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Spectrum Occupancy Measurements in the 2.3-2.4 GHz band: Guidelines for Licensed Shared Access in Finland

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Abstract

This paper presents results from spectrum occupancy measurements in the 2.3-2.4 GHz band at Turku, Finland. The band is currently under study in European regulation and standardization for mobile communication systems. We review the recently introduced Licensed Shared Access (LSA) concept as a potential means for making the 2.3-2.4 GHz band available for mobile communications on a shared basis while protecting the rights of the incumbent spectrum users. The spectrum occupancy measurements conducted in one location in Finland show that the use of this band is rather low indicating that there might be potential for mobile communication systems to share this band with the incumbents under the LSA approach. Based on the obtained knowledge about the use of the studied band in Finland we create a set of guidelines for LSA to make the operation efficient both from the technical and economic viewpoint.

Keywords: cognitive radio, spectrum measurement, spectrum occupancy, spectrum sharing.

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1. Introduction

Mobile data traffic forecasts predict a significant growth towards the year 2020 as summarized e.g. in [1]. As the increasing demand of mobile traffic is leading to increasing spectrum demand for mobile broadband, it is important to find cost-efficient means to respond to the growth in a timely manner.

Making new spectrum bands for the mobile service is currently under discussion in international, regional and national levels. This process takes time from the start of the discussions until the band becomes available for the operators of mobile/fixed communication networks (MFCNs) to deploy their networks. The timely availability of the bands is important to successfully respond to the growing demand. In particular, there are already globally allocated bands for the mobile service but they currently encompass other type of incumbent spectrum use. Making these bands available for sharing could help operators of MFCN to continue offering wireless services to the growing market. Attempts into this direction are currently taking place in the European regulation and standardization in the form of the LSA concept in the 2.3-2.4 GHz band, see [2], [3], and [4]. When applied to the mobile broadband, the

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LSA concept would allow spectrum sharing between an operator of MFCN and another type of incumbent spectrum user under the supervision of the regulator with licensing conditions and rules that guarantee attractive access conditions for both stakeholders.

Spectrum occupancy metric is a tool to assess the current use of spectrum as described e.g. in [5]. Spectrum occupancy describes the utilization rate of the band based on measurements of the radio spectrum. Several general spectrum occupancy measurement studies have been conducted in different locations with the aim to capture the overall utilization rate of spectrum, see e.g., [6] and [7]. Specific measurement studies have focused on selected bands, such as the ISM band [8], [9]. However, little effort has been spent on measuring specifically the 2.3-2.4 band which is currently under study as the first application area for the new LSA concept in Europe. Partly the band has been studied in Netherlands few years ago in the 2.36-2.4 GHz band. The study shows low occupancies with a bursty traffic [10]. The signals analyzed in detail in this paper were narrowband low data rate amateur transmissions.

This paper addresses specifically the current spectrum use of the 2.3-2.4 GHz band in Europe and presents initial findings of spectrum occupancy measurements in this band in one location in Finland. The paper is an extended version of [11], focusing on the situation in Finland and developing guidelines for national LSA sharing framework based on the obtained knowledge during the measurement campaign. Proposed guidelines are complementary to the LSA workflow described in [12]. The rest of this paper is organized as follows. The status of the 2.3-2.4 GHz band regarding its current use and availability for mobile communications in Europe is presented in Section 2. The spectrum occupancy measurement setup is described in Section 3. Analysis of the spectrum occupancy measurement results is presented in Section 4. Opportunities and guidelines for LSA operation are defined in Section 5. Research challenges are discussed in Section 6 and finally, conclusions are drawn in Section 7.

2. Use of 2.3-2.4 GHz Band in Europe

2.1 Regulatory status

International Telecommunication Union Radiocommunication sector (ITU-R) has globally allocated the 2.3-2.4 GHz band to the mobile service and identified it for International Mobile Telecommunications (IMT) systems at the World Radiocommunication Conference in 2007 (WRC-07). Currently in Europe, this band is predominantly used by other incumbent radiocommunication systems than the mobile communication systems. To study the potential of this band, an economic analysis of the impact of making the 2.3-2.4 GHz band available for mobile communications in Europe is presented in [13]. The analysis indicates that in certain scenarios the total value of this band in Europe could rise up to 30 billion €. Thus, this band has a considerable value if used for mobile broadband. Compatibility studies on the potential use of this band by mobile communications are presented in [14] including sharing scenarios within the band as well as between adjacent bands.

The current use of the 2.3.-2.4 GHz band in Europe is summarized in the results of the WGFM questionnaire [15]. 27 countries are currently using all or parts of this band for PMSE (programme making and special events) applications, such as cordless cameras and video links. Other usage in at least five countries included amateur services, aeronautical telemetry, governmental use including military, mobile applications and fixed links. In Finland, this band is currently used for amateur service, wireless cameras and video links.

The concept of LSA is currently under study in Europe in the 2.3-2.4 GHz band as a possible means for making this band available for mobile communication systems on a shared basis. The European Commission (EC) has defined LSA as *"A regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the Licensed Shared Access (LSA) approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorised users, including incumbents, to provide a certain Quality of Service (QoS)* [2]*"*.

The CEPT is studying the LSA concept in its two frequency management project teams, FM52 and FM53. FM53 is developing the regulatory framework for LSA containing general analyses of LSA, related regulatory framework, current practices for management of spectrum and frequency authorizations as well as application of LSA to the mobile broadband, see [3]. FM52 is studying specifically the applicability of the LSA concept for MFCN in the 2.3-2.4 GHz band. FM52 has developed an ECC Decision aimed at harmonising implementation measures for mobile/fixed communications networks (including broadband wireless access systems) in that band including least restrictive technical conditions as well as border coordination issues [17]. In standardization, ETSI has developed a system reference document [4] for mobile broadband in the 2.3-2.4 GHz band with LSA and is currently working on the requirements as well as architecture for LSA.

In the Northern America, the 2.3-2.4 GHz band is used for satellite radio repeaters, medical devices, aeronautical telemetry and amateur radio, all of which need protection. Some results and analysis about the USA situation can be found in [11]. Due to multitude of incumbent services and rather heavy use of this band the sharing of the band would be much more complicated than in Europe. Thus, the maximum bandwidth that might be released for mobile services is 20 MHz in the US and Canada whereas up to 100 MHz is possible in Europe.

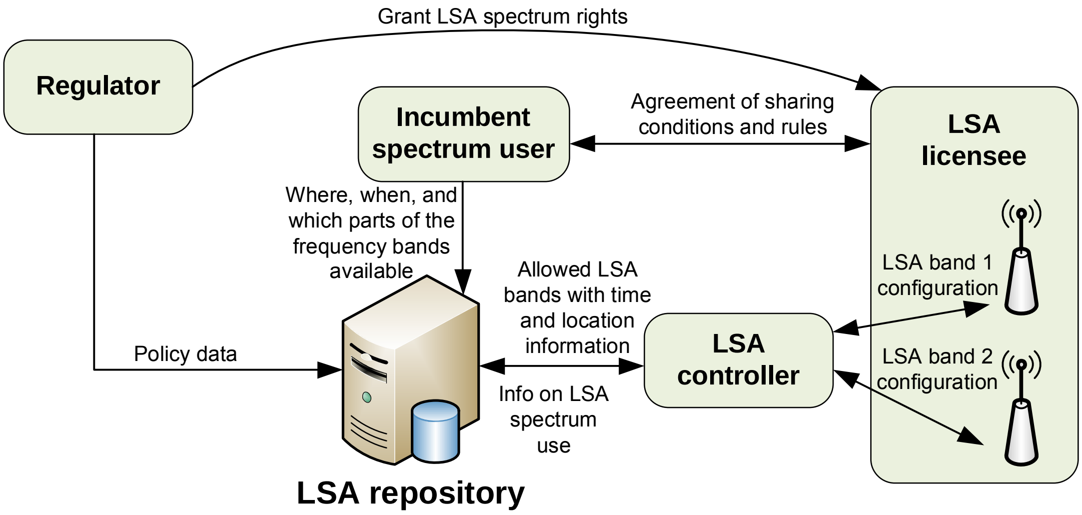


Figure 1. LSA functional architecture

2.2 Incumbents in Finland

The 2.3 GHz band is reserved for PMSE services and amateur radios in Finland. Mostly the band is used by wireless cameras while amateur radios use the spectrum only occasionally as a secondary service. Thus, we focus on the PMSE services in this paper. There are both mobile, dynamic users such as TV crew attending some sports or cultural events with their wireless cameras as well as more fixed or static use at key theatres and TV studios located e.g., in Helsinki.

Transmission parameters for the incumbent PMSE services are described in [14] and [16]. Maximum effective isotropic radiated power (EIRP) for cordless cameras reserving 20 MHz bandwidth for their transmissions is 6 dBW, i.e., 4 W. Transmission power of a wireless camera is dependent on scenario but usual values are 17 dBm (handheld) and 30 dBm (e.g., from motorcycle). In addition, there are cameras with 10 MHz bandwidth as well.

Wireless camera users do not allocate their spectrum with a specific protocol nor using any centralized controller in the 2.3 GHz band in Finland. Instead, they coordinate the use of frequencies among themselves and can select any frequency inside the band which makes the spectrum use somewhat unpredictable. Additionally, there is a high degree of locality and temporality in the use of PMSE devices. Wireless cameras are typically used in a limited area for a certain event over a limited time span. Outside of the static wireless camera use at the key theatres and TV studios the sharing arrangements can be enabled by the LSA concept. Static exclusion zones will be used to protect key studios and theatres.

2.3 LSA architecture

The objective of LSA is to grant limited number of additional spectrum rights of use while ensuring guaranteed QoS for all spectrum sharing services. Administrations wishing to introduce LSA based MFCN in the 2.3 GHz band will be required to follow guidelines provided in [17] regarding the potential MFCN deployments and potential incumbent usage scenarios. However, details for the implementation of LSA are left to national administrations to increase flexibility and to allow efficient sharing that takes national spectrum use into account.

High-level architecture and related connections between the main LSA components are shown in Figure 1. The LSA concept is based on the spectrum database called LSA repository. It contains policy data from the regulator as well as agreement of sharing conditions and rules from the incumbent user. Incumbents are required to inform the LSA licensee not only of the current availability of the spectrum but also of the spectrum availability for the whole duration of the sharing framework [3]. Location information needs to be attached in the data both by the incumbent user and by the LSA licensees requesting the spectrum for limited amount of time.

Repository can be accessed in real-time to support dynamic spectrum sharing as well. In that case, an important part of the repository would be to keep so called interference map [18] (part of radio environment map) up-to-date. The interference map defines RF power distribution in time, space, and frequency domains. The map is constructed by combining spectrum measurements from several points with the suitable spatial interpolation techniques to obtain knowledge about the current interference environment. The concept has been proposed for LSA based LTE-Advanced network recently in [19]. Interference map has not yet been included in LSA related regulatory discussions but we see it as an improvement to the basic concept.

Figure 2. CRFS RFeye spectrum monitoring node

LSA controller manages the access to the local spectrum in the 2.3 GHz band based on the rules and information retrieved from the repository. It can update the repository by providing spectrum use information from the LSA licensees. In addition, LSA controller evacuates the channel on demand by shutting down LSA licensee transmissions in the band e.g., when requested by regulator or the incumbent user or when the licensing agreement expires [20]. Controller may be connected to several LSA repositories through a secure and reliable communication path. As is defined in [3], interfaces between different components in the LSA architecture need to be standardized to ensure interoperability and harmonized market in Europe.

The LSA concept has been trialed in Finland in April 2013 with a live TD-LTE network sharing the 2.3-2.4 GHz band with PMSE services, see [20]. Based on these initial experiments the evacuation time λ from the request to actually block the LTE base stations in the area is up to 30 seconds. This time is mainly dependent on the used hardware and provides insights on the possible dynamic spectrum use with these systems.

In the study of the potential for the LSA concept in the 2.3-2.4 GHz it is useful to assess the current use of this band by measuring the spectrum occupancy. For this purpose, spectrum occupancy measurement system has been setup in Finland which is described next.

3. Spectrum Occupancy Measurement Setup

The spectrum occupancy measurement setup consists of a CRFS RFeye receiving system [21], data storage, and data transfer equipment. The RFeye receiver (shown in Figure 2) is a dedicated FFT-based spectrum analyzer that has the following technical specifications: frequency range 10 MHz to 6 GHz, fast digital sweep with maximum of 20 MHz bandwidth, resolution bandwidth (RBW) selectable between .073-1200 kHz, four RF inputs, rugged compact outdoor environment construction and Global Positioning System (GPS) support. It is able to send the measured data via Ethernet to a centralized database. We used a broadband omni-directional and multi-polarized antenna covering the 85-6000 MHz frequency range. The antenna is mounted on a four meter mast. Used RBW in 2290-2400 MHz sub-band is 78.125 kHz a revisit time of 3 seconds and measurement time is a few milliseconds per frequency bin. The whole band is divided into 17 sub-bands and is continuously monitored with a selected set of parameters. See [22] for details regarding the RBW and revisit time in other sub-bands.

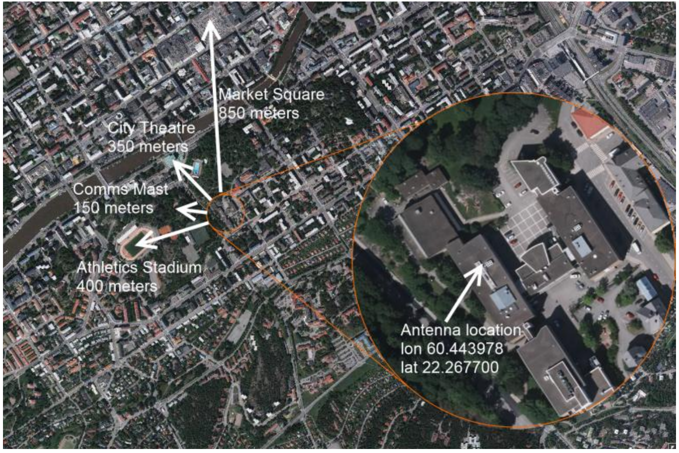


Figure 3. Spectrum occupancy measurement antenna in Turku, Finland

The measurement setup used in the Finnish measurements is located near central Turku, installed on the roof of a four story building at Turku University of Applied Sciences Sepänkatu campus. The location of the antenna as well as the nearby environment is shown in Figure 3. There are several cellular base stations and wireless local area network (WLAN) access points installed to serve campus area users. A nearby communications mast is equipped with public safety as well as cellular antennas. City theatre and stadium are places where PMSE users may operate. The power supply and intermediate data storage drives are co-located in the building. A more detailed description of the setup including related global spectrum observatory can be found in [22].

The measurement setup has certain limitations, especially regarding the generalization of the results. The measurements have been conducted at a single location in Turku. Thus, it shows the situation exactly at that point, being able to report the transmissions of power-limited devices at near vicinity. The environment is not controlled, i.e., we do not know what the possible devices to be seen in that area are. However, to obtain confirming results we have made measurements also with a known wireless camera transmitter using 23 dBm transmission power. Due to limited transmission power of incumbent users in Finland there is a need for location specific measurements in other places in order to obtain better generalized results regarding the use of 2.3-2.4 GHz band. Another RFeye has already been obtained and we are currently conducting measurements in different locations.

One limitation is related to the resolution of the measurements in time domain. The revisit time [5] of the measurements is 3 seconds which means that you cannot detect short idle and busy times in the primary transmission. Thus, modelling of traffic patterns is limited. However, the measurements show a long-term situation at a centre of a decent sized city (180 000 inhabitants) in Finland. This provides insights to the use of band in other cities as well.

4. Measurement results

Two different weeks have been measured in Turku, Finland, and analyzed for this paper (10.10.–16.10.2013 and 7.11–13.11.2013). The weeks represent typical spectrum use at the measurement location in consecutive months, allowing us to do correlation studies between these time periods.

Power spectrum plots of Turku measurements for each day are shown in Figure 4. The first row shows Thursday measurements at 10.10.2013 and 7.11.2013, the second row Friday measurements 11th October and 8th November 2013 etc. The figures include both maximum signal powers on the measured day as well as average power spectrum over the measurements at each frequency bin.

The max signal power is much higher than the average power in the shown figures even in the frequencies where no signal is measured. This is because of the automatic gain control (AGC) and attenuation settings of the used RFeye device. The noise floor rises as the RFeye uses AGC/attenuation that changes rapidly from frequency to frequency. The RFeye has several sub-bands (like 1200 to 4100 MHz band) in the RF front-end. If there is a very strong signal in any of the sub-bands (now strong cellular signals near 1800 MHz), the device uses a high attenuation to prevent overload. The high attenuation setting raises the noise floor, leading to higher max power spectrum as well. When the strong signal is absent, the RFeye uses a lower attenuation setting causing the noise floor to fall, which over time results in a low average power spectrum. Thus, the difference between the noise floors of average and max shows the range of dBs that the AGC/attenuator changes in the RFeye.

It can be seen in the figure that there are signals seen across the entire band. As was expected, we can see 20 MHz wide signals in the power spectrum, representing the wireless cameras that are licensed users of the band in Finland. In addition, some 10 MHz wide wireless camera signals and sporadic narrow signals are seen in the max spectrum. These narrow signals most probably represent amateur radios that can operate in this channel.

The threshold to use for the spectrum occupancy calculations can be calculated as 9-12 dB above the average power spectrum or 2 dB above the max power spectrum to account for the AGC changes. Thus, we set the threshold as -93 dBm for the analysis. The frequency band occupancy (FBO) can be defined as [5] $FBO = N_O/N$ where N_O is the number of measurement samples with levels above threshold and N is total number of measurement samples taken on the channel concerned during the integration time. The detected occupancy values in the band were really low in all the measured days, showing $FBO \ll 1\,\%$. The same was true for separate channels as well, i.e., there were no channels where the spectrum use was long term during the observation time.

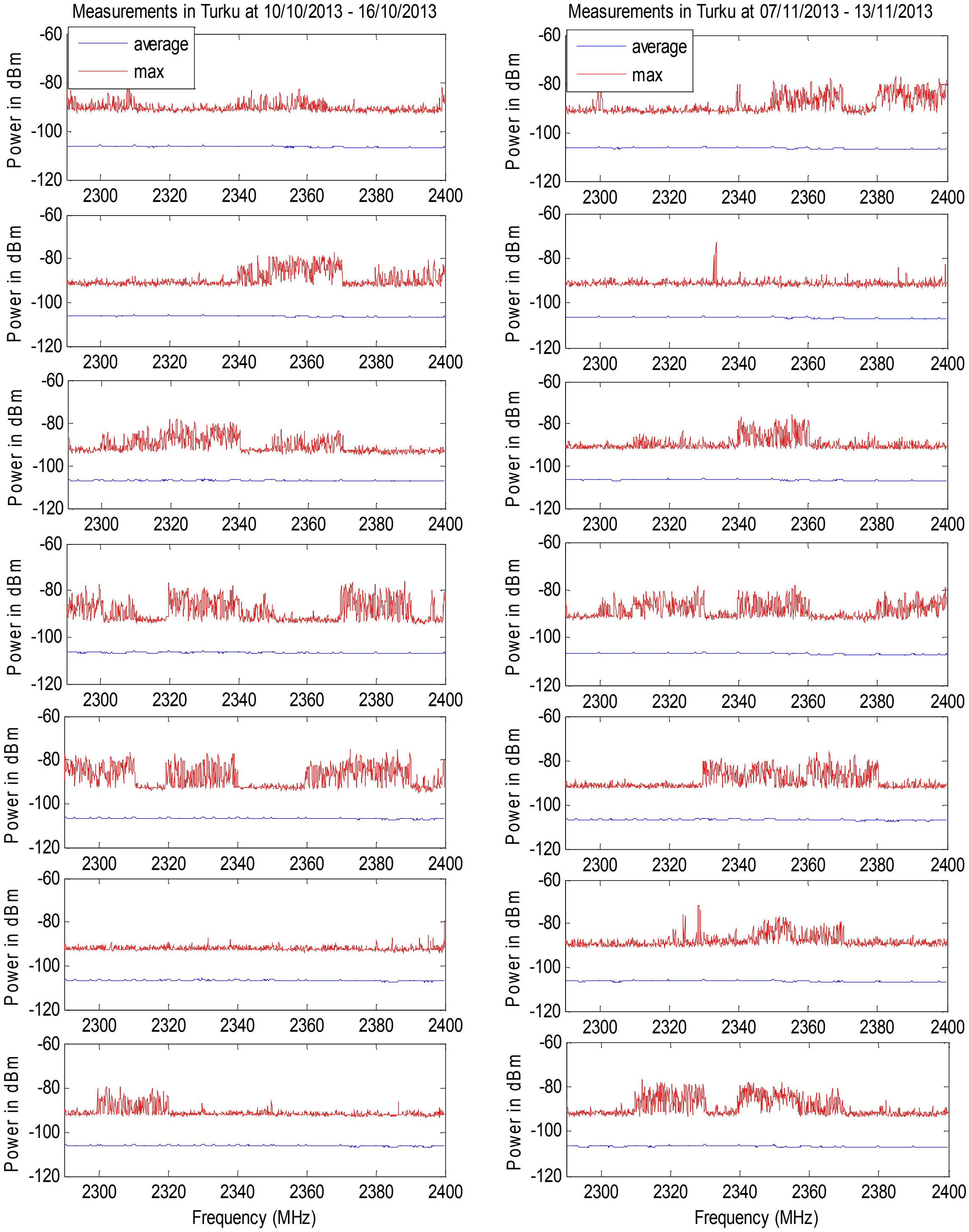
Busy period examination was made to see the type of signals in time domain. Busy period T_O where a particular channel has a measured signal above the defined threshold is given as $T_O = N_C \cdot T_R$ where and N_C is the number of consecutive occupied time slots and T_R is the revisit time. We assume that when a channel is still found to be occupied after the revisit time, it is assumed that it has also been occupied during the time in between two subsequent measurements on that channel. The detected busy periods with this method in the 2.3 GHz band in Turku measurements were all $N_O = 1 - 3$ time slots long, i.e., between 3 and 9 seconds. This means that all the detected signals were rather short in time.

One of the reasons to study whole weeks from the consecutive months was to investigate whether there is correlation seen in the use of the channel. However, the spectrum use is low and sporadic. It can be seen in Figure 4 that the 20 MHz wide signals produced by wireless cameras in October are located at different frequencies in November. Thus, there seems to be no correlation between the observed signals in October and the ones seen in the following month. The same conclusion regarding the correlation can be seen in the time domain as well as in the frequency domain. The main reason for this is the fact that wireless camera users can select any frequency inside the band for their use which makes the spectrum use somewhat unpredictable.

To further investigate the duty cycle and usage patterns of the wireless video cameras and amateur signals detected at Turku, a graph of the time series of integrated powers in the 2.3-2.4 GHz band, and a second occupancy time series graph were generated for the 2 weeks mentioned earlier. The integrated time series and percentage occupancy for the Turku measurement weeks are shown in Figures 5 and 6.

The time series graphs show the integrated power of the whole band during the respective measurement weeks. The instantaneous integrated power is the summation of all the power measurements within the 2.3-2.4 GHz band during each measurement sweep. In the upper plots of Figures 5 and 6, the values in yellow correspond to the instantaneous power values, while the red values are obtained with a 5-minute moving average filter that reveals usage trends. This filter averages samples over previous 5 minutes to reveal whether the spectrum is used over longer periods. The gaps in the time series plots are due to missing data.

Percentage occupancy graphs (lower plots in Figures 5, 6) show the amount of the band in use at a certain time. During each sweep, a threshold is applied at each frequency point to determine if the measured power exceeds the noise floor and is a valid signal. The selection of the threshold and the noise floor calculation algorithm are introduced in [22]. The fraction of frequency points that exceed the noise threshold corresponds to the occupancy percentage during that sweep. The values in green correspond to the instantaneous occupancy values, while the blue values are obtained using a 5-minute filter, again to reveal any patterns in the traffic usage.


Measurements in Turku at 10/10/2013 - 16/10/2013

Measurements in Turku at 07/11/2013 - 13/11/2013

Figure 4. Average (blue) and maximum (red) power spectrum in 2.3 GHz at Turku, Finland. Each column represents a week and a row in a column represents a day.

From the occupancy time series, it is seen that the occupancy is close to 20% when a wireless camera transmits (as labeled in Figures 5 and 6). This is expected as a typical camera channel uses 20 MHz out of the 100 MHz band for its transmission. Some of the other short duration higher power peaks in the time series of integrated powers are likely to be narrowband amateur radio services.

Since the wireless cameras are low power, detection sensitivity is a problem. This is exacerbated by the fact that simple energy detection via thresholding is used to calculate the occupancy numbers. The signal powers of the wireless cameras at the measurement location are often below the noise threshold, which leads to a rather noisy instantaneous occupancy graph. However, the filtered occupancy plots indicate that the previous detection of very short busy periods might be underestimated and cameras could be active for clearly longer times. Still, due to limited detection capability we are not able to see real activity times.

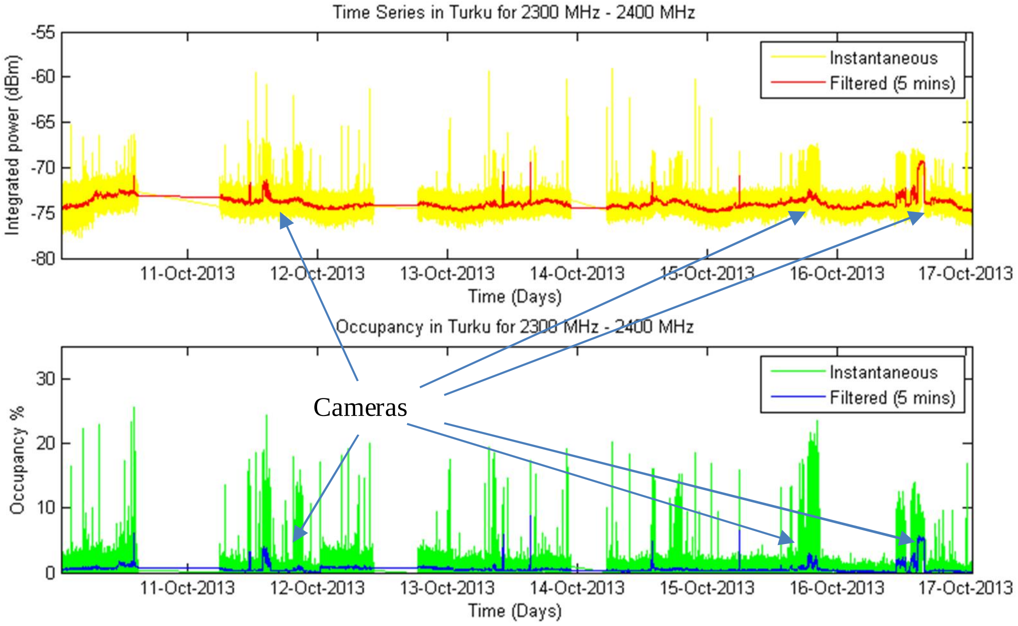


Figure 5. Integrated power time series and percentage occupancy at Turku (Oct 10th – 17th 2013)

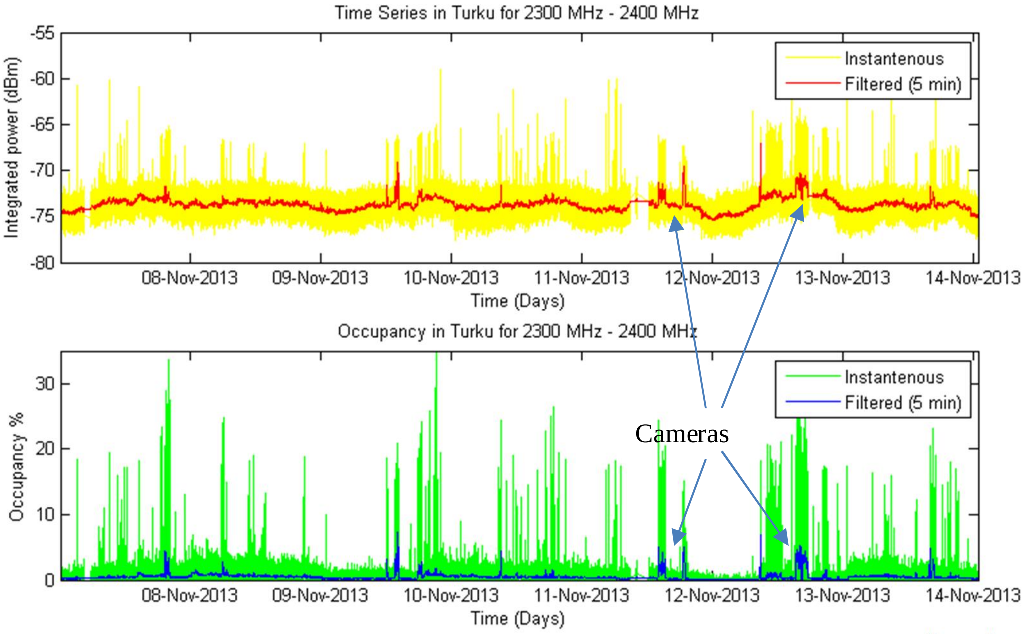


Figure 6. Integrated power time series and percentage occupancy at Turku (Nov 7th- 14th 2013)

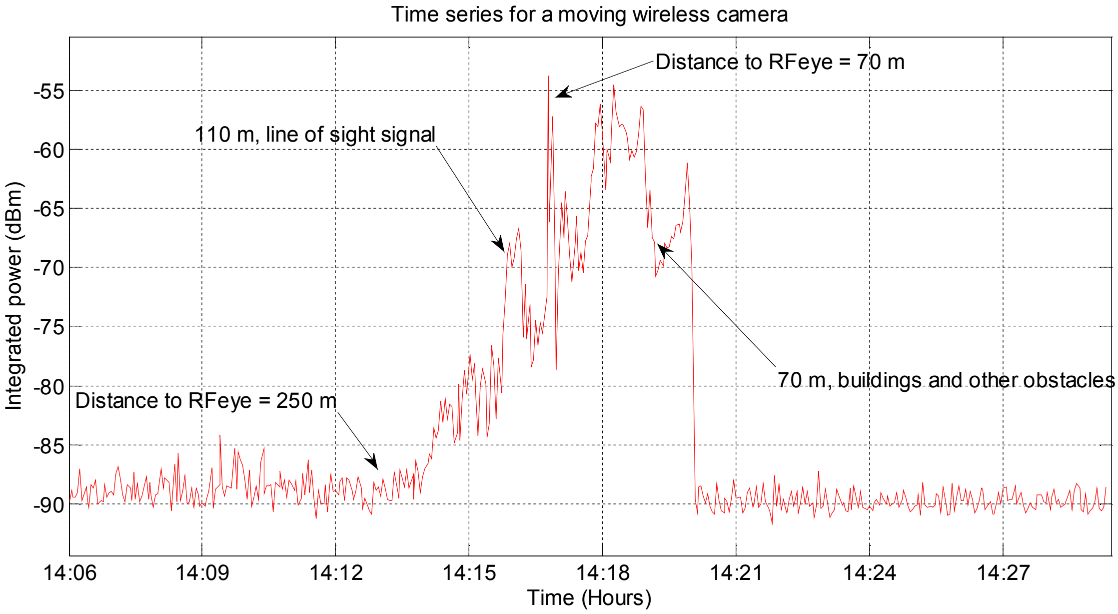


Figure 7. Integrated power time series for a moving wireless camera.

Finally, in order to have a better view on the detection performance of the system we performed measurements with a portable wireless camera. The integrated power time series results for a moving 23 dBm camera signal are shown in Figure 7. It can be seen that the RFeye was able to detect the signal when the camera was closer than 250 meters from the measurement point. Naturally the detected power is increasing when the camera approaches. The signal power is higher than -70 dBm when the distance is around 110 m and there is a line-of-sight connection from the RFeye antenna. Finally the camera passes the measurement point roughly 70 meters away and signal power varies due some obstacles in the signal path. However, the signal is clearly detected until the camera is switched off at 14:20.

These results show that in order to detect low-power wireless camera signals the measurement devices need to be located rather close to them. Thus, a single measurement device gives only hints about local spectrum use and therefore the location of measurement device(s) need to be carefully selected. It should be noted, as described in Section 2.2, that wireless cameras may use higher power than the device measured here and are thus detectable from a greater distance compared to the camera we tested.

5. Opportunities and guidelines for LSA operation

Detected spectrum occupancy levels in the measurements show that the 2.3-2.4 GHz band might provide significant amount of additional capacity in the future through spectrum sharing. Clearly more than 90 % of the spectrum was shown to be idle in one specific measurement location in Turku, Finland.

The 2.3 GHz band has potential for the LSA concept in Finland. In particular, it is critical in LSA to protect the current incumbent users, such as wireless cameras in Finland, and make rules that allow interference-free operation both for incumbent spectrum users as well as the upcoming LSA licensee. This allows e.g., mobile communication systems to share the same band and provide additional capacity for ever-increasing need of cellular users.

We propose here guidelines specifically for Finland since LSA is likely to differ from country to country due to current spectrum allocations. Operational guidelines are shown in the Table 1. Exclusion zones regarding the co-channel as well as adjacent channel operation are needed for PMSE devices in order to protect their operation from the LSA licensee interference.

The first guideline defines a mandatory, static exclusion zone for key TV studios and theatres for the whole 2.3 GHz band. The protection distance between a typical LTE base station and cordless cameras was defined to be 3-4 kilometers for 10 MHz and 20 MHz wide camera links in urban area in [14]. Thus, static co-channel exclusion zone should be at least 4 kilometers in the worst case. With directional antennas and beamforming the separation distance can be reduced considerably.

Guideline number 2 considers events held in a limited area over a limited time. During the event the same conditions as in rule 1 are valid, otherwise the sharing in that area is dynamic. Examples of this kind of events could be rock concerts or sports events held in a large stadium.

Guideline 3 considers protection of mobile PMSE users. LSA framework should support mobility of the incumbents such as motorcycles with wireless cameras. The dynamic sharing limits especially the co-channel interference whereas other channels than the one used by mobile wireless camera can be allowed when the protection distance is enough. Based on the analysis done in [14], adjacent channel is required to be free at least over 400 meters in the worst case where antenna directions are aligned.

This cannot be provided without *guideline 4* since the location of the device need to be known. The PMSE devices need to report their locations and frequency allocations. Otherwise interfering LTE transmissions cannot be avoided around these devices. This should happen automatically without PMSE users' need to constantly contact the LSA repository in order to update their locations. The same protection distances as discussed above apply for mobile users as well. Especially this is important due to limited capability in detecting the devices as was shown in Figure 7. *Since the protection distance is much larger than the detection distance, the operation cannot be based on the spectrum measurements conducted at locations where LTE users are.*

Interference control can be made more efficient by optional *guideline 5*. If the PMSE devices would report their characteristics to the repository, more efficient sharing in spatial domain would be enables. When the interference tolerance of a victim PMSE device is known the LTE transmissions can be allocated accordingly, using different protection distances to different type of PMSE devices. Worst case assumptions on interference tolerance are used if the type of the device is not known.

Guideline 6 describes a step further that would be to define an interference map based on the available information about PMSE devices and their characteristics over a specific area. The interference map or power spectral density map defines radio frequency (RF) power distribution in time, space, and frequency domains [18], [19]. The map would show the possible locations for LTE users using either same or adjacent bands for transmission. This is also an optional feature that would enhance the simpler basic LSA concept.

As *guideline 7* proposes, LTE operation should focus on those frequencies offering reasonably long transmission possibilities. LSA repository creates a list of available frequencies and times in the area of interest that is used as a basis for selection. In case of incumbent appearance the LTE transmissions need to be offloaded to other frequency bands possibly using different technology such as Wi-Fi. Based on the real-world demonstrations reported in [20] the evacuation time of the LTE base station from a certain band is up to 30 seconds to carry out seamless handover without connection breaks. Thus, due to this time, appearance of PMSE devices should be known in advance.

Guideline 8 states the evacuation should start at latest λ seconds before the appearance of PMSE users. This parameter is dependent on the implementation of the LTE modules and can change considerably among available devices in the market. Mobile PMSE devices need to report to the LSA controller/repository when they are planning to start their operation. In vast majority of cases it is not a problem at all for the user of PMSE device to wait for evacuation time λ before starting her operation. For example, delay of 30 seconds is totally acceptable in almost all cases. Size of the area of evacuation can either follow worst-case assumptions or if possible, taking the characteristics of requesting devices into account.

Table 1. Operational guidelines for LSA

Guideline	Type
1) Exclusion zones for key TV studios and theatres	Mandatory, static
2) Exclusion zones during large events where PMSE devices used	Mandatory, static during event, e.g., around stadium
3) Exclusion zone for mobile PMSE users	Mandatory, dynamic
4) PMSE devices need to tell locations and frequency allocations	Mandatory
5) Interference tolerance of the PMSE users to be reported to the repository	Optional, required for dynamic sharing situations
6) Interference control via use of interference map	Optional, recommended for dynamic sharing situations
7) Cellular LSA licensee should aim to use spectrum holes longer than few minutes	Mandatory, offloading to other bands to be used
8) Evacuation of the LSA spectrum should be started at latest evacuation time λ before incumbent appearance	Mandatory, mobility of PMSE devices to be taken into account
9) Data in the repository should be updated often enough to enable interference-free operation	Mandatory

Finally, *guideline 9* states that the data in the LSA repository should be kept up-to-date by the incumbents as well as by calculating e.g., required interference information based on the given data. Then, both PMSE and LSA users can experience predicted QoS in an interference-free environment. It is important that the repository can be contacted with different type of devices, e.g., mobile PMSE user might send an evacuation request using her mobile phone. Spectrum measurement results can be updated in the repository to obtain additional information about the current spectrum use.

6. Research challenges

We have addressed here guidelines for definition of sharing rules to be used within the LSA concept in Finland. Additional information on LSA work flow regarding tasks of incumbent, regulator, and mobile network operator are discussed in [12].

Important issues to be solved in the future include the following. Interference measurements are required to make practical rules for sharing. Interference tolerance studies of PMSE devices with the planned LSA users need to be performed. Worst case coexistence analysis between LTE and wireless cameras was conducted already in [14], showing that "In cordless or portable camera scenarios, coexistence can be feasible in the adjacent and alternate channel case; it has to be decided on a case-by-case basis if additional protection and sharing mechanisms have to be employed. In the co-channel case, dedicated protection and interference mitigation mechanisms would be required if LTE and video links are used at the same time in the same area." However, interference measurement studies with real devices in real environments are needed to better understand the potential for LSA operations both in co-channel and adjacent channel scenarios.

Location awareness together with rules conducted from interference measurements can help to create a spectrum database [23] (such as LSA repository). In addition, it is important to consider how to enable sharing when the locations of PMSE devices are not known because not all of the current devices could easily provide their location information unless new incumbent manager tools are developed. This can be done in some cases by following the guideline 2, i.e., by local exclusive reservations of the band.

7. Conclusions

This paper has summarized the results of initial spectrum occupancy measurements conducted in one specific location in Finland focusing on the 2.3-2.4 GHz band. The measurements give useful insight into the current use of this band which is very low and sporadic at least in the selected measurement location in Finland. Clearly there is room for spectrum sharing to boost the wireless capacity. However, current measurements only show some indications on the channel use. We can see that there can be wireless camera users across whole band in Finland. Thus, we have to be very careful in allowing other users to operate in any part of the band.

If licensed sharing based on the LSA concept was introduced, there would be a need to protect the incumbent spectrum users such as wireless cameras operating in the studied band in Finland. Conducted measurements with a known wireless camera signal show that the ability to detect signals is limited to close vicinity of PMSE devices. A lesson learned is that spectrum knowledge cannot be gathered by sensing at the locations of LTE users due to large difference in sensing and protection ranges.

We have proposed multiple operational guidelines for LSA and discussed about related opportunities and challenges in the measured band. The proposed guidelines are designed to support Finland situation but can be easily modified to cover other countries as well taking their specific regulatory constraints into account. Still more spectrum measurements on several locations as well as interference measurements with the current incumbent users need to be performed before LSA operation can be allowed and final rules for the operation given.

Sporadic use and low-power transmissions of wireless cameras make the occupancy measurements challenging. The future occupancy measurements need to be performed with optimized parameter settings, meaning that resolutions, antenna heights, filters etc., to be set according to 2.3 GHz signal scenario. To obtain better overall picture on the spectrum use in 2.3 GHz band in Finland the measurements need to be done both in different locations in Turku as well as in other cities, e.g., in Helsinki. In addition, more measurements are needed during the events where PMSE devices are transmitting. We are planning to continue the measurements with several mobile measurement devices that will be used simultaneously in different locations.

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