a single point [32], [**?**], [34], [35], [36], [37], [38]. Also, the figures reveal that for strong signals, there exists a difference of several dBs between the median and mean value.

Area	Median $\mu_{1/2}$	Mean μ	Std. dev. σ
public safety trun. rad.	-131	-134	8
comm. trunked radio	-137	-139	4
digital radio (T-DAB)	-124	-123	11

In Figure 4 the accompanying cumulative distribution functions (CDFs) are shown for three frequency bands; the public safety trunked radio network (around 400 MHz), the commercial trunked radio networks (around 425 MHz) and a T-DAB digital radio network (around 225 MHz). In Table I the median and standard deviation of these signals have been listed.

First of all, the broadcast network has a higher median value compared to the trunked radio networks. The downlink of the TETRA systems are always active, even when the system is not used. However, the T-DAB network is based on a single-frequency network (SFN) in which all transmitters use the same frequency. In our opinion this is the main reason for the higher median value. Moreover, the figure shows that the public safety system contains more transmitters than the commercial one, as it has a higher median value and standard deviation.

In the next step, the measured data is fitted to a model that represents the spectrum usage. In a basic model, the usage can be represented as a log-normal distribution and the regulator can use this model to perform its tasks. In this way the huge amount of data is represented by a model and a few parameters. Basically a single mark can be given to indicate the spectrum usage. In Figure 4 the measured data and the fits to the basic model are depicted. The maximum fitting error is 2 dB and in most cases this basic model slightly overestimates the spectrum usage.

In this example, the regulator may require from the commercial trunked radio network, that the 90% threshold is at least -125 dBm/Hz. If the measured value is lower, the license will be withdrawn, due to inefficient use. In case of Figure 4, the license will be withdrawn as the measured value is about -132 dBm/Hz.

So, this method allows a quick and efficient overview of the spectrum usage in all geographic areas. More research and data are required to study our proposed methods into more detail, but the initial measurements show promising results. Of course, it should be noted that the size of the geographic area can be dynamically assigned and more measurements and/or measurement vehicles will enhance the resolution of this data. So, overall this measurement setup is very flexible and can be tailored to the needs of the regulator.

IV. CONCLUSIONS AND FUTURE WORK

In this paper we have described a new monitoring network for spectrum governance. It consists of fixed monitoring sites and mobile monitoring vehicles. The fixed
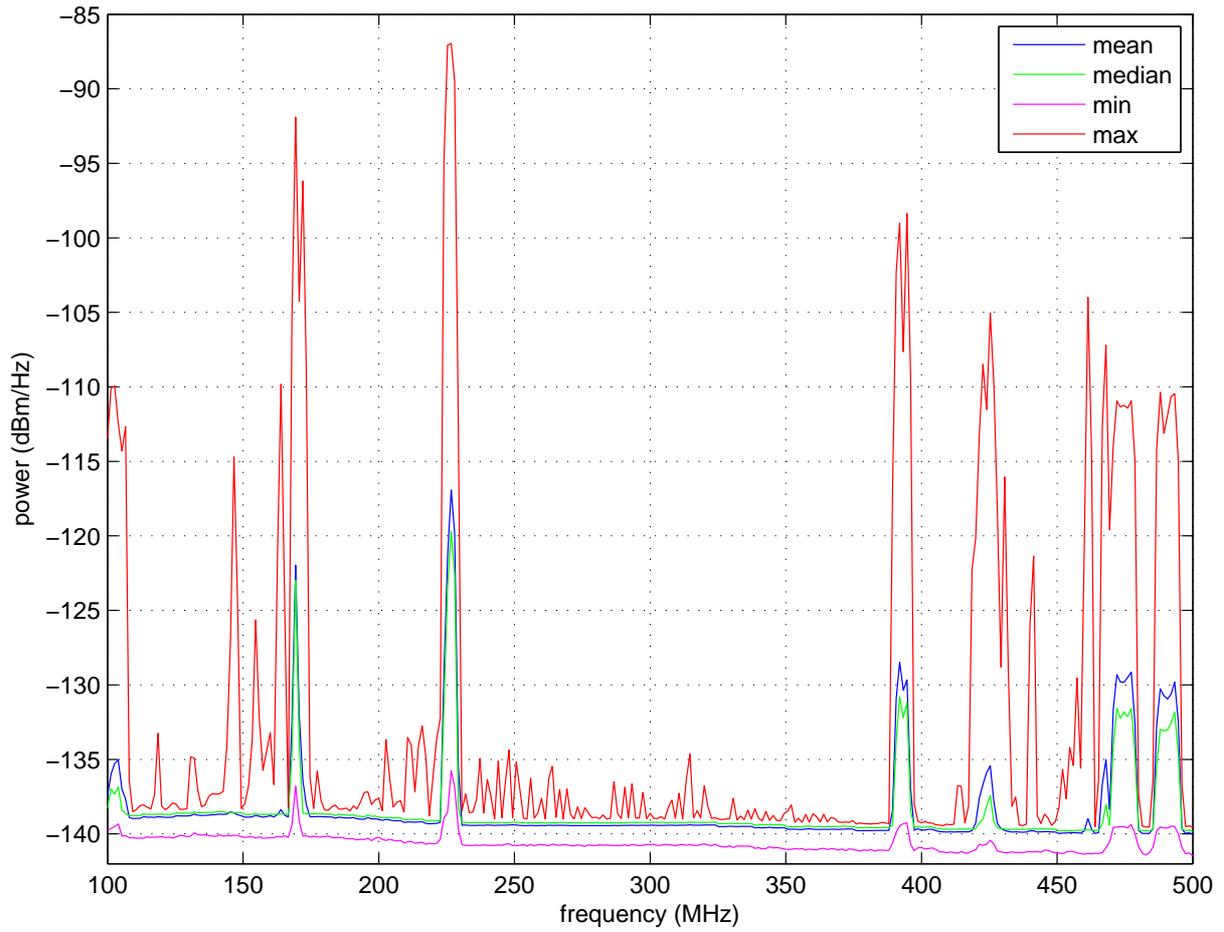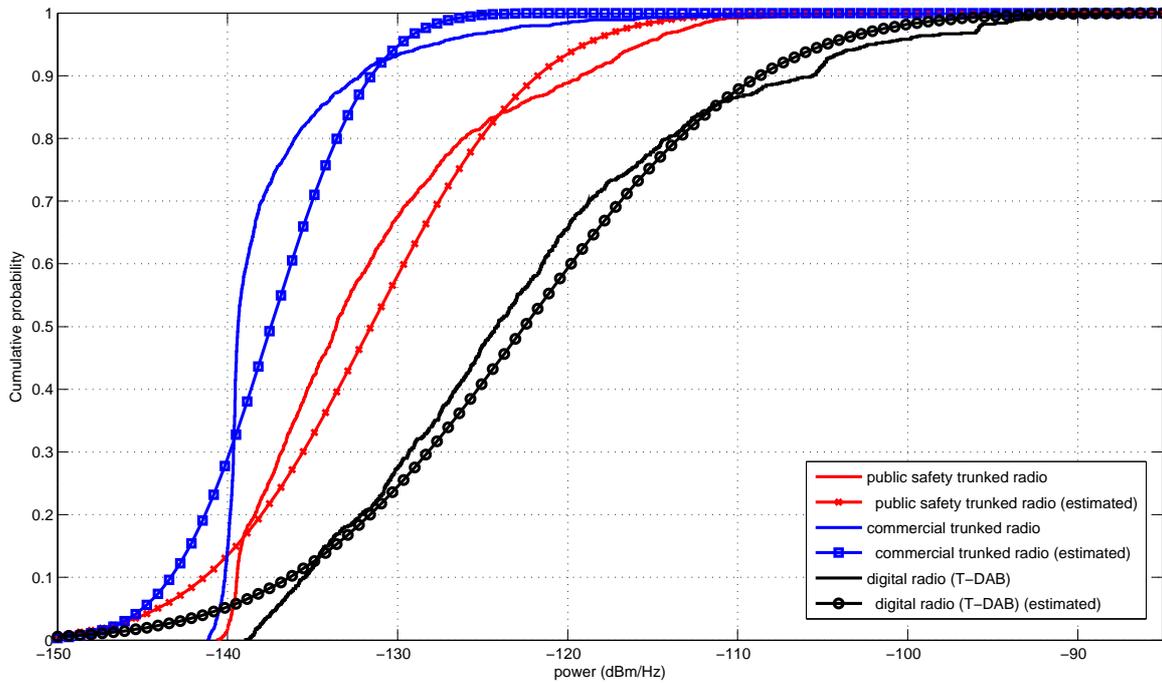
Fig. 3. The measured radio spectrum in Amsterdam.

Fig. 4. CDFs of a several radio networks based on the measurement data of Figure 3.

monitoring sites are used for the 'traditional' tasks of spectrum governance such as locating interferes. However, for modern communication this monitoring network is not qualified anymore. The main reason for this is that modern communication use high frequencies, above the 800 MHz, and communicate mainly locally. Hence, a very dense network of monitoring sites would be required which is economically infeasible. Therefore, we have proposed to use mobile monitoring vehicles. In addition, we have described methods to analyze the measured data, which we have validated by example measurements in the 100 MHz to 500 MHz band. The proposed method allows to determine the usage in a particular frequency band and geographic area. The size of this geographic are can be dynamically changed according to the needs of the regulator. Moreover, more measurements and measurement vehicles enhance the resolution of monitoring network.

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