Measurements and Analysis of Spectrum Occupancy in the 2.3-2.4 GHz band in Finland and Chicago

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***Abstract*—This paper presents results from spectrum occupancy measurements in the 2.3-2.4 GHz band at Turku, Finland and Chicago, USA. 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.**

Keywords—cognitive radio, spectrum measurement, spectrum occupancy, spectrum sharing

I. Introduction

Mobile data traffic is experiencing significant growth towards the year 2020 as predicted by different traffic forecasts 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 mobile network operators (MNOs) 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 mobile communications could help MNOs 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 Licensed Shared Access (LSA) concept in the 2.3-2.4 GHz band, see [2], [3], and [4]. When applied to the mobile broadband, the LSA concept would allow spectrum sharing between an MNO 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 with a comparison to the situation in US. 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 II. The spectrum occupancy measurement setup is described in Section III. Analysis of the spectrum occupancy measurement results is presented in Section IV. Finally, conclusions are drawn in Section V.

II. Status of 2.3-2.4 GHz Band in Europe

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 [11]. 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 [12] 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 [13]. 27 countries are currently using all or parts of this band for PMSE (programme making and special events) applications,

CROWNCOM 2014, June 02-04, Oulu, Finland

DOI 10.4108/icst.crowncom.2014.255077

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 Licensed Shared Access (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 Mobile Network Operators (MNOs) in the 2.3-2.4 GHz band. FM52 is developing a draft 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. 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.

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 [14]. The incumbent PMSE services are described in more detail in [12] and [15]. 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). Amateur radios are also allowed in this band in Finland. However, mostly the band is used by wireless cameras.

In the USA, the 2.3-2.4 GHz band is used for satellite radio repeaters and amateur radio, among others. Some wireless video surveillance products for military and law enforcement use and their characteristics available in USA in 2.3 GHz band are described in [16], showing that rather high transmission powers are used in the band, e.g., 40 W for long range transmissions.

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.

III. SPECTRUM OCCUPANCY MEASUREMENT SETUP

The spectrum occupancy measurement setup consists of a CRFS RFeye receiving system [17], data storage, and data transfer equipment. The RFeye receiver (shown in Figure 1) 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 [18] for details regarding the RBW and revisit time in other sub-bands.

Figure 1. CRFS RFeye spectrum monitoring node

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 2. 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 [18].

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. 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 is in the process of being deployed in a different location.

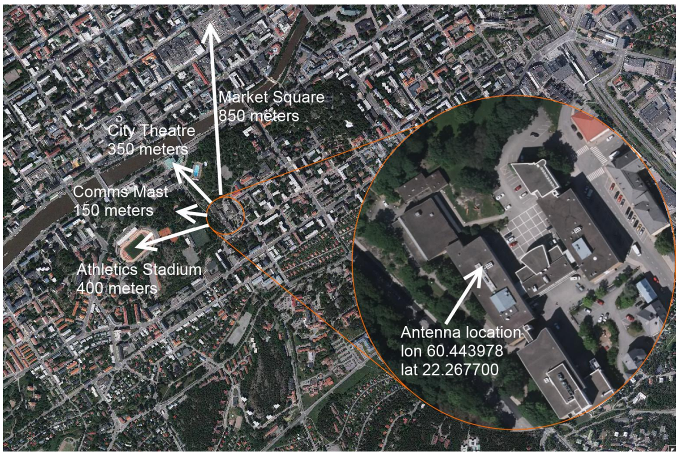

Figure 2. Spectrum occupancy measurement antenna in Turku, Finland

Another 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.

IV. Results

A. Turku Data

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. In addition, we have compared the spectrum use to US situation. These measurements have been made in Chicago in the large city environment, showing also the differences between the regulatory status in the 2.3 GHz band between Europe and USA.

Power spectrum plots of Turku measurements for each day are shown in Figure 3. 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_0 where a particular channel has a measured signal above the defined threshold is given as $T_0 = N_C \cdot T_R$ 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 3 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. Actually wireless camera users coordinate the use of frequencies among themselves and can select any frequency inside the band 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 4 and 5.

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 Figure 4, 5, 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. The gaps in the time series plots are due to missing data.

Percentage occupancy graphs (lower plots in Figures 4, 5) 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 [18]. 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.

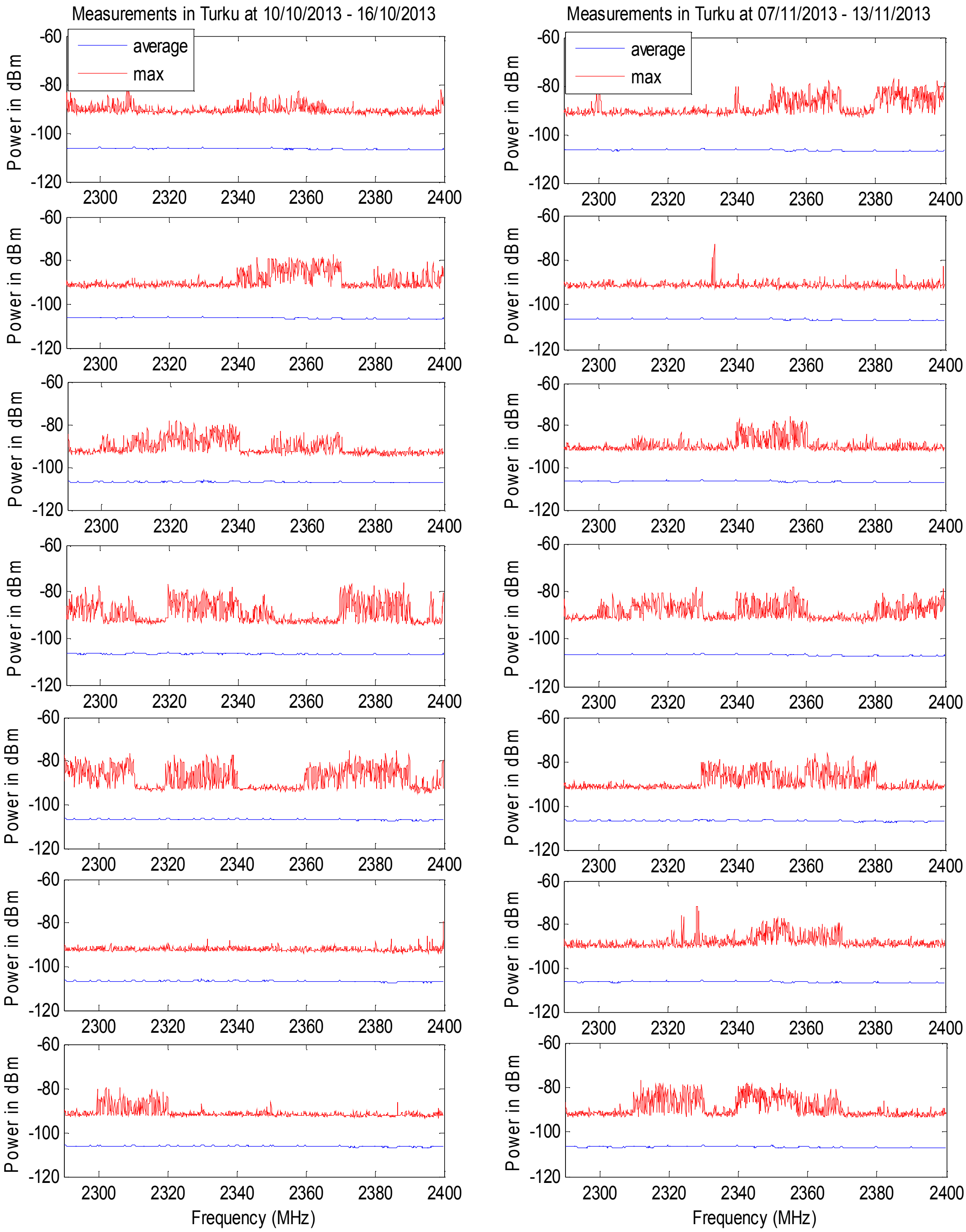

Figure 3. Average (blue) and maximum (red) power spectrum in 2.3 GHz at Turku, Finland.

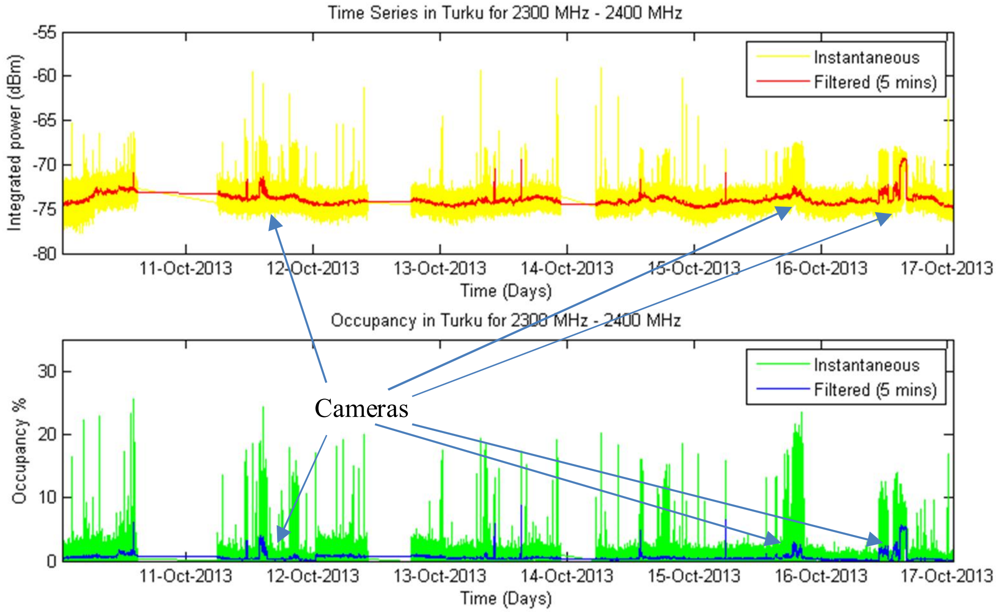

Figure 4. Integrated power time series and percentage occupancy at Turku (Oct 10th – 17th 2013)

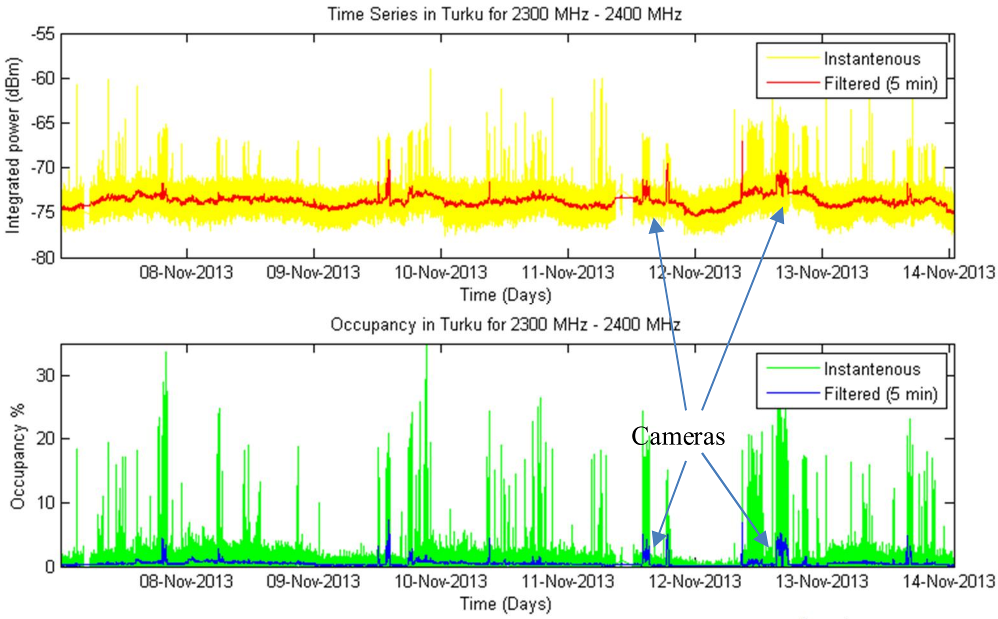

Figure 5. Integrated power time series and percentage occupancy at Turku (Nov 7th- 14th 2013)

From the occupancy time series, it is seen that the occupancy goes to near 20% when a wireless camera transmits (as labeled in Figures 4 and 5). 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.

B. Chicago Data

Similar studies were carried out at Harbor Point, in the eastern part of downtown Chicago, by the IIT partners. Here results are presented from the week of 28th of December 2013 to 4th of January 2014. As is seen by the power spectrum plots in Figure 6, the main signals detected are from Sirius (2324.54-2327.96 MHz) and XM (2336.225-2341.285 MHz) repeaters, and an unidentified 20 MHz signal (2360-2380 MHz) which possibly could be from an analog wireless camera source or aviation telemetry, and amateur radio (2390-2400 MHz). The spectrogram readily shows that the first three wideband signals as always on, whereas, the amateur signals are difficult to see due to their low duty cycle.

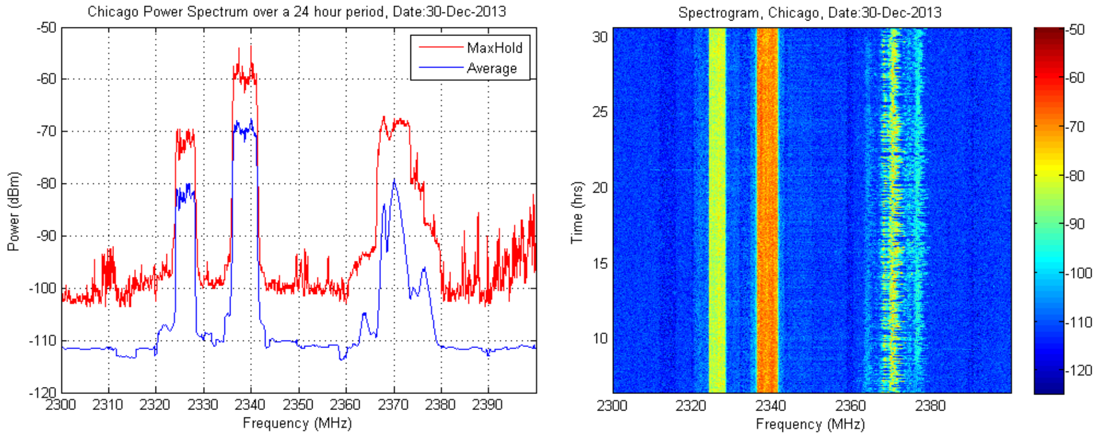

Figure 6. Power spectrum plots and Spectrogram plot for Chicago (Dec 30-31st, 2013)

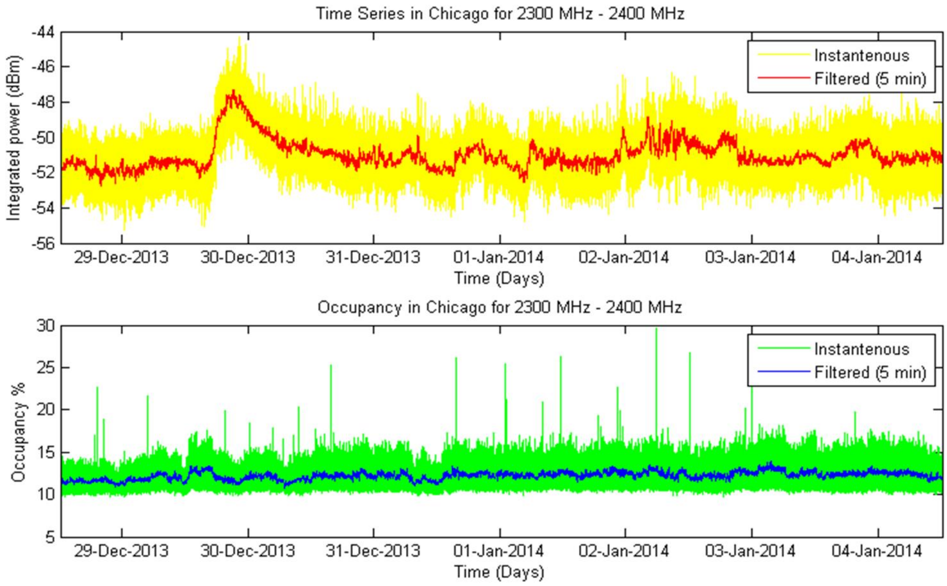

Figure 7. Integrated power time series and percentage occupancy at Chicago (Dec 28th 2013 to Jan 4th 2014)

To further investigate this, we look at the time series' of integrated power and occupancy. These were generated in the same way as described above in Section IV A. Both the smoothed time series plots of Figure 7 for Chicago show low variability as the 3 aforementioned prominent signals are always on. The peaks in the instantaneous occupancy and integrated power plots are possibly due to amateur radio activity.

One of the main challenges in using this spectrum in the US for sharing is the multitude of incumbent services that are utilizing the band, all of which need to be protected. For instance, 2305-2360 MHz [20] in the US is being used for satellite-based (SDARS) and terrestrial-based (WCS) communication services, the 2360-2395 MHz [21] is used for Aeronautical Mobile Telemetry by federal and non-federal aviation entities, the 2390-2400 MHz [22] is used by the Amateur Radio Service and finally, the 2360-2390 MHz [22] is used for medical devices (MBANs).

V. Opportunities 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. Also the US measurements show that there is some potential for spectrum sharing, although, incumbent user occupancy is higher.

Even though the 2.3 GHz band has potential for the LSA concept in Finland, additional measurements are needed to be able to make estimations of the potential availability of this band for LSA. In particular, it will be 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.

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 [12], 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 [19] (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. There could be the need to reserve parts of the band purely for the incumbent use, such that e.g. the wireless cameras in some special events where media needs capacity, by local exclusive reservations of the band.

VI. 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. In addition, results in the same band regarding the spectrum use in Chicago, USA were shown. The measurements give useful insight into the current use of this band which is very low and sporadic at least in the measurement location in Finland. Clearly there is room for spectrum sharing to boost the wireless capacity in Finland. 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. The challenge of sharing the same band in the USA is complicated due to the multitude of incumbent services like satellite repeaters, medical devices, aeronautical telemetry, and amateur radio – all of which need protection.

In Europe, 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. We presented initial ideas and discussed about opportunities and challenges for LSA concept in the measured band. 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 clear 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. We are planning to continue the measurements with several mobile measurement devices that will be used simultaneously in different locations.

References

[1] Report ITU-R M.2243. Assessment of the global mobile broadband deployments and forecasts for International Mobile Telecommunications. 2011.

[2] RSPG, "RSPG Opinion on Licensed Shared Access", RSPG13-539, European Commission, Radio Spectrum Policy Group, November 2013.

[3] Draft ECC Report 205. Licensed shared access.

[4] ETSI, "Mobile Broadband services in the 2300-2400 MHz frequency band under Licensed Shared Access regime", ETSI RRS TR 103.113 v 1.1.1, July 2013.

[5] Report ITU-R SM.2256. Spectrum occupancy measurements and evaluation. 2012.

[6] M. McHenry, D. McCloskey, G. Minden and D. Roberson, "Multi-band multi-location spectrum occupancy measurements," in *Proc. ISART*, March 2006.

[7] V. Kone, L. Yang, X. Yang, B. Y. Zhao and H. Zheng, "The effectiveness of opportunistic spectrum access: A measurement study," *IEEE/ACM Transactions on Networking,* vol. 20, pp. 2005-2016, December 2012.

[8] D. Denkovski, M. Pavloski, V. Atanasovski and L. Gavrilovska, "Parameter settings for 2.4 GHz ISM spectrum measurements," in *Proc. ISABEL*, November 2010.

[9] M. Höyhtyä, J. Lehtomäki, J. Kokkoniemi, M. Matinmikko and A. Mämmelä, "Measurements and analysis of spectrum occupancy with several bandwidths," in *Proc. IEEE ICC*, June 2013.

[10] R. De Francisco and A. Pandharipande, "Spectrum occupancy in the 2.36 GHz-2.4 GHz band: Measurements and analysis," in *Proc. European Wireless Conference*, pp.231–237, April 2010.

[11] Plum Consulting. The economic benefits of LSA in 2.3 GHz in Europe. December 2013.

[12] ECC Report 172. Broadband wireless systems usage in 2300-2400 MHz. March 2012.

[13] ECC document FM(12)017rev1, "Results of the WG FM questionnaire to CEPT administrations on the current and future usage of frequency band 2300-2400 MHz," April 2012.

[14] M. Matinmikko, M. Palola, H. Saarnisaari, M. Heikkila, J. Prokkola, T. Kippola, T. Hänninen, M. Jokinen, S. Yrjölä, "Cognitive radio trial environment: First live authorized shared access-based spectrum-sharing demonstration, " IEEE Vehicular Technology Magazine, vol. 8, no. 3, pp. 30-37, September 2013.

[15] ERC Report 38. Handbook on radio equipment and systems video links for ENG/OB use. May 1995.

[16] RF-video, video surveillance system specs, [online], accessed January 2014: http://www.rf-video.com/uav.html.

[17] CRFS product RFeye. [online], accessed January 2014: http://www.crfs.com/products/rf-sensor-rfeye-node/

[18] T. Taher *et al.,* "Global spectrum observatory network setup and initial findings," in *Proc. CrownCom*, June 2014.

[19] ECC report 186, "Technical and operational requirements for the operation of white space devices under geo-location approach," January 2013.

[20] Bennett Z. Kobb, *Wireless Spectrum Finder*, McGraw-Hill, 2001.

[21] FCC 10-82 Report, May 20, 2010: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-82A1.pdf

[22] 2.36-2.4 GHz wireless medical and amateur radio service: http://www.commlawblog.com/tags/23602400-mhz/