Availability assessment of TVWS for Wi-Fi-like secondary system: A case study

Pero Latkoski, Jovan Karamacoski, Liljana Gavrilovska
Faculty of Electrical Engineering and Information Technologies
Ss Cyril and Methodius University
Skopje, Macedonia
{pero, jovan, liljana}@feit.ukim.edu.mk

Abstract—**This paper presents a countrywide assessment of TV whitespace availability for Wi-Fi-like secondary system, using the Republic of Macedonia as an example study area. The presented methodology is general and applicable to any European country. Before introducing the specifics of the assumed secondary system, the paper provides in details the steps of TVWS assessment procedure, considering the regulatory ruling paradigms defined by ECC and FCC. The performance evaluation assumes Wi-Fi-like access points operating as secondary system that utilize vacant frequency chunks in TV band. The paper investigates viable combinations of frequency chunks-width and regulatory ruling which can be employed for TVWS utilization by Wi-Fi-like secondary network, regarding the achievable throughput by secondary users.**

Keywords-TVWS assessment; Wi-Fi-like secondary users; Frequency chunks utilization; Performance Evaluation

I. INTRODUCTION

As the Digital Switchover in TV band is taking progress in Europe, following its conclusion in USA in 2009, the regulatory bodies are now opening up the spatially unused portion of TV bands for cognitive radios. The vacant TV channels, also known as TV whitespace (TVWS), can be reused by low power whitespace devices in a way not causing harmful interference to the primary system and incumbent services. The TV band is preferable for secondary communication because the radio signals in this band have much lower penetration and propagation loss, achieving longer range and wider coverage.

So far most of the works on TVWS assessment and its re-use have assumed an existence of point-to-point links as secondary users placed in each evaluated location within TV transmitter coverage area. The typical examples are the groundbreaking papers [1] and [2], which provide estimation of TVWS respectively in USA and several European countries. Both papers apply the Shannon equation to provide capacity estimation and general potential of the TVWS. While the methodology in [1] uses only the ITU propagation model [3], the work in [2] extends the analysis by testing both ITU and Longley-Rice propagation model [4] which additionally takes into account elevation characteristics of the terrain. In general, both papers lack of reasonable secondary system model definition, which will give a realistic availability assessment and economical viability of the TVWS usage.

The work presented in [5] overcomes the general problem of [1] and [2] by investigating the feasibility of wireless broadband delivery using so called "inside-out" community network architecture, where residential broadband customers share a portion of their home access point bandwidth for outdoor public use. The paper shows that community networks operating in TVWS spectrum are a viable and significantly less expensive alternative to the cellular operators' next generation networks. Additionally [5] points out to a greater need for interference management techniques in TVWS networks compared to the original WiFi networks due to increased RF coverage in TV bands. However, the paper does not explain in a clear manner the assessment methodology of available spectrum in TV band, claiming an existence of at least 100 MHz of TVWS for over 70% of UK population.

Besides the idea of Wi-Fi based community network, the implementation of Wi-Fi-like secondary system in TVWS represents a general course for many network operators interested in TVWS utilization. Wi-Fi like systems in TVWS are foreseen as cost-effective high data rate communication systems which at the same time will provide significant coverage area compared to the concurrent technologies. This potential of Wi-Fi-like technology in TVWS triggered a new amendment in IEEE 802.11 family, named as IEEE 802.11af [6]. The IEEE 802.11af working group has been set up to define a standard to implement the use of Wi-Fi in TVWS, also known as White-Fi.

This paper assumes Wi-Fi like devices operating as secondary users within TV band as well. Such Wi-Fi systems comprise of an access point (AP) and Wi-Fi users connected to the AP. The Wi-Fi users have relatively low transmission power (i.e. 15 dBm) and inherit the principle of auto-rate function that determines the communication link bit-rate according to the minimum received SINR (signal-to-interference-plus-noise ratio). Additionally, the Wi-Fi-like secondary users implement CSMA/CA MAC layer protocol, which controls the access to the wireless medium, directly influencing the achievable throughput by each secondary user and the mean network throughput in general.

In order to verify the relevance of the selected methodology for assessing the TVWS, this paper firstly investigates the influence of the used propagation model on the channel availability, taking the territory of Republic of Macedonia as an example study area. The following figures (Figure 1 and Figure

CROWNCOM 2012, June 18-20, Stockholm, Sweden

DOI 10.4108/icst.crowncom.2012.248453

2) present the number of free TV channels for each pixel within the target territory, when applying two different propagation models. Figure 1 presents the estimated available channels when the calculations include the statistical ITU propagation model, without taking into consideration the real geographical terrain in the area. Figure 2 uses the Longley-Rice propagation model and the actual terrain. Both cases apply same regulatory criteria for channels availability. The figures reveal that due to the highly mountainous geographical characteristics of the area, the results significantly differ from each other. In particular, the most common number of available channels per location in the first case is one or two, while in the second case this number varies between five and ten. In the first case, the maximum number of free channels is 20, while in the second case this number is 40. Consequently, the rest of the analysis in the paper will use the second methodology (actual terrain plus Longley-Rice propagation model), as it provides more realistic white space availability.

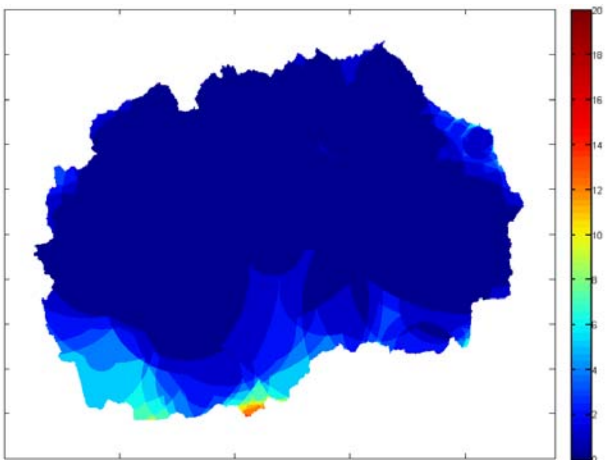

Figure 1. TV channels availability (ITU propagation model)

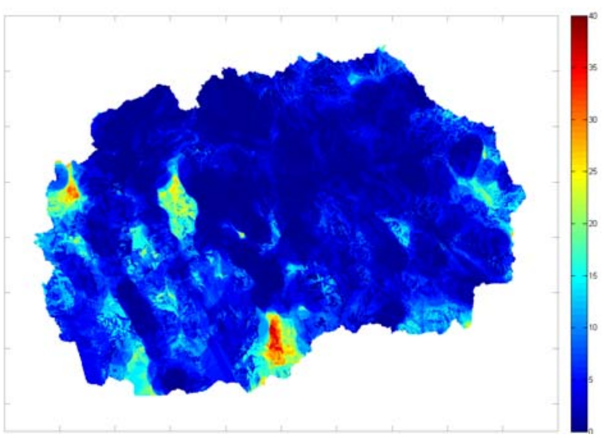

Figure 2. TV channels availability (Longley-Rice propagation model)

The reminder of the paper is organized as follows. Section II provides the TVWS assessment methodology, along with the simulation tool and regulatory rules applied in the calculations. Section III investigates the possibilities for organization of the estimated secondary spectrum and finds the most suitable solution for available frequency chunks utilization. Finally, Section IV gives the results of the performance evaluation of Wi-Fi like secondary system operating in TVWS, assuming one secondary user per AP, as well as multiple secondary users per AP. The last section presents the discussion and conclusions of the paper.

II. General TVWS Assessment Methodology

Generating accurate radio coverage maps is the basis for reliable secondary spectrum assessment in TV band. For such purposes, the paper uses off-the-shelf calculation software named Radio Mobile Deluxe [7], as one of the most promising tools for producing accurate coverage maps. The software implements Longley-Rice propagation model which predicts the propagation of the radio signals in the environment for frequency range of 20 MHz to 20 GHz, taking into account parameters such as: effective earth curvature, atmosphere refractivity and conductivity, climate conditions, height and polarization of the antenna. For terrain elevation information, Radio Mobile can use data provided in different formats. The preferred type is SRTM (Shuttle Radar Topography Mission) [8]. This data is provided by NASA and is publicly available with different resolutions for different countries (for most of the world the resolution step is approximately 100 m). In order to obtain a proper simulation, Radio Mobile needs additional parameters such as: transmitter frequency, power, receiver sensitivity, antenna pattern, antenna gain, antenna height, connector and cable loss. There is a possibility to define some additional parameters such as: polarization type, climate coefficient, surface refractivity, ground conductivity, and relative ground permittivity.

The Radio Mobile tool is usually used for calculating point-to-point radio communication. However, in this paper it is used to create the TV coverage maps. The Radio Mobile can calculate them either as single polar-based or as combined Cartesian-based maps. The single polar-based simulation is fast and not sufficiently accurate. Accuracy is lost because of the radial representation of the pixels. The accuracy for smaller radial angle steps is higher, but still there is an insufficient accuracy for points placed away from the transmission point. The combined Cartesian-based coverage calculation creates coverage maps with rectangular regions of interest. The precision of the calculated value depends on the resolution of the pixels, so creating a map with 1x1 pixel size will give the best results. A drawback of this method is the processing time consumption. One calculation can last for hours depending on the computer performance. There is a tradeoff between the time consumption and picture details which leads to possibility of choosing smaller resolution (for example, 2x2 or 3x3 pixels), while losing in accuracy. The advantage over single polar method lies in the ability to calculate coverage map from more than one transmitting unit. At the end of the simulation, Radio Mobile generates one coverage map with combined signals that cover the area of interest. The process of generating separate coverage maps precedes the process of creating the combined coverage map. For that reason, the output coverage maps for each transmitting unit is available at the end of the simulation.

The regulatory body in Macedonia (Agency for Electronic Communications - AEC) provided the input data for the assessment. The database contains information for all TV transmitters in the country along with transmitters' locations (longitude and latitude in decimal degrees), antenna heights, transmission powers, working channels, channel bandwidths etc. The territory of the country is divided into a regular grid of pixels, which represents an actual territory of 100m x 100m. The computation of the secondary spectrum applies both FCC and ECC ruling sets for coverage and protection area definition, and additionally includes the real geographical terrain obtained from the NASA shuttle mission. The analysis assumes no transmissions from the neighboring countries.

In order to implement and extensively test the calculation process, before going to a country wide observation, the paper firstly investigates the TVWS availability observing a small area of 150 × 200 pixels. For each pixel within this area, the Radio Mobile software derives the received TV signal power on channels 21-60, (470-790 MHz, with channel bandwidth of 8 MHz). The software incorporates terrain model, as well as appropriate propagation models and algorithms to obtain the propagation loss of the TV signals.

The first part of the analysis implements the FCC ruling [9] for operation of unlicensed devices in UHF band, targeting as an example TV channel 45 (666 MHz). According to the FCC rules, protection of channels 44, 45 and 46 should be provided. Figure 3 presents the results for spectrum occupancy of channel 45 across the observed area. The blue area represents the TV whitespace, which is available for secondary usage by whitespace devices with transmission power of 20 dBm. The red zone represents the TV coverage area, and the yellow strip is the co-channel protection zone, which according to the rules is also forbidden for secondary usage.

According to the European rules for possible operation of cognitive radio systems in the whitespaces of UHF band [10], the maximum permitted cognitive radio transmission power is location-specific. Figure 4 depicts the allowable transmission power within the observed area, denoted in dBm. Assuming a WSD transmission power of 20 dBm, Figure 5 presents the 45th channel availability according to ECC rules. Again, the blue area represents the available space for secondary operation. Although, Figure 5 shows minor channel availability compared to the FCC case (Figure 3), Figure 4 verifies that in some areas, ECC allows significantly higher transmission power for WSD operation, compared to the fixed transmission power constraint defined by FCC rules.

In order to derive the total number of available channels per pixel using ECC and FCC rules, the analysis makes this kind of calculations for every channel in the UHF frequency band (470-790 MHz). For this particular example, the average number of available channels per pixel according to FCC estimation is approximately 5-7, while the one compatible with ECC rules is 2-3 channels. The following section (Section III) provides more extensive analysis of channel availability for Wi-Fi like secondary systems, only this time on a country wide scale.

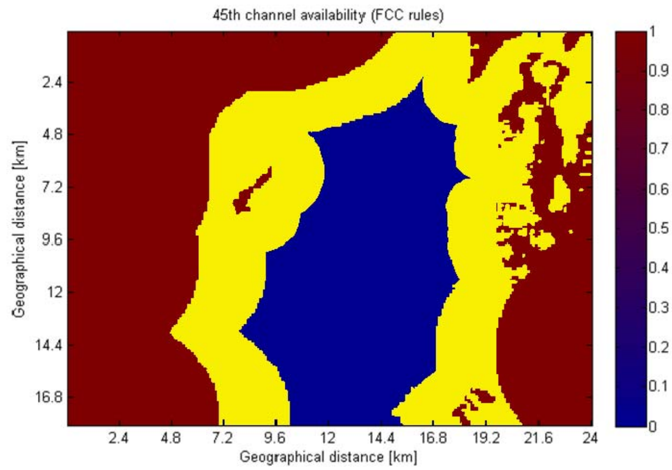

Figure 3. Channel 45 occupancy according to the FCC rules (red-TV coverage area, yellow-protection zone, blue-TVWS)

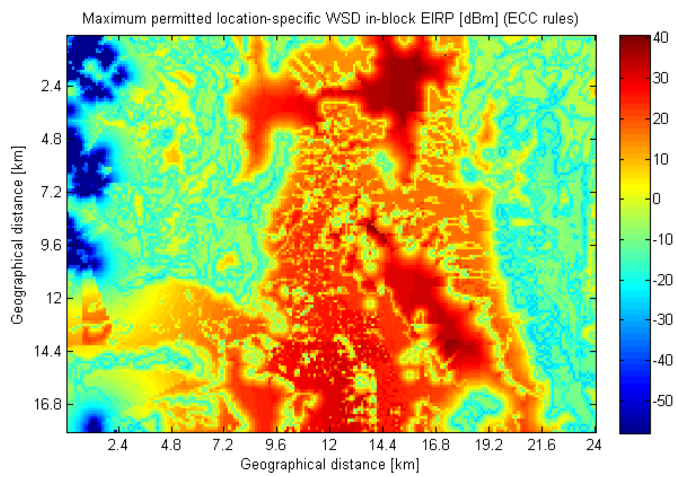

Figure 4. Maximum permitted cognitive radio transmission power for Channel 45 in dBm (ECC rules)

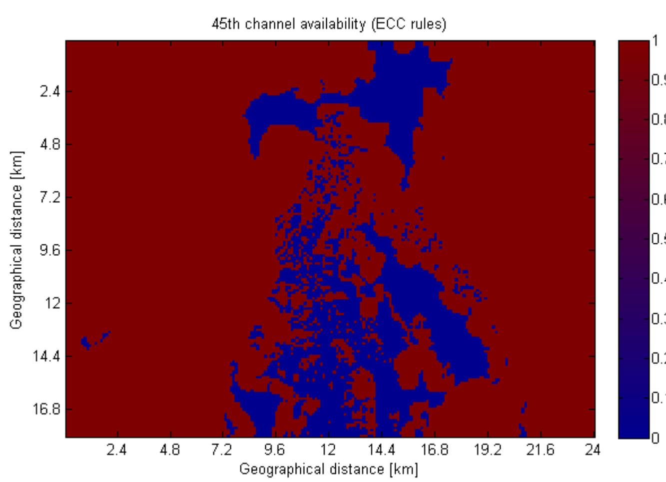

Figure 5. Channel 45 occupancy according to the ECC rules (red-TV coverage area, blue-TVWS)

III. ESTIMATION OF THE AVAILABLE FREQUENCY CHUNKS

As the current Wi-Fi communication systems typically utilize 20 MHz channels, the following analysis begins with investigation of presence of available frequency chunks (multiple consecutive TV channels) in UHF band for every pixel within the study area. Again, each pixel represents 100m x 100m of the real terrain. According to the FCC rules, an Nx8 MHz frequency chunk is considered to be available at a certain location, if there are N consecutive TV channels for which the pixel is outside the TV coverage and co-channel protection area (in this case defined according to the FCC rules for unlicensed device with maxEIRP of 20 dBm and antenna height less than 3m). Additionally, the pixel needs to be out of the adjacent channel protection zone for the ±1 adjacent TV channels of the frequency chunk where the WSD will operate. On the other hand, ECC rules require calculation of maximum tolerable WSD EIRP for each pixel. For this purpose the analysis uses the reference geometry for adjacent channel situations assuming a portable WSD [10] and protection of ±10 adjacent TV channels. In this case, an Nx8 MHz chunk is available if the pixel is allowed with maxEIRP equal or higher than 20 dBm for all N consecutive TV channels.

Table I shows the percentage of the observed territory with a non-zero number of available frequency chunks, considering different values of TV channels per chunk (N). The values in the table reveal that there is a scarce availability of locations in Macedonia where the secondary system can utilize 24 MHz channels (or wider). Additional investigation has revealed that these few locations are situated in highly remote rural places with low population densities. Because of this, in the following the paper investigates the usage of TVWS by Wi-Fi-like secondary systems that utilize only 8 MHz or 16 MHz channels. Figure 6a and Figure 6b show that such TVWS chunks are almost uniformly distributed throughout the country. The maps present the case of 8 MHz channels when FCC and ECC rules are applied for protection of the DTT system, respectively. The maps which present the 16 MHz chunks distribution throughout the country are similar to the maps in Figure 6, only with lower values for the number of available chunks per pixel. In order to make an appropriate comparison between these two cases, Figure 7 shows the histogram of the maximum number of available frequency chunks per pixel over the territory of Macedonia, for all combinations of ruling (FCC or ECC) and channel width (8 or 16 MHz).

TABLE I. PERCENTAGE OF THE TERRITORY OF MACEDONIA WHERE AT LEAST ONE Nx8 MHZ TVWS FREQUENCY CHUNK IS AVAILABLE

	N = 1	N = 2	N = 3	N = 4	N = 5
FCC rules	77.1 %	33.2 %	14.9 %	7.9 %	4.3 %
ECC rules	64.7 %	25.8 %	12.4 %	5.4 %	3.0 %

Table I shows that generally the case of FCC-based TV system protection provides the highest coverage of the territory with a non-zero number of available chunks, but Figure 7 additionally reveals that the ECC rules result in a higher percentage of the territory with a maximum of one 8 MHz available chunk per pixel.

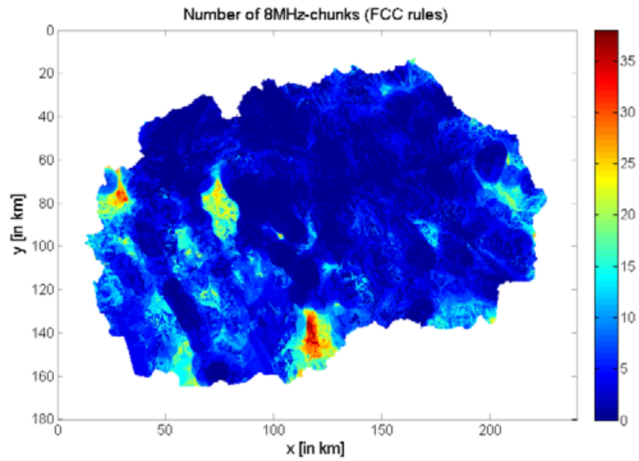

Figure 6a

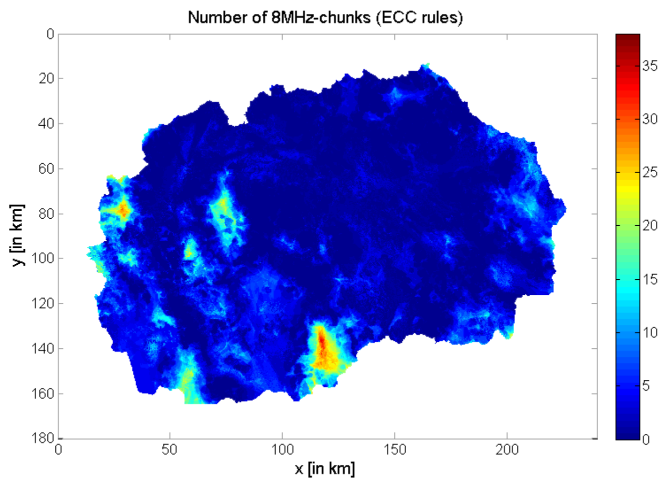

Figure 6b

Figure 6. Number of available 8 MHz channels throughout Macedonia (a): according to the FCC; (b): according to the ECC

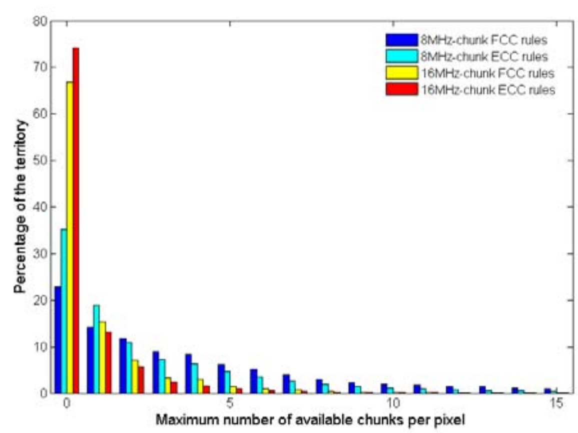

Figure 7. Maximum number of available TVWS frequency chunks per pixel as a percentage of the territory of Macedonia

TABLE II. MAPPING OF SINR TO MAC LAYER THROUGHPUT

SINR (dB)	21	20	16	12	9	7	5	4
MAC layer throughout (Mbps) for 8 MHz channel	10.24	9.73	8.28	6.32	5.15	3.74	2.94	2.05
MAC layer throughout (Mbps) for 16 MHz channel	20.49	19.46	16.56	12.65	10.30	7.48	5.89	4.11

The first part of the rest of this analysis considers a Wi-Fi-like secondary system operating in a TVWS frequency chunk, consisting of one Wi-Fi-like access point communicating with one Wi-Fi-like user. In particular, it assumes an existence of one such secondary link in each available frequency chunk. Because the chunks are non-overlapping, we assume that there is no interference between secondary links. Later, the analysis investigates the influence of multiple Wi-Fi-like users connected to each AP.

The aim is to calculate the achievable throughput for each of the secondary systems and then to sum the obtained values, providing in such way the total achievable throughput for each pixel (aggregate throughput). The achievable throughput for each secondary user is calculated according to the auto-rate function specifications in the existing Wi-Fi IEEE 802.11g standard [11], by mapping the current SINR into an appropriate value for the link rate. Because the IEEE 802.11g standard assumes 20 MHz channels, here the auto-rate function scales down the achievable rates to fit the analyzed 8 MHz and 16 MHz channels. Then the achievable rates are additionally corrected according to the [12] and [13] in order to take into account the operation of CSMA/CA protocol on MAC layer. Similarly to [12], the calculation assumes saturation conditions of the link traffic load. The mapping of SINR to MAC-layer throughput is according to Table II.

As the case study does not assume any particular indoor scenario geometry for the secondary system (walls, access point location and user positions), the analysis investigates the achievable throughput taking values for the receiving signal strength of the secondary system as an independent variable. When calculating the SINR, the analysis takes the noise (N) as thermal noise at room temperature, and the interference (I) as interference only from the television system. The TV signals, which penetrate from the outdoor environment inside the room, are assumed to be reduced by 5 dB as a result of the wall penetration. This very same wall penetration loss is taken into consideration when calculating the influence of the secondary to primary system, i.e. when calculating the number of available frequency chunks per pixel.

IV. PERFORMANCE EVALUATION

As a final result of this analysis the paper provides the achievable combined MAC-layer throughput by all secondary systems operating in each pixel on different frequency chunks, averaged over the observed territory. Figure 8 presents the averaged throughput over all pixels with non-zero number of available frequency chunks, i.e. pixels where at least one secondary system can operate. On the other hand, Figure 9 averages the throughput over all pixels within the territory of Macedonia, including those with zero throughput.

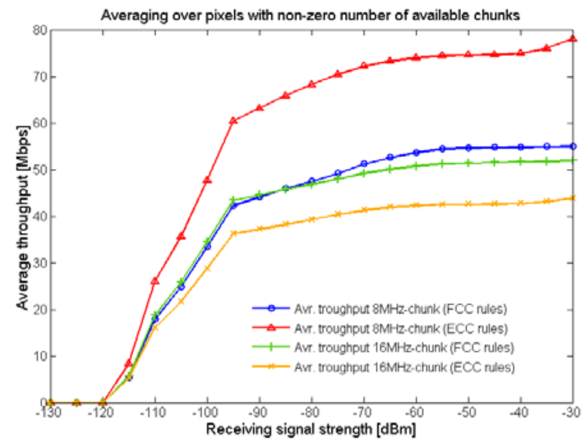

Figure 8. Average combined throughput of independent Wi-Fi-like SUs in TVWS (averaged over locations where at least one frequency chunk is available)

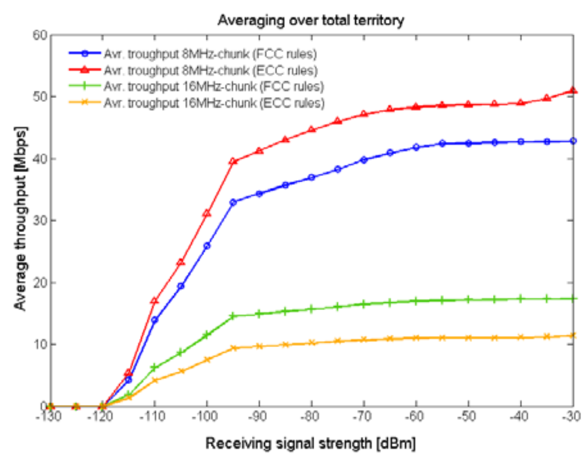

Figure 9. Average combined throughput of independent Wi-Fi-like SUs in TVWS (averaged over all locations)

Figure 8 reveals that when considering only the locations where at least one frequency chunk is available, the average throughput per pixel varies between approximately 40 and 75 Mbps in the case of satisfactory received signal strength (between -70 and -30 dBm), depending on the applied primary system protection ruling (FCC or ECC) and TVWS utilization (8 MHz chunks or 16 MHz chunks). Generally when applying the ECC rule-set, the utilization of TVWS in 8 MHz chunks provides much higher average throughput compared to the 16 MHz chunks case. In the FCC scenario the averaged throughput is almost the same for 8 and 16 MHz chunk utilization. However, the 8 MHz organization of the chunks provides more uniform and wider geographical distribution of the availability, covering almost twice as large a territory when compared to the 16 MHz chunk case (see Table 1). This is more obvious when considering Figure 9, where the throughput is averaged over all pixels within Macedonia. In this case, the 8 MHz channel usage dominates regarding the averaged throughput values, both for the ECC and FCC rules.

The comparison of the average throughput in the case where 8 MHz chunks are used shows that the ECC case provides higher values compared to the FCC. This can be explained by the existence of higher number of pixels with maximum one available 8 MHz chunk in the ECC case compared to the FCC case (see Figure 7). For other values of maximum number of available chunks per pixel (two or more), the FCC performance is better than ECC.

Finally the analysis takes into account multiple secondary users connected at each access point. Figure 10 presents the influence of multiple users over the averaged aggregate throughput per pixel, assuming three different values for the average received signal strength at users' location.

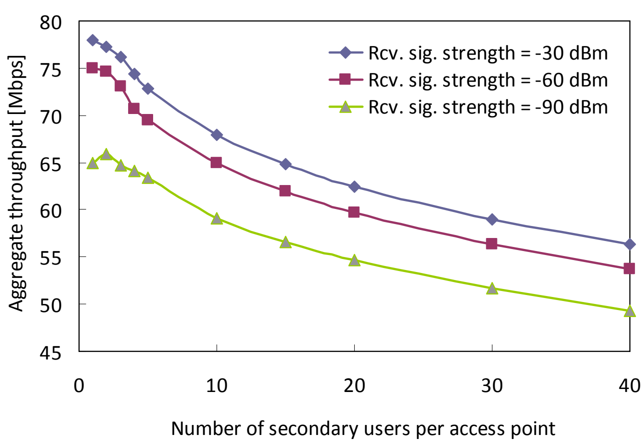

Figure 10. Average combined throughput as function of number of users per access point

The case of received signal strength equal to -30 dBm corresponds to a situation where in average secondary users get strong radio signal from the access point. Oppositely, the value of -90 dBm corresponds to a poor signal reception. In each case, the higher number of users drops the average aggregate throughput calculated for the observed territory.

V. Conclusion

The paper presents a methodology for availability assessment of TVWS and its usage by Wi-Fi-like secondary systems. The results of the performed analysis suggest that the usage of TVWS according to the ECC rules by a Wi-Fi-like secondary system should be organized by applying 8 MHz secondary system channels. In such way the usage of secondary spectrum is possible on wide territory and it provides the highest average throughput for the secondary system, compared to exploiting wider secondary channel widths. Furthermore, the results obtained via illustrative case study investigating the TVWS availability in Macedonia, show that there is a substantial TVWS opportunity which can be exploited by short range Wi-Fi-like secondary systems. The achievable throughput for Wi-Fi-like secondary systems highly depends on the organization of the detected secondary spectrum. The estimation of TVWS availability needs to take into calculation the actual terrain elevation in order to provide reliable results. The presented case investigates scenarios with one and multiple secondary users connected to each Wi-Fi access point. The analysis indisputably suggests that scenarios which include multiple users are feasible and could provide significant throughput per user, depending on the cognitive capabilities of the secondary users.

Acknowledgment

Parts of this work are funded by EC through the FP7 project QUASAR (248303) and inspired by the FP7 project ACROPOLIS (257626). The authors would like to thank everyone involved.

References

[1] K. Harrison, S.M. Mishra, and A. Sahai, “How Much White-Space Capacity Is There?”, In 2010 IEEE Symposium on New Frontiers in Dynamic Spectrum, pages 1 –10, April 2010.

[2] J. van den Beek, J. Riihijarvi, A. Achtzehn, and P. Mahonen, “UHF white space in Europe – a quantitative study into the potential of the 470-790 MHz band”, In 2011 IEEE Symposium on New Frontiers in Dynamic Spectrum, April 2011.

[3] “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz,” International Telecommunications Commission (ITU), ITU-R P.1546-3, 2007.

[4] P. Rice, A. Longley, K. Norton, and A. Barsis, “Transmission Loss Predictions for Tropospheric Communication Circuits, Volume I,” National Bureau of Standards, Technical Note, vol. 101, 1967.

[5] S. Kawade and M. Nekovee, "Broadband Wireless Delivery Using An Inside-Out TV White Space Network Architecture," IEEE GLOBECOM 2011, Houston, USA, December 2011.

[6] R. Kennedy, IEEE P802.11af tutorial, July 2010, [Online]. Available: https://mentor.ieee.org/802.11/dcn/10/11-10-0742-00-0000-p802-11af-tutorial.ppt.

[7] Brian J. Henderson, "Program operation guide", December 2011, http://www3.telus.net/hendersb/documents/Radio%20Mobile.pdf

[8] http://www2.jpl.nasa.gov/srtm

[9] Federal Communications Commission (FCC) 08-260: Second Report and Order and Memorandum Opinion and Order in ET Docket Nos. 02-380, Nov. 14, 2008.

[10] Draft ECC report 159, “Technical and operational requirements for the possible operation of cognitive radio systems in the 'White Spaces' of the frequency band 470-790 MHz,” report out for public consultation.

[11] IEEE 802.11 - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, (Revision of IEEE Std 802.11-1999), 2007.

[12] G. Bianchi, “Performance analysis of IEEE 802.11 distributed coordination function,” IEEE J. Select. Areas Commun., vol. 18, pp. 535–547, Mar. 2000.

[13] Szczypiorski, K., Lubacz, J.: Saturation Throughput Analysis of IEEE 802.11g (ERP-OFDM) Networks. Telecommunication Systems: Modelling, Analysis, Design and Management, ISSN: 1018-4864 (print version), ISSN: 1572-9451 (electronic version), Springer US, Journal no. 11235 Vol. 38, Numbers 1-2, June, 2008. pp. 45-52.