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COgnitive radio systems for efficient sharing of TV white spaces in EUropean context

D4.6
TV White Spaces measurements and characterization in Slovakian scenarios

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Abstract:

This deliverable D4.6 summarises the results of Task 4.5 which address the TVWS characterisation in Slovakian scenarios based on off-air measurements, propagation and interference modeling.

Keyword list: TVWS characterization, spectrum occupancy, spectrum measurements, white spaces database

Executive Summary

This deliverable addresses the characterization of TV White Spaces in Slovakian scenarios. Following the key conclusions and achievements are summarized.

- Spectrum occupancy measurements in Slovakia show that for the target COGEU frequency range (Ch 40 to Ch 60 - 626 MHz to 786 MHz) there are 13 vacant channels available (i.e. a total of 104 MHz) in Bratislava and Banska Bystrica areas. In Bratislava two channels are occupied with DVB signals coming from Austria.
- Due the vast number of possible combinations of TV channels, locations of TV receivers and locations of WSD (White Space Devices), is not practical to measure the maximum allowed transmit power for each vacant channel, instead we use propagation modeling and interference analysis. The methodology proposed by COGEU in D6.2 to compute TVWS maps is applied for the Slovakian scenarios using as inputs the DVB coverage maps provided by TOWERCOM.
- For a range of up to few km, as expected for WSDs operation, the simple 20/30/40 dB model is appropriate to describe propagation. So for convenience and speed this model is used for the WSD propagation.
- When calculating the maximum WSD transmit power several assumptions are required. The scenarios and values were chosen aligned to recent CEPT SE43 discussion. One of the first parameters required for calculating the acceptable WSD interfering signal is the acceptable degradation. CEPT SE43 had some discussion on whether this parameter should be 0.1% or 1%. To investigate the effect of this parameter, we doubled the acceptable degradation from 1% to 2% and we concluded that the increase on the maximum allowed WSD's power is very small (between 1 and 1.5 dB).
- One parameter which has a significant influence on WSD transmit power and who lies completely in the hand of WSD equipment manufacturer is the more restrictive WSD's spectrum mask. The investigations in Slovakia show that reducing the out of band emissions and hence applying a stricter spectrum mask offers a good opportunity to increase WSD transmission power, increases of up to 20 dB are possible in some locations. COGEU recommends to use this approach as a first step for optimization of TVWS use.
- In general, in Slovakia less multiplexes are in the air than in the Munich area. In Slovakia protection of portable broadcast reception is not required by the regulator, this leads to a situation where more TVWS are available in Slovakia than in Munich region. Detail maps with the number of available channels for a given WSD max. transmit power are reported in this deliverable. In the investigated areas of Slovakia there are usually more than 6 channels where WSD operation is possible with 30 dBm (1W). In Munich portable broadcast reception must be protected which leads to a situation where the WSD maximum transmission power is limited to below ~20 dBm (100 mW) (i.e. operational range of approx. 300 m).
- In the valleys region of Banksa Bytrica there are some channels used by DTT but the signal strength is low and varying, so the possible WSD transmit power is correspondingly low and may drop below the required threshold (e.g. WSD max=30dBm). The effect is clearly seen in East of Zvolen or North West of Bansky Bystrica which are shaded by the mountains.
- The COGEU geo-location database is extended with TVWS maps for the Slovakian areas of Bratislava and Banska Bystrica (200 m resolution). This extension is needed for the validation of COGEU demonstrator in Slovakia (T7.4). The COGEU geo-location database provides a User Web interface for visualization of white space maps in several formats and is public available in the COGEU website. The geo-location database communicates with the WSDs through a protocol (draft-PAWS) developed in T6.4, this allows external researches to use and exploit COGEU white space maps.

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1- Introduction

This deliverable reports the work performed in T4.5: “TV White Spaces measurements and characterization in Slovakian scenarios” which main target is to characterize spectrum opportunities in TV bands through spectrum occupancy measurements in different locations of Slovakia (rural, sub-urban and urban areas, mountain and lowland areas).

Chapter 2 presents results from spectrum occupancy measurements in Bratislava and Banska Bystrica. The objective is to get an initial view of potential TV vacant channels before start with the actual computation of the maximum allowed power for WSD transmission. These measurements also aims the identification of the sites and channels to be used in the COGEU system validation in Slovakia (WP7).

Chapter 3 reports the computation of TVWS maps in Slovakian scenarios. The maximum power that is possible to transmit in each vacant TV channel without harmful interference to incumbent systems are computed using propagation and interference analysis. In particular wave propagation models for the interfering signals and the protection ratios of the involved TVWS services (COGEU use cases) are taken into account in the analysis. TOWERCOM (Slovakian broadcaster and COGEU partner) use their own data required for the calculation: locations of TV transmitters, transmit powers, antenna diagrams, height information, topographical data and propagation models.

An important aspect addressed in Chapter 3 is a sensitivity check on how does the amount of TVWS available in Slovakia change if parameters such as the acceptable degradation of DTT coverage and the WSD’s spectrum mask are varied. Moreover, Chapter 3 compares the availability of TVWS in Munich/Germany (investigated in T4.1) with the availability of TVWS in Bratislava/Slovakia.

Chapter 4 describes the extension of COGEU geo-location database for Slovakian areas. TVWS maps in Slovakia are uploaded to the web-based COGEU geo-location database in several formats, this data will be used for the validation of COGEU final demonstrator in Slovakian scenarios (WP7).

2- Spectrum occupancy measurements in Slovakian scenarios

Slovakia is a mountainous country, 41% of the territory is covered by mountainous terrain above 300 m. Density of inhabitants per km2 is relatively high (110 inh. per km2), but a high percentage of the population (44%) is living in the rural areas. This is a very different scenario to the Munich area characterized in T4.1 and reported in D4.1.

Two target scenarios are identified in Slovakia:

Bratislava, lies close to three-border points, Hungary, Austria and Czech Republic. The existence of unused TV channels is significantly impacted by the Analog Switch Off (ASO) process of these neighboring countries and the proximity of high dense inhabited areas such as Vienna – capital city of Austria (60km) and Budapest – capital city of Hungary (200km). The ASO process are at different stages in the above mentioned countries: Austria is almost concluded, Slovakia and Czech Republic are in progress, and Hungary is postponed. TVWS availability in Bratislava suffer from the combination of several cross border issues and therefore provides an interesting case study.

Banska Bystrica, extremely broken and mountainous region in the middle of Slovakia with high dense populated areas (Banska Bystrica and Zvolen cities). Its average distance of 100 km from borders and geographical conditions (surrounded by hills) makes the existence of unused TV channels highly probable, and a good case study for COGEU rural broadband.

TVWS characterization can be done based on exhaustive measurements campaigns (only possible for limited areas), or based on simulation using a statistical interference analysis tool with suitable propagation models. COGEU combines the two approaches to obtain accurate maps of TVWS in Slovakian areas. This section presents results from spectrum occupancy measurements in Bratislava and Banska Bystrica. The objective is to get an initial idea of potential vacant TV channels before start with the actual computation of the maximum allowed power for WSD transmission. These measurements also aims the identification of the sites and channels to be used in the COGEU system validation in Slovakia (WP7).

For the spectrum measurements TOWERCOM has used a van equipped with a Rohde&Schwarz TV analyzer 500kHz-3GHz and a Logaritmic antenna with 5 m mast and vertical polarization. Spectrum measurements were done for azimuths: 0º, 60º, 120º, 180º, 240º and 300º.

The DVB-T transmitters in Slovakia are shown in the following map.

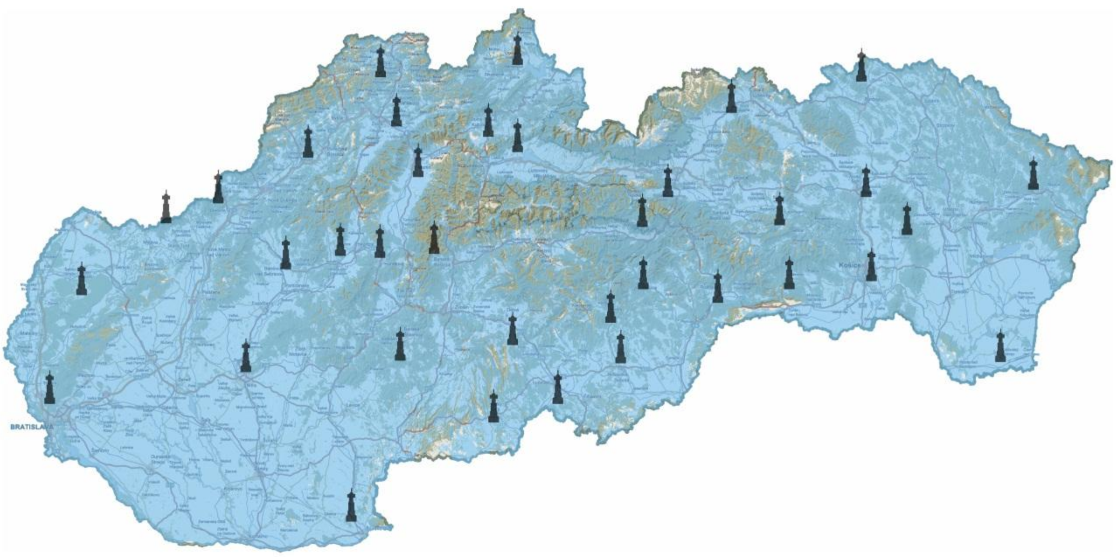

Figure 1 DVB-T transmitters in Slovakia [source http://www.dvbtmap.eu/mapglobal.html].

2.1- Spectrum measurements in Bratislava

For the Bratislava scenario tree locations were selected: Bratislava city center and Raca as illustrated in Figure 2.

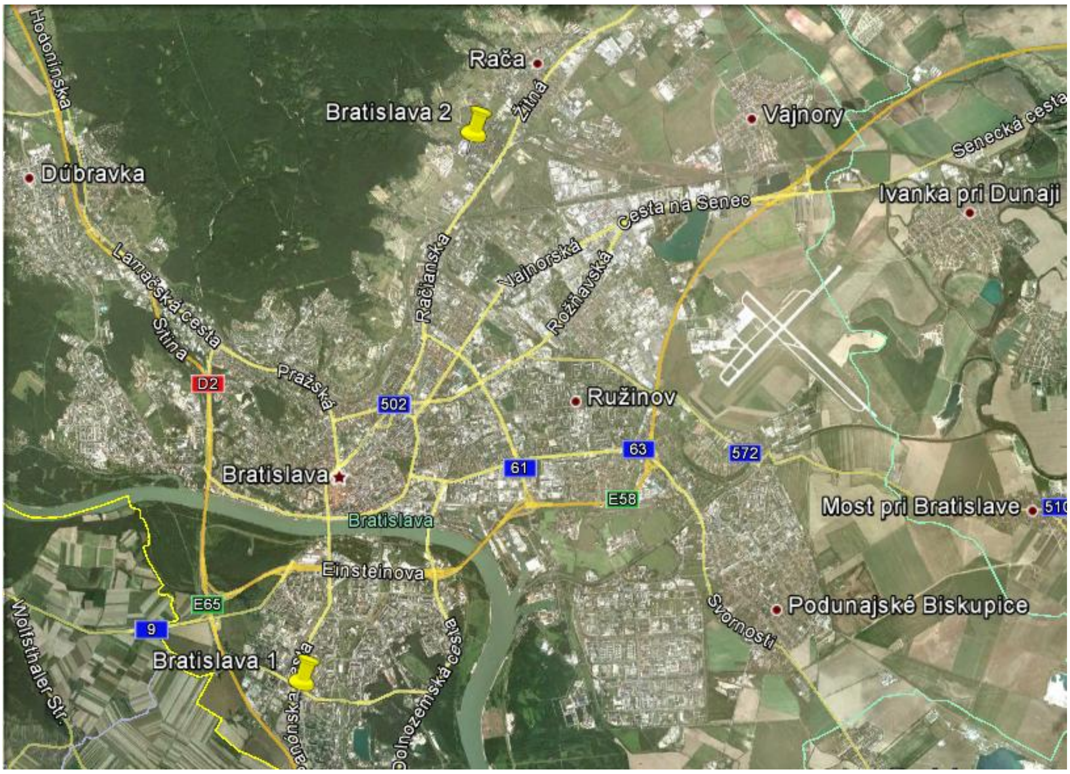

Figure 2 Google view of the Bratislava area with the position of the measurement points.

Figure 3 TOWERCOM's measurement van used in Bratislava city with a 5 m antenna height.

The average field strength measured in Bratislava are illustrated in Figure 4. In the target range of COGEU spectrum band (from TV channel 40 to 60), only 5 channels are occupied, including some multiplexers from Austria, i.e., 15 channels are potential available for WSD operation in a total of 120 MHz.

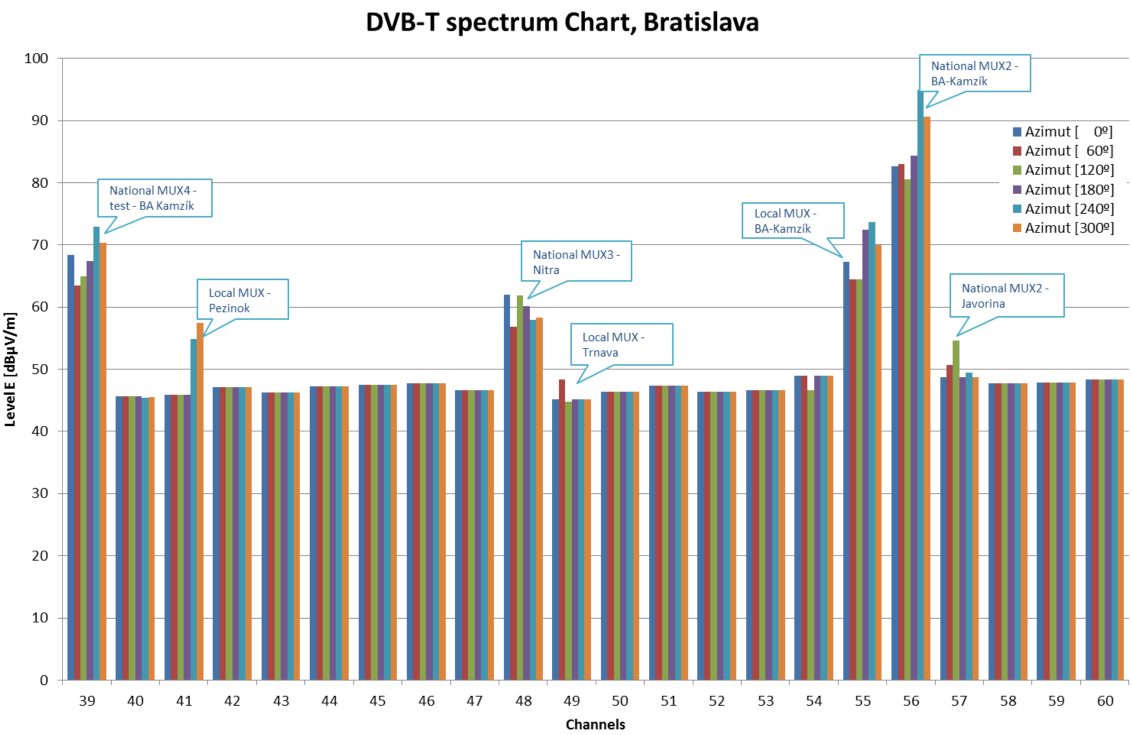

Figure 4 Average field strength in Bratislava area (azimut 0º, 60º, 120º, 180º, 240º and 300º).

2.2- Spectrum measurements in Banska Bystrica

Spectrum occupancy measurements were carried out in the Banska Bystrica city (4 sites) and the rural area of Ponika in the mountains (2 sites) as illustrated by Figure 5.

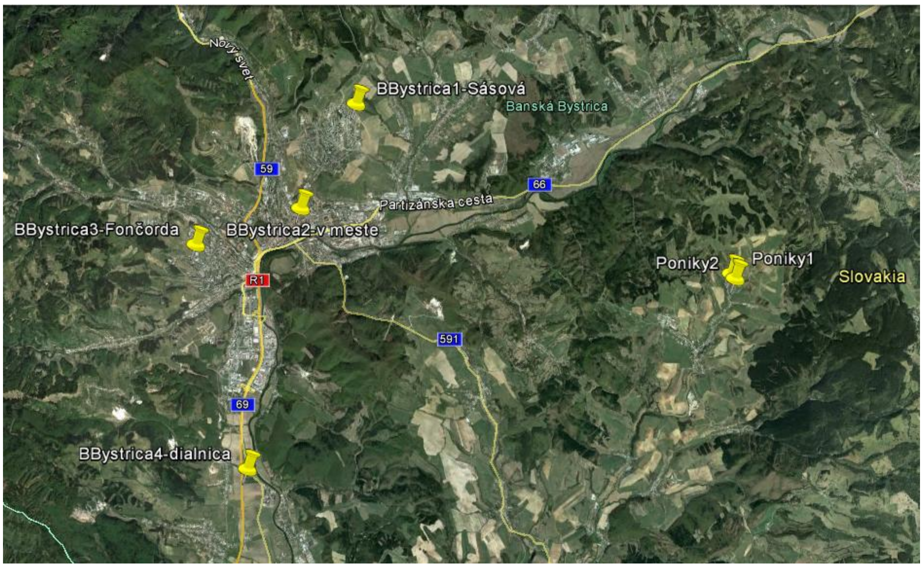

Figure 5 Google view of the Banska Bystrica area with the position of the measurement sites: Banska Bystrica city and Poniky.

Figure 6 Measurement site in the rural scenario of Ponicka (15 Km from Banska Bystrica).

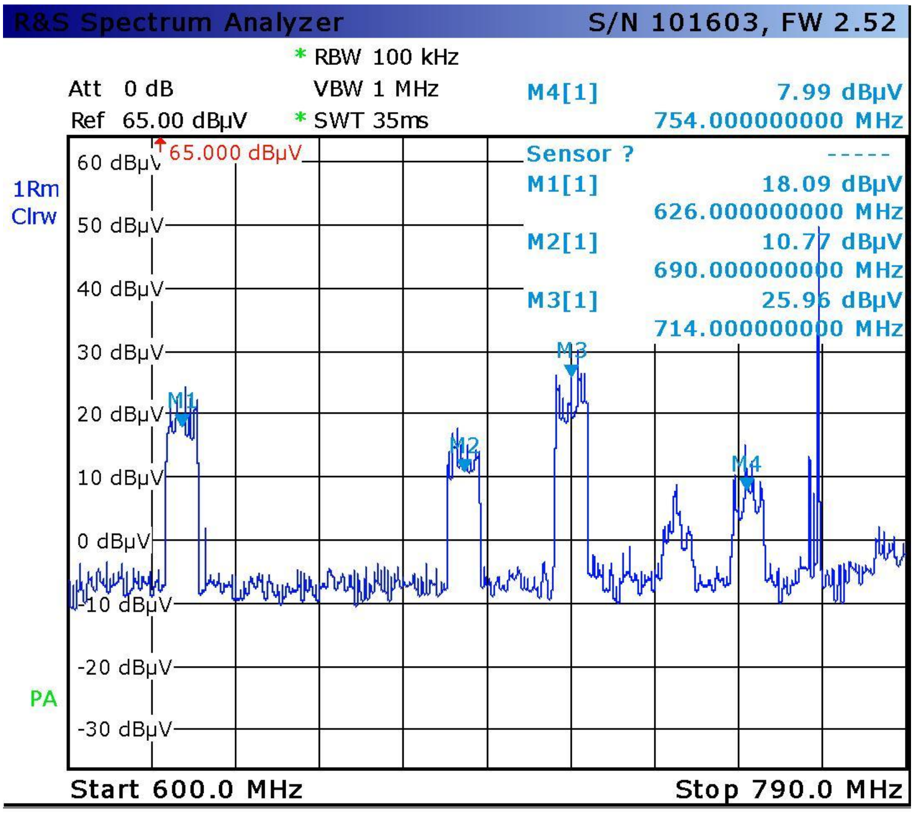

Figure 7 Example of a spectrum analyser screen shot in the rural scenario of Ponicka (15 m from Banska Bystrica).

Figure 8 Measurement site in the Banská Bystrica city.

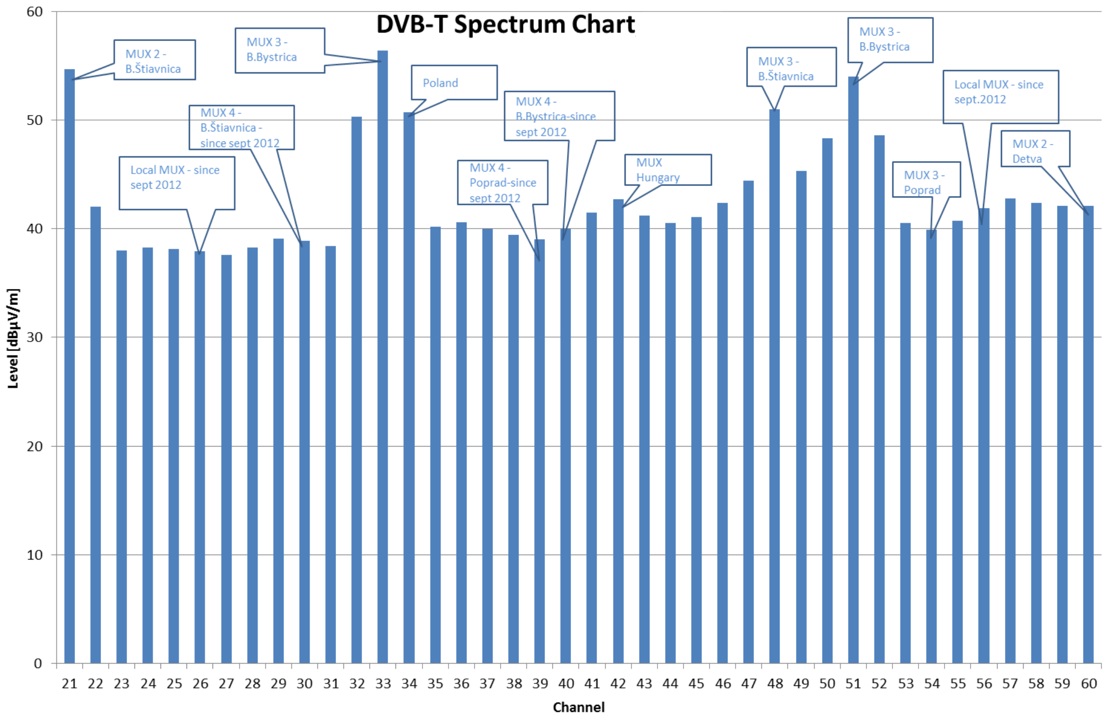

Figure 9 Average field strength in Banka Bystrica area.

In the target range of COGEU spectrum band (from TV channel 40 to 60), only 6 channels are detected in Banska Bystrica, including two foreign multiplexer from Poland and Hungary.

Table 1 summarizes the results of the channel occupation measurements in the Bratislava and Banska Bystrica regions. Channels which are not used in the region are indicated green and those channels with acceptable reception conditions in most of the area are red. For the yellow marked channels reception is possible in only parts of the area under consideration.

channel	*Bratislava*	*Banska Bystrica*
31	free	free
32	free	free in most locations
33	free	transmitters in Banska Bystrica and Detva
34	used	free
35	free	free
36	free	free
37	free	free
38	free	free
39	free	free
40	used	free
41	free	free
42	used	free
43	free	free
44	free	free
45	free	free
46	free	free
47	free	free
48	used, signal from Austria	used, signal from Nitra
49	free	free
50	free	free
51	free	transmitter in Banska Bystrica
52	used	free in most locations
53	used, signal from Austria	free
54	free	free in most locations
55	transmitter in Banska Bystrica	free
56	transmitter in Banska Bystrica	free in most locations
57	free in most locations	free in most locations
58	free	free
59	free	free in most locations
60	free	transmitter in Detva

Table 1 Channel occupation in Bratislava and Banska Bystrica areas.

Note that during the measurements period, from July 2012 to October 2012, the DVB-T network in Slovakia was upgraded, e.g., in Bratislava a new multiplexer in Channel 55 was activated. Since Slovakian plans for the DTT network are not yet concluded more changes on vacant TV channels list are expected.

These spectrum measurements provide a first view of the availability of TVWS, however to compute the maximum transmit power for each vacant channel we need to apply propagation modelling and interference analysis, this is the subject of the investigation reported in the next chapter.

3- Computation of TVWS maps in Slovakian scenarios

3.1- Summary of COGEU methodology to compute TVWS maps

The method to calculate TVWS device's maximum transmit power is described in detail in deliverable D6.2. Here only a short summary is given.

For a broadcast network operator the knowledge on the coverage of their broadcast signals is essential for optimizing their network. The following calculations set up from the data provided by these systems:

For each channel and for each location, i.e. pixel, the field strength of the wanted signal E_w [dBµV/m] and the aggregation of all the signal contributions, coming from remote transmitters not being able to be decoded at that location, termed as E_i [dBµV/m] are provided. Alternatively, the location probability (q) can be given. The parameters are log normal distributed and are related to each other by Gaussian statistics:

$$q_1 = 1 - \frac{1}{2}\ erfc\left\{\frac{1}{\sqrt{2}}\frac{m_s[dBm] - m_u[dBm]}{\sqrt{\sigma_s^2 + \sigma_u^2}}\right\}$$

where the m's are the median values of the wanted and interfering signals over a pixel and the σ's are the corresponding standard deviations.

Figure 10 shows as an example Channel 51 in the Banska Bystrica region. The left diagram shows the wanted field strength and the center figure shows the interfering field strength. Brighter pixels indicate higher values (dBµV/m). The bright dot in the North West area represents a transmitter in the vicinity of Banska Bystrica. The right diagram shows the location probability. Here in order to have white areas indicating white spaces, the gray scale is reversed, i.e. black areas indicate those regions with broadcast coverage.

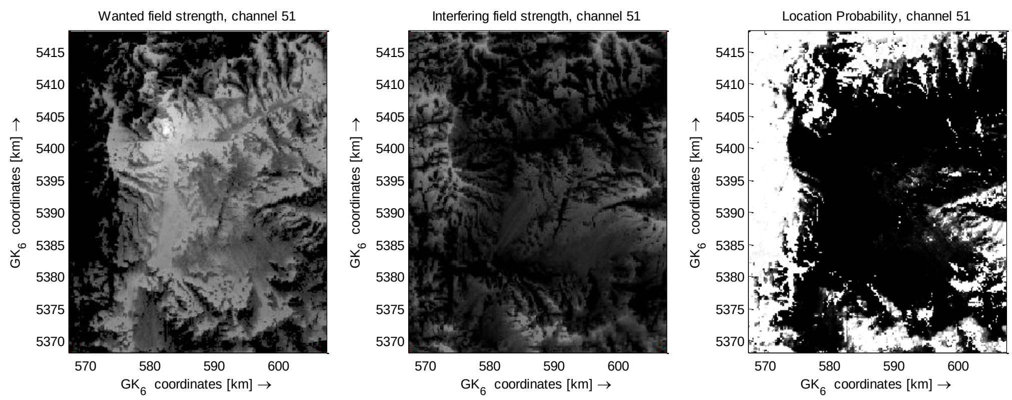

Figure 10 Wanted and unwanted field strength and location probability for channel 51 in the Banska Bystrica region

If now a WSD is operated in the vicinity of a DVB-T receiver, additional interfering signal is generated at the location of that receiver. As the interference can be co channel or adjacent channel the nuisance fields are calculated:

$$Nu_i(ch) = I_i(ch') + PR(ch - ch')$$

and then

$$Nu_{total} = Nu_{noise} \oplus Nu_1 \oplus \ldots \oplus Nu_{wsd}.$$

The additional interferer reduces the probability for broadcast reception. If a certain degradation of the location probability is accepted, the acceptable nuisance caused by the WSD can be calculated. Knowing this WSD nuisance, the protection ratio PR(ch-ch') and the distance between the WSD and the broadcast receiver the maximum WSD transmit power $P_{wsd,max}$ can be determined.

As the locations of all the broadcast receivers are not known, some statistical assumptions have to be made. In Slovakia fixed reception scenario is protected and so, all locations with q ≥ 70 % are protected. For a WSD operated outside of a coverage area the closest distance to that area is used as the proxy distance to the nearest DVB-T receiver. If the WSD is operated inside a coverage area then worst case assumptions for the distance are taken, following CEPT SE 43 scenarios:

WSD base station (BS) to DVB-T fixed antenna: 30 m
WSD mobile terminal (UE) to DVB-T fixed antenna: 20 m

The protection scenarios and used parameters are listed in Table 2.

Parameter	*Value*
Pixel size	200 m x 200 m
Protected locations	q ≥ 70 %, for 'acceptable reception' according to GE06
Acceptable degradation	1 %
DVB-T scenario	In Slovakia fixed reception is protected
Modulation	64 QAM 2/3
d_{BSfi}	30 m (WSD BS to DVB-T rooftop antenna)
d_{UEfi}	20 m (WSD UE to DVB-T rooftop antenna)
Protection ratios and Overload Thresholds	taken from ECC report 148 for 16 QAM 2/3
N_{adj}	9 adjacent channels to each side are taken
G_{fi}	9.15 dBi, antenna gain of DVB-T rooftop Yagi
σ_s, σ_u	5.5 dB, standard deviation of wanted and interfering signal
Search radius	10 km

Table 2 Parameters used for TVWS calculation.

3.2- Path loss channel model

To describe the signal attenuation from the transmitter location to the receiver location propagation models are available. For the (long range) broadcast coverage calculations terrain based models are used. These calculations are executed with commercial software and the results are the input to our calculations. It should be noted that the quality of these data is essential for TVWS calculations.

For the WSD signals due to limited transmit power and hence its operational range 'short range' propagation models (non-terrain based) are appropriate. Okumura-Hata is widely used. Document ITU-R SM.2028-1 Appendix 1 to Annex 2 describes extensions which allow the model to be used from 'zero' up to 20 km. The following figures compare some models, the left ones with modified Hata rural, the right one with modified Hata suburban. Above different antenna heights, below same antenna heights:

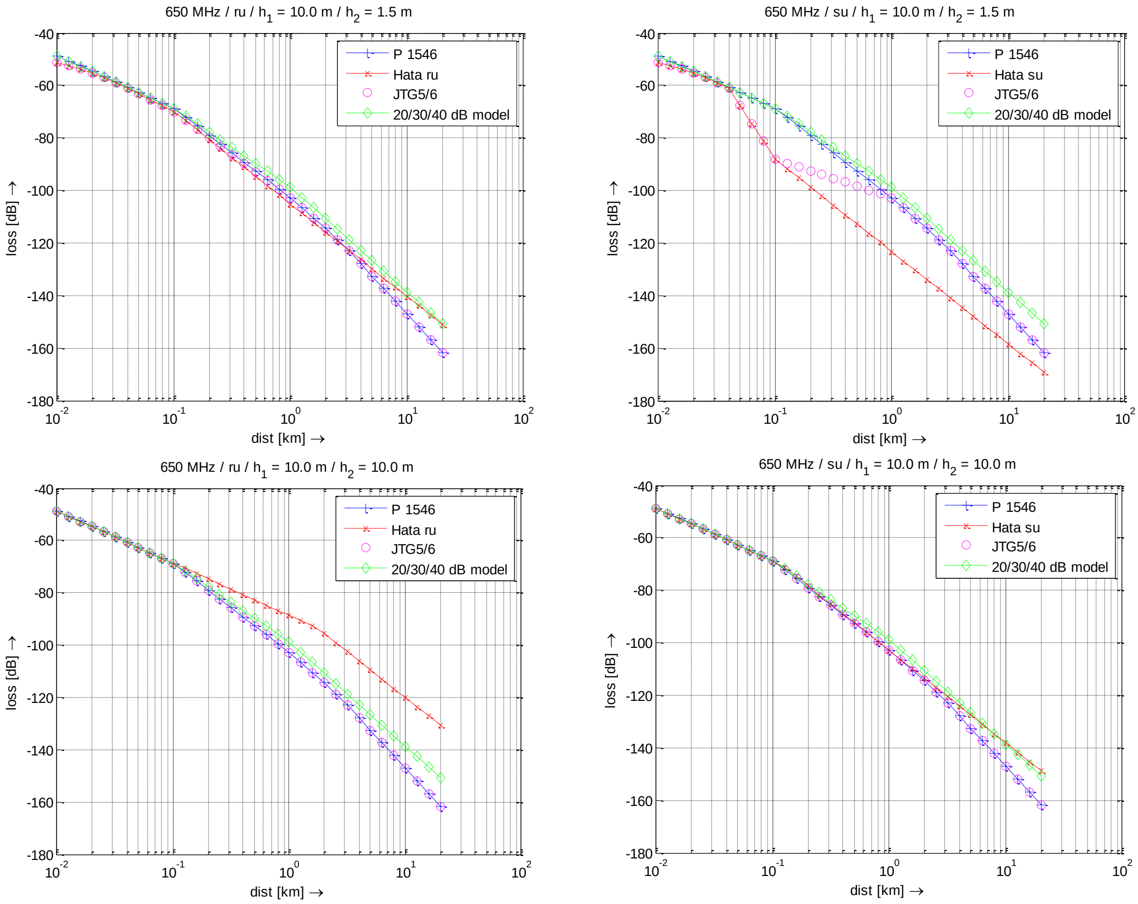

Figure 11 Analysis of propagation models.

The simple 20/30/40 dB model uses:

> 20 dB/decade below 100 m (free space propagation)
> 30 dB/decade between 100 m and 1000 m
> 40 dB/decade above 1000 m

For a range of up to few km, as expected for WSDs operation, the simple 20/30/40 dB model is appropriate to describe propagation. So for convenience and speed this model is used for the WSD propagation. Besides from the DTT coverage calculations we do not have information on the environment of each pixel which makes it impossible to choose the corresponding Hata curve (ru/su/ur).

3.3- TVWS availability in Bratislava and Banska Bystrica regions

The TVWS availability were computed for two Slovakian regions: Bratislava and Banska Bystrica.

In the Bratislava region the area of investigation is 44.8 km x 44.8 km with Bratislava in the center but also covering border regions of Austria and Hungary. In the North of Bratislava locates a large forest area which marks the beginning of the Carpathian mountains.

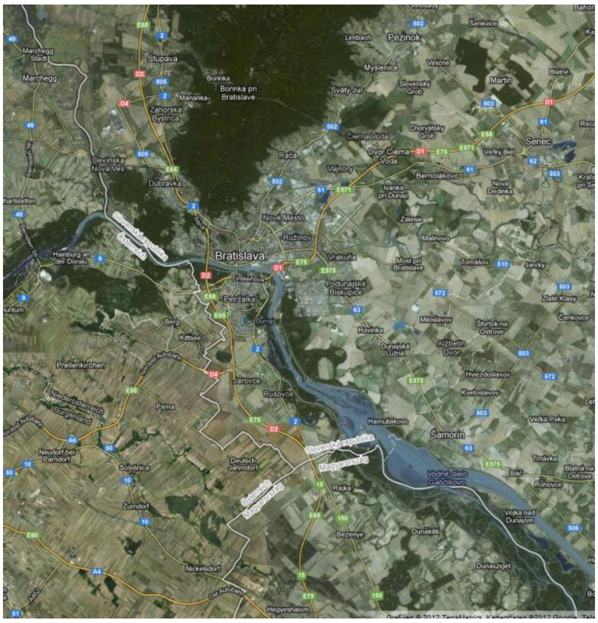

Figure 12 Target area in Bratislava region

The region around Banska Bystrica is a mountainous region, the towns are located in valleys. The area, ranging 20 km x 30 km covers two towns, Banska Bystrica in the North and Zvolen in the South West.

Figure 13 Target area in Banska Bystrica.

In Table 1 for the Banska Bystrica region Channel 54 is labeled ‘free in most locations’. Figure 14 shows the location probability for that region. Broadcast reception is possible at the locations with black and dark gray pixels (q ≥ 70%). For the white and light gray pixels broadcast reception is not protected, though reception may be possible at few locations.

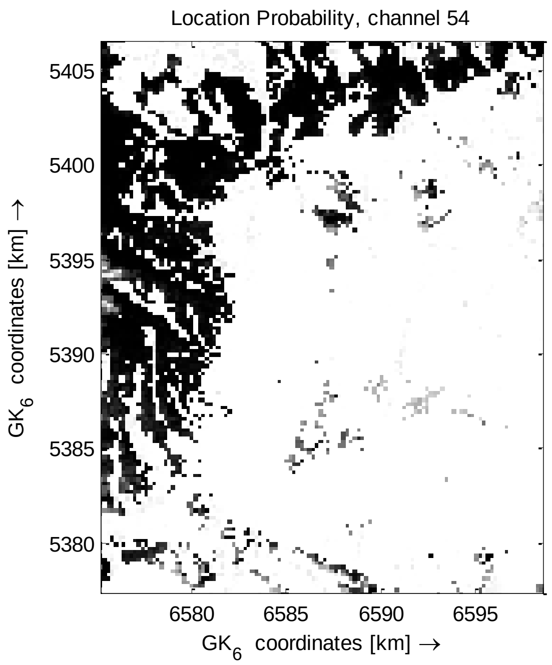

Figure 14 Location probability for Channel 54 in the Banska Bystrica region.

Due to the short distances to a possible DVB-T reception antenna within coverage areas the maximum possible transmit power for WSD is very low. Outside the coverage area the transmit power increases with the distance to the closest coverage area until protection requirements of adjacent channels limits further increase. Figure 38 shows the maximum WSD transmit power for Channel 54. The low transmit power within the coverage areas (dark blue), the increasing transmit power outside the coverage area (cyan → orange) and the limitations caused by adjacent channel situation (inhomogeneous red/orange/ yellow area on the right) are clearly shown.

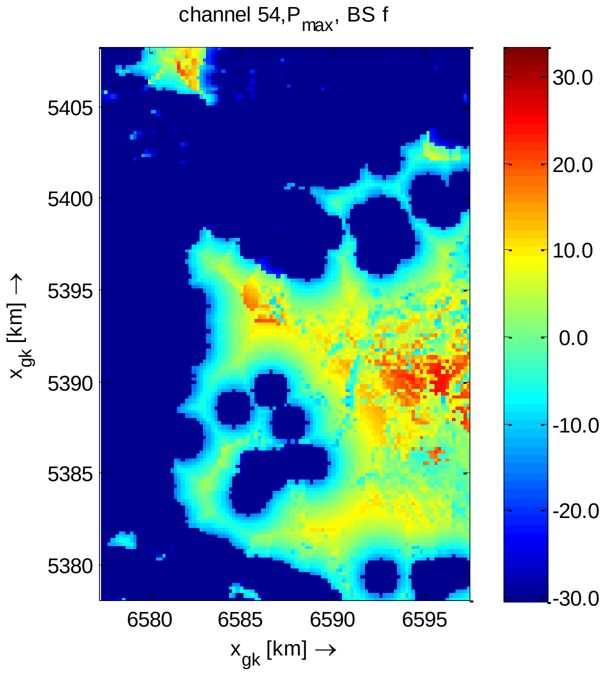

Figure 15 $P_{wsd,max}$ for Channel 54 in the Banska Bystrica region.

Channel 40 in the Banska Bystrica region is not used and also adjacent channels are free (Table 1). In this case WSD transmit powers up to 40 dBm are possible (Figure 16). This limitation in transmit power here is caused by possibly overloading DVB-T receiver. The lower max. transmit powers indicated by light red, orange and yellow pixels are caused by occupied adjacent channels, here n-7 (ch33) and n+8 (ch48).

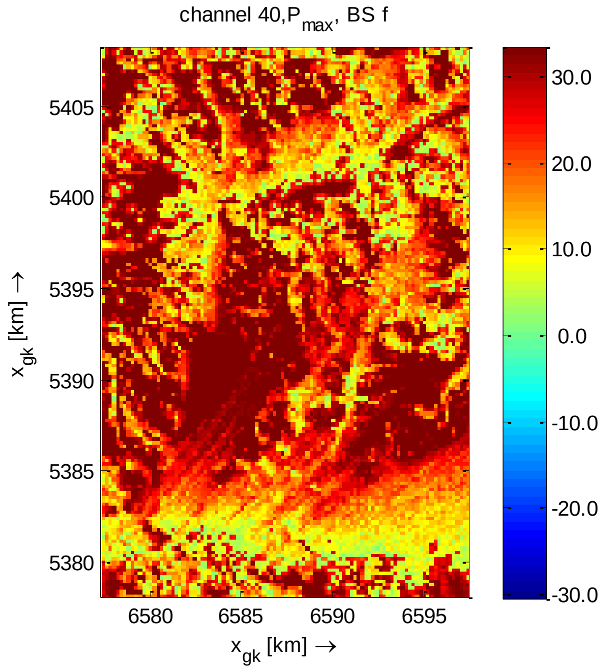

Figure 16 $P_{wsd,max}$ for Channel 40 in the Banska Bystrica region.

As a final example channel 56 in the Bratislava region is shown in Figure 17.

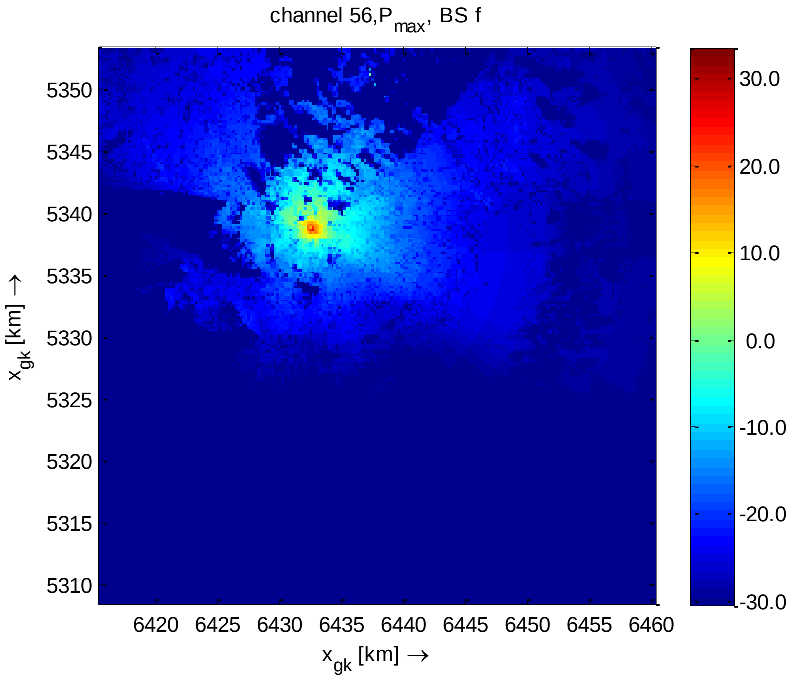

Figure 17 $P_{wsd,max}$ for channel 56 in the Bratislava region.

According to Table 1 channel 56 is used (i.e. within coverage area) and hence the maximum WSD transmit power should be low, as is for most of the locations. The location in the upper left corner where the maximum transmit power reaches up to 30 dBm is at the location of the broadcast transmitter. In this small area the wanted field strength is such high that a reasonable WSD transmit power would be possible inside coverage area. However operation of a WSD in this channel at this location is not reasonable because the DVB-T transmitter acts as a very strong interferer causing the operational range for the WSD system to go down to zero.

Note that the maximum transmit power is not the only relevant parameter for WSD operation, the strength of the interfering signal is as well relevant. This aspect is discussed in more detail in COGEU deliverable D7.2 – Section 7 (Coverage calculation for TVWS Base-Stations).

3.4- Sensitivity analysis on the availability of TVWS in Slovakia

When calculating the maximum WSD transmit power several assumptions were required. The scenarios and values were chosen aligned to CEPT SE43 discussion. To learn about the influence of the parameters we underwent them a sensitivity analysis, which is discussed in the following.

3.4.1- Broadcast coverage scenario

Not all countries in Europe protect the same broadcast coverage scenario. In Germany for example, portable (and fixed of course) reception is protected, while in Slovakia only fixed reception is protected.

The impacts of protecting portable reception and fixed reception were already compared in section 2.1.3 of deliverable D6.2: though the coverage area for portable reception is significantly smaller and lies completely inside the fixed coverage area, the limitations are in some locations caused by the portable reception situation (using different parameters) whereas at other locations they are caused by fixed reception scenario.

But even if only the fixed scenario is protected, the level of protection can vary. According to GE06 agreement 70% location probability is considered as 'acceptable' reception and 95% is seen as 'good' reception. For our investigations in COGEU we used 70% coverage to protect broadcast reception. Some countries however decided to protect only the smaller 95% coverage area. The implication of the different protection levels towards TVWS availability and $P_{wsd,max}$ are investigated here.

In realistic scenarios with terrain based propagation models the coverage area is not a simple outline. The location probability can change very fast over short distances (e.g. at the edge of a hill) or vary only smoothly over wide areas. Hence we could not put the effects in simple formulas but instead did simulations based on our coverage data.

For a broadcast provider aiming e.g. for 70% coverage the ideal characteristic would be:

- LP ≥ 70% inside
- LP = 0 outside

Indeed, in a well designed broadcast net the location probability drops fast at the edge of coverage, see Figure 18. The left diagram shows the calculated $P_{wsd,max}$ for protection of 70% coverage area and the right one shows for 95%: the figures are quite similar.

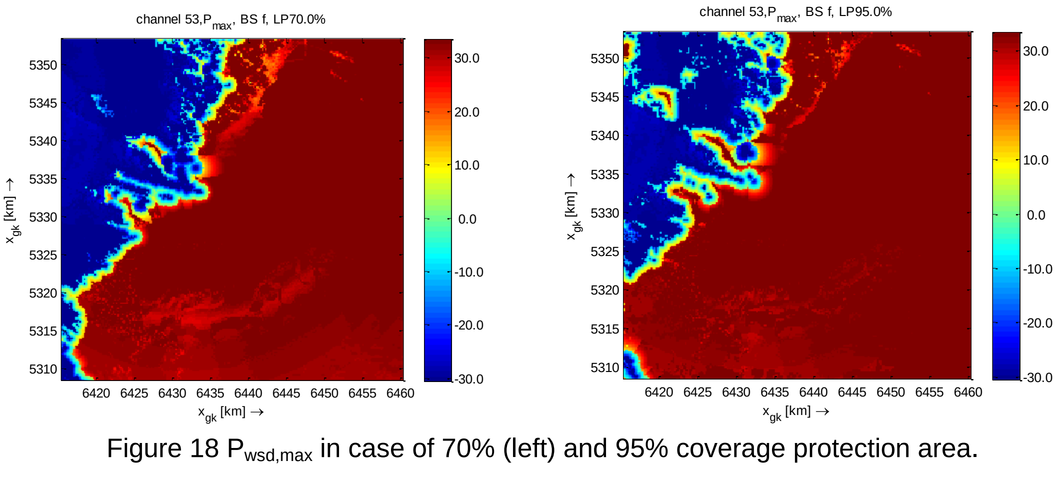

Figure 18 $P_{wsd,max}$ in case of 70% (left) and 95% coverage protection area.

Although not being planned or intended, on other locations the location probability may smoothly decrease from 95% to 70%. As a consequence there can be larger areas where the $P_{wsd,max}$ is significantly higher in the 95% protection case (right) than in the 70% case (left), Figure 19.

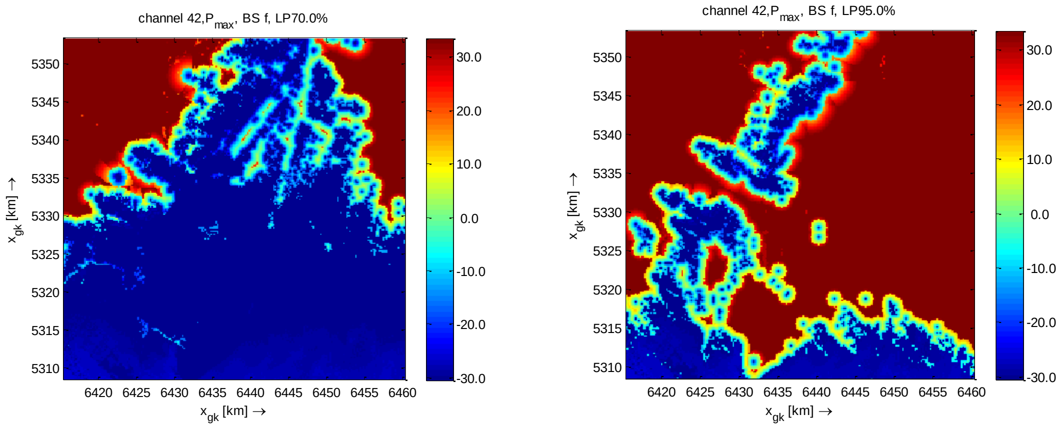

Figure 19 Smooth transition of location probability causes differences in $P_{wsd,max}$ in large areas.

As the 95% coverage area lies completely inside the 70% coverage area and all other parameters are the same, the $P_{wsd,max}$ values are identical inside the 95% coverage area. Outside the 70% coverage area, in a reasonable distance, the $P_{wsd,max}$ are again comparable for both scenarios because the adjacent channel situation and overloading determine the WSD transmit power (note that the coverage areas in adjacent channels are smaller for the 95% scenario which can cause higher transmit powers at some locations).

In principle it can be concluded that the main difference in $P_{wsd,max}$ for 70% and 95% DTT protection lies in the transition region, i.e. those pixels having location probability between 70% and 95%.

The next two pairs of diagrams show that within the (95%) coverage area there are no differences, as expected. Outside the (70%) coverage area the WSD Pmax increases and is finally limited by the adjacent channel situation. Figure 20 and Figure 21 show broadcast transmission from Kamzik tower near Bratislava where in channel 56 a high power signal is radiated (large coverage → low $P_{wsd,max}$) and in channel 55 a low power is radiated. It is easily seen that the $P_{wsd,max}$ inside the 95% coverage region and outside the 70% coverage edge are quite similar. The smaller coverage area of Figure 21 (lower right corner) causes higher possible $P_{wsd,max}$ for channel 55.

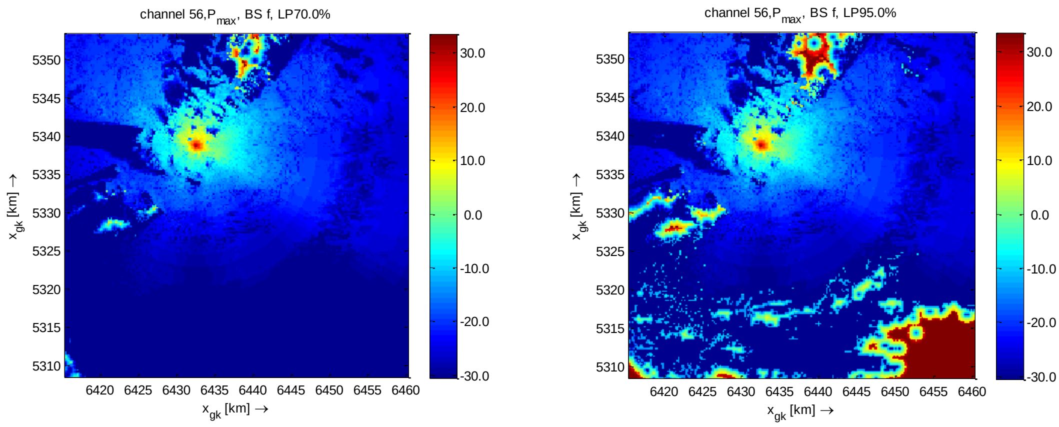

Figure 20 High power transmitter at Kamzik tower.

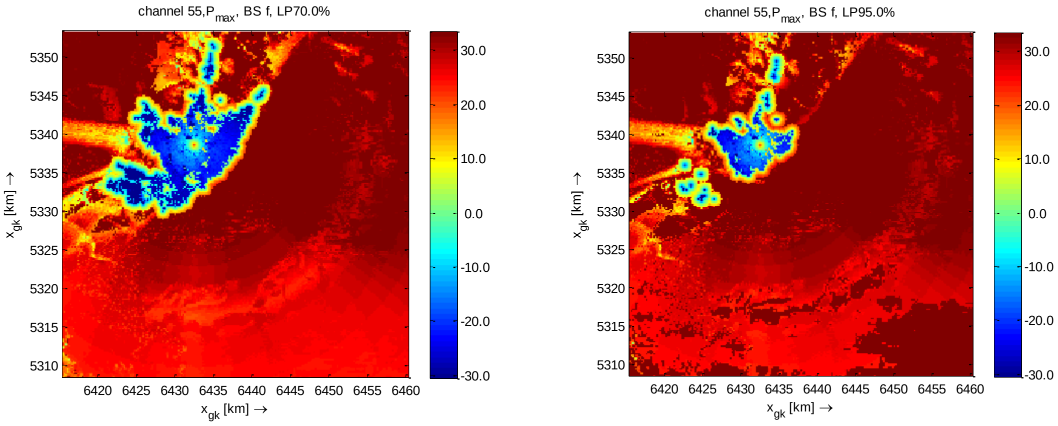

Figure 21 Low power transmitter at Kamzik tower.

Although the protection scenario (fixed or portable, 70% or 95%) is one of the fundamental decisions when planning a broadcast network and is in common not subject to change, we compared two situations with protection of those areas with 70% and 95% coverage. Results show that at locations with high location probability and also at locations with low location probability the differences in $P_{wsd,max}$ are small. Significant higher WSD transmit power can be possible in the transition regions however these are in common not the regions with high population density.

3.4.2- Maximum acceptable degradation

One of the first parameters required for calculating the acceptable WSD interfering signal (Nu_{wsd}) is the acceptable degradation. CEPT SE43 had some discussion on whether this parameter should be 0.1% or 1%. For our investigations we used 1%. To investigate the effect of this parameter, we doubled the acceptable degradation from 1% to 2%.

Increasing the acceptable degradation has two effects:

a) Reduction of the broadcast coverage area and hence increasing the area where WSD may operate
b) Increase the WSD's acceptable transmit power

a) Increase in TVWS
Figure 22 shows the location probability in Bratislava region for channel 55 (low power) and channel 56 (high power). The red pixels indicate those locations where due to 2% degradation the TVWS area increases, i.e. those which were former protected because LP ≥ 70% and now have LP < 70% (no longer protected).

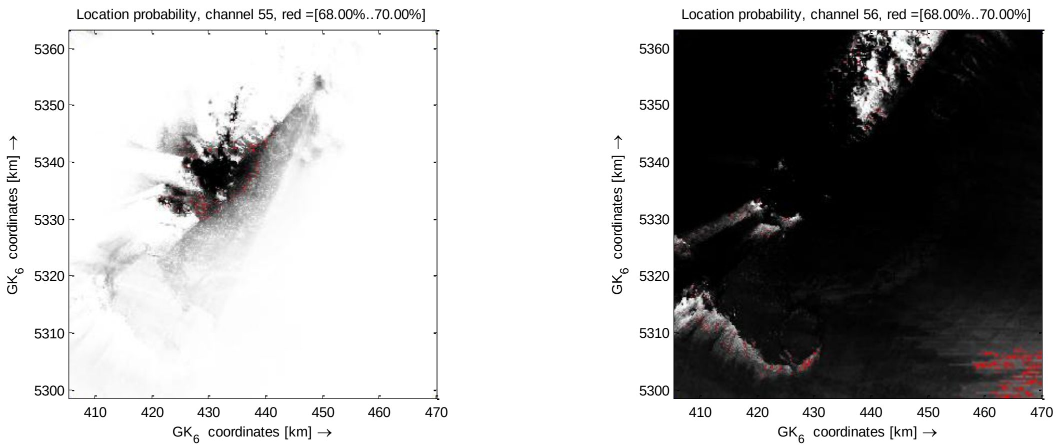

Figure 22 Location probability in Bratislava region for ch55 and ch56

This effect is very weak, hence relaxing the protection of DVB-T reception by higher degradation does not extend the TVWS area remarkably. It should be noted that the effect can be stronger at the edge of a 95% coverage area, see Figure 23, but it can be doubted that network operators that 'only' protect 95% coverage would accept a further decrease in their coverage reliability.

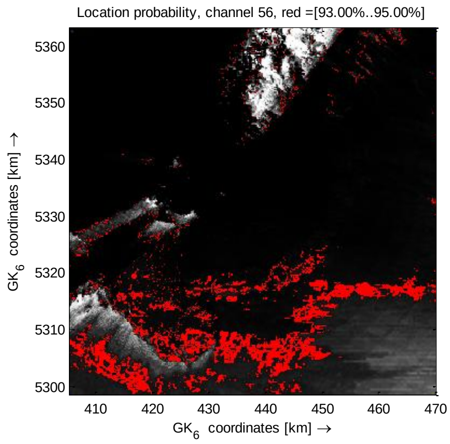

Figure 23 Location probability in Bratislava region for ch56 with degradation 95% → 93%.

b) Increase the WSD's acceptable transmit power

According to D6.2, section 2.1.2.1 the nuisance field can be calculated:

$$Nu_{max}^{wsd} = m_s + 10 * log_{10}\left(10^{-\frac{\sigma_{eff}\varepsilon(q_1-\Delta q)}{10}} + 10^{-\frac{\sigma_{eff}\varepsilon(q_1)}{10}}\right)$$

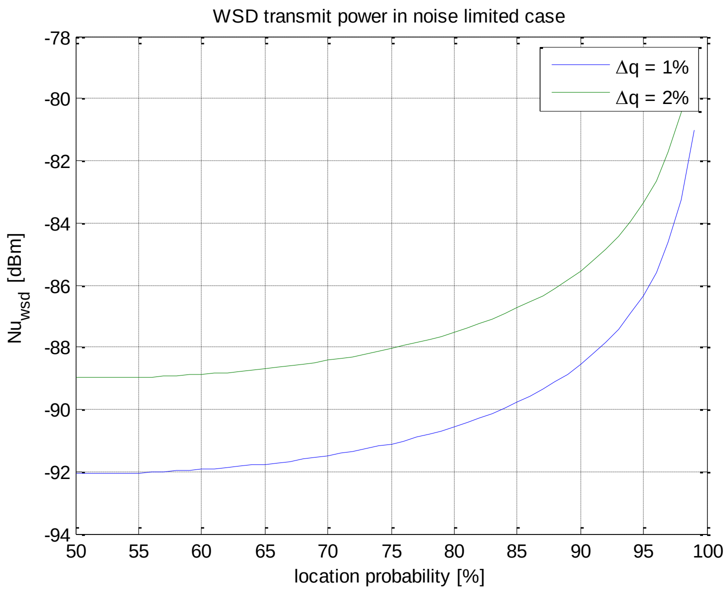

Figure 24 Increase in Nu_{wsd} due to higher degradation

Figure 24 shows that the higher degradation (2% instead of 1%) allows a higher Nu_{wsd}. In the relevant range of 70%…99% location probability the increase in Nu_{max} is ≤ 3 dB. As all the other parameters like PR, antenna gain, path loss etc. are the same, the increase (in dB) of P_{max} is the same as for Nu_{max}.

In summary, the gain in WSD possibilities due to an increase in acceptable degradation is limited:

- The increase of TVWS is very limited and happens on locations where population density is not too high (would there live many people then the coverage area was extended).
- The increase in maximum power is in regions with good broadcast coverage (≥95%) is as little as 1…1.5 dB.

3.4.3- Modified spectrum mask of WSD

With the COGEU protection ratio measurements made two years ago (document SE43(10)32) all the area under the LTE spectrum mask from ECC report #30 (for N < -2 and N > 2) was filled with noise. Note that COGEU considers as WSD a LTE-like device. In the following in SE43 device manufacturer argued that if this would be the case, the portable device's battery would be exhausted soon and hence the real masks are better. Figure 25 from document SE43(10)89_Nokia shows the spectrum mask and an emission spectrum from a Nokia device.

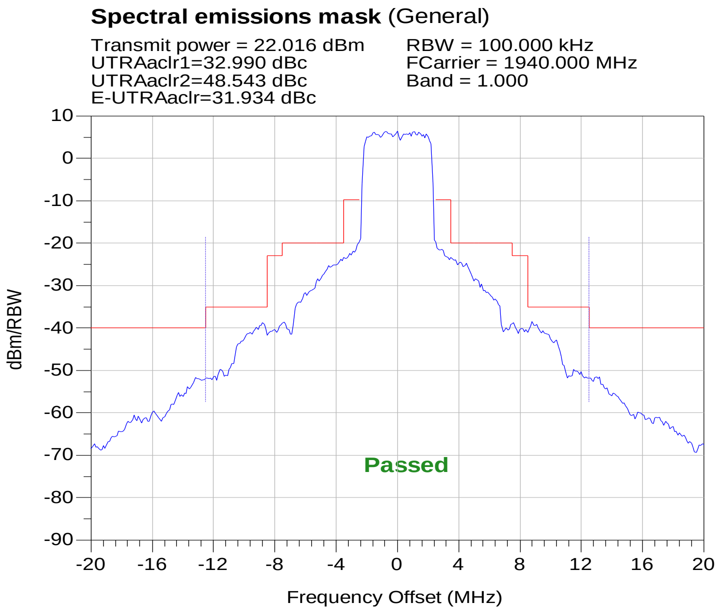

Figure 25 Emission spectrum provided by Nokia (source: SE43(10)89)

New protection ratio measurements made at IRT (for deliverable D4.4) were made with a signal without additional noise, were now the protection ratios are much better for channel separation higher than 3.

To investigate the effect on $P_{wsd,max}$ we first performed calculations for up to N = ±9 channels with the protection ratios from ECC report 148. Then we repeated calculations with only considering the two adjacent channels on each side, i.e. N-2, N-1, N, N+1, N+2.

As a consequence, if a block of 5 contiguous free channels is available then the $P_{wsd,max}$ for the center channel is only limited by overloading thresholds (for overloading the channel separation is as a first approximation irrelevant).

Figure 26 left shows $P_{wsd,max}$ for the case N_{adj} = 9 (N-9…N+9). The limitation is caused by used channels N-3 (ch42) and N+3 (ch48).

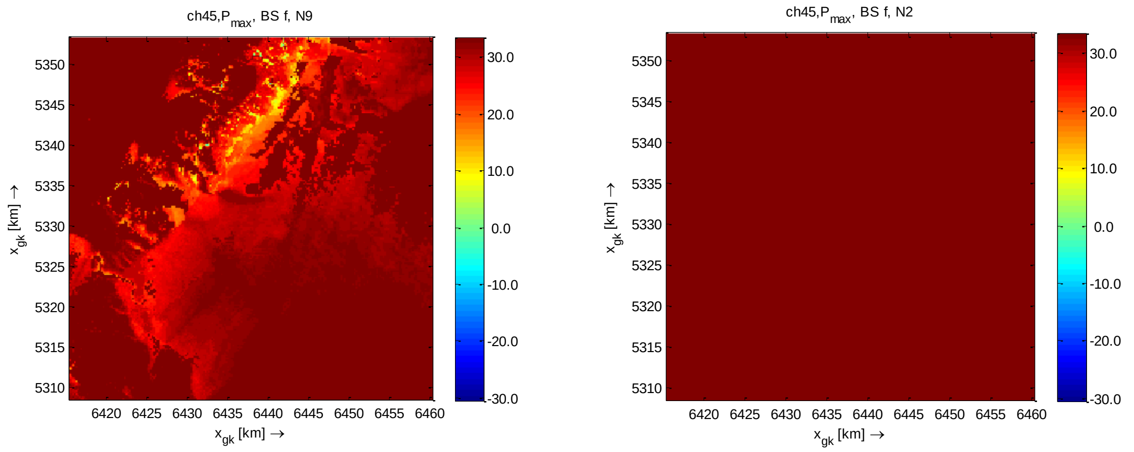

Figure 26 $P_{wsd,max}$ in ch45 for Bratislava region for N_{adj} = 9 and N_{adj} = 2

Figure 27 shows the situation for ch53. The difference in the two figures is caused by ch56 (N+3) which is only considered in the left. Although almost the whole area around Bratislava is ch56 coverage area, there are limitations to $P_{wsd,max}$ only in the South and North areas. This is because of the high wanted signal strength in ch56 which allow high $P_{wsd,max}$ in ch53. Only at those location where the wanted signal strength in ch56 is lower (but still high enough for LP≥70%) the max. WSD transmit power experiences limitations. This is a good example to show that it's not enough just to decide whether adjacent channels are used or not (US view), instead the signal strength of the wanted signals is relevant.

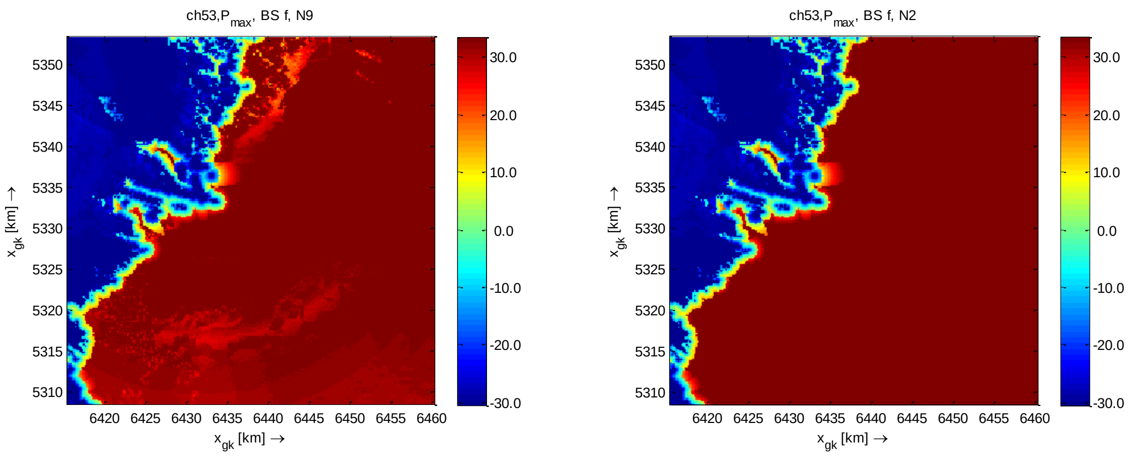

Figure 27 $P_{wsd,max}$ in ch53 for Bratislava region for N_{adj} = 9 and N_{adj} = 2

The investigations show that reducing the out of band emissions and hence applying a stricter spectrum mask offers a good opportunity to increase WSD transmission power. Figure 27 shows that increases of up to 20 dB are possible in some locations.

In the area under investigation around Bratislava only few channels are used. In areas where many TV channels are used (as is the case in the Munich area), the locations where improved spectrum masks provide higher WSD transmit power are more frequently and are often the only means to get reasonable WSD transmit power. For the Munich area COGEU database provides the two variants:

N_{adj} = 9, DTT fixed + portable protected: 'Munich database (more restrictive)'
N_{adj} = 2, DTT fixed only protected: 'Munich database (less restrictive)'

It should be noted that this chance to increase $P_{wsd,max}$ lies purely in the hand of WSD manufacturer and their willingness to define stricter masks and to comply with.

3.4.4- Further parameters that influence the $P_{wsd,max}$

Coming back to the calculation of $P_{wsd,max}$ from the WSD nuisance field Nu_{wsd} there are further parameters that do influence the maximum WSD transmit power:

- Protection ratios
  The protection ratios of the incumbent systems (DTT, PMSE, …) influence $P_{wsd,max}$. If new equipment with improved PR is coming to market (e.g. with silicon tuners which do not use 36 MHz IF and hence are not susceptible for N+9 interference) and with the die out of older systems the $P_{wsd,max}$ may increase: e.g. 2 dB increase in PR can rise $P_{wsd,max}$ by 2 dB, too.

- Distance between WSD and incumbents
  - Inside coverage area
    These distances are derived from worst case assumptions and do severely influence the $P_{wsd,max}$. There are some thoughts on how to relax these limiting parameters. SE43 e.g. has proposed that WSD base station equipment should only be installed by professionals who can choose the best locations related to DTT aerials. Further work in this field is required.
  - Outside coverage area
    Outside of a coverage area the minimum distance to the coverage area is assumed to be the distance to the closest incumbent receiver. If coverage area could be fitted better to the real distribution of DTT receivers, an improvement could be expected. This as well is a matter of further investigations.

- Propagation model
  The propagation model and hence the predicted path loss has a very strong influence on $P_{wsd,max}$. For our calculations we used Hata model and a simple '20-30-40 dB' model (see COGEU D4.1 chapter 2), which is like an average of Hata rural, suburban and urban curves.
  In general the non-terrain based models do have a significant variation which makes predictions difficult. Other methods (for short distances) like ray tracing may only be applicable for very simple scenarios due to complexity and required input data.

Summary of the sensitivity analysis:

WSD transmit power calculations and the resulting powers are strongly dependent on assumptions, e.g.
- Protected scenario
- Accepted Degradation
- Shape of WSD spectrum mask
- Protection ratios and overload thresholds of DTT receiver
- Distance between WSD and DTT receiver
- Propagation model

The influence of these parameters was investigated here. Some of them are not expected to undergo a change in the near future (e.g. change from DTT portable reception scenario to fixed reception scenario), others will cause some controversial discussions at national or international regulatory bodies (e.g. acceptable degradation and minimum distances). The accuracy of the propagation model has a strong influence but is however determined by physics.

One parameter which has a significant influence on WSD transmit power and who lies completely in the hand of WSD equipment manufacturer is the more restrictive spectrum mask and it is recommended to use this as a first step for optimization.

3.5- Compairson between TVWS availability in Munich/Germany and Bratislava/Slovakia

The motivation for repeating the propagation measurements made in the Munich area in Bratislava and Banska Bystrica has been lying in the different situations related to topography and number of used channels.

- Munich

  The area invested in Munich is flat land with different scenarios:

  + rural area (20 km East of Munich)
  + suburban area (in the North of Munich)
  + urban area (in the South of Munich)

  50 km south of Munich the Alps with its high mountains arise; also in the other directions in reasonable distances (20+ km) the country becomes hilly. This has influence on the signal strength of remote DVB-T transmitters in the Munich region.

  Munich is reasonably far away from German border (and shielded by the alps) so that foreign broadcast signals do not influence broadcast reception in the Munich region.

  In the Munich area 16 QAM 2/3 is the primary modulation scheme, where fixed and portable reception is protected.

- Bratislava

  Bratislava lies close to three-border points, Hungary, Austria and Czech Republic. The existence of unused TV channels is significantly impacted by the Analog Switch Off (ASO) process of these neighboring countries and the proximity of high dense inhabited areas such as Vienna – capital city of Austria (60km) and Budapest – capital city of Hungary (200km). The ASO processes are at different stages in the above mentioned countries: Austria is almost concluded, Slovakia and Czech Republic are in progress, and Hungary is postponed. TVWS availability in Bratislava suffers from the combination of several cross border issues and therefore provides an interesting case study.

- Banska Bystrica

  Banska Bystrica is an extremely broken and mountainous region in the middle of Slovakia with high dense populated areas (Banska Bystrica and Zvolen cities). Its average distance of 100 km from borders and geographical conditions (surrounded by hills) makes the existence of unused TV channels highly probable, and a good case study for COGEU rural broadband.

Note:
For the Munich area the COGEU database hosts two variants:

‘more restrictive’: 16QAM2/3, DTT fixed + portable reception protected with N_{adj} = 9
‘less restrictive’: 16QAM2/3, DTT fixed only protected with N_{adj} = 2

The Slovakian data are calculated for 64 QAM2/3 fixed only protected with N_{adj} = 9.
This has to be taken into account when comparing data.

Figure 33 shows the difference in $P_{wsd,max}$ for fixed and portable reception.

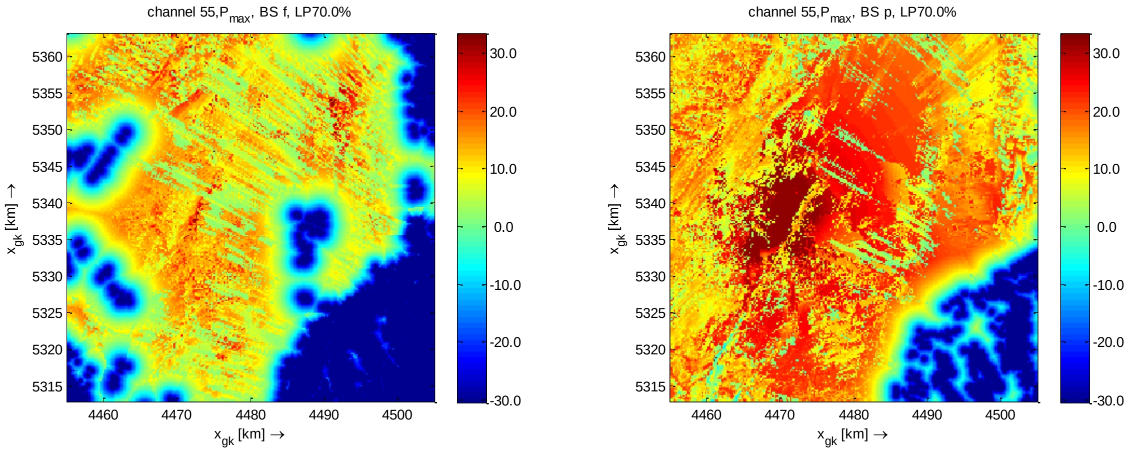

Figure 28 $P_{wsd,max}$ for channel 50 for the 'fixed reception' (right) and 'portable reception' (left) case

Comparing both $P_{wsd,max}$ graphics it might be assumed that the fixed reception scenario causes the more restrictive limitations. However this is not in general the case. Protecting portable reception also includes protecting fixed reception and so for protecting both scenarios the more restrictive value has to be taken: $P_{wsd,max} = \min(P_{wsd,max}(\text{fixed}), P_{wsd,max}(\text{portable}))$. This has been discussed in deliverable D6.2.

The 'more restrictive' data protect both fixed and portable and consider 9 adjacent channels on each side ($N_{adj} = 9$). The 'less restrictive' data protect fixed reception (only) and consider only 2 adjacent channels on each side ($N_{adj} = 2$)

Figure 29 shows the differences for channel 40.

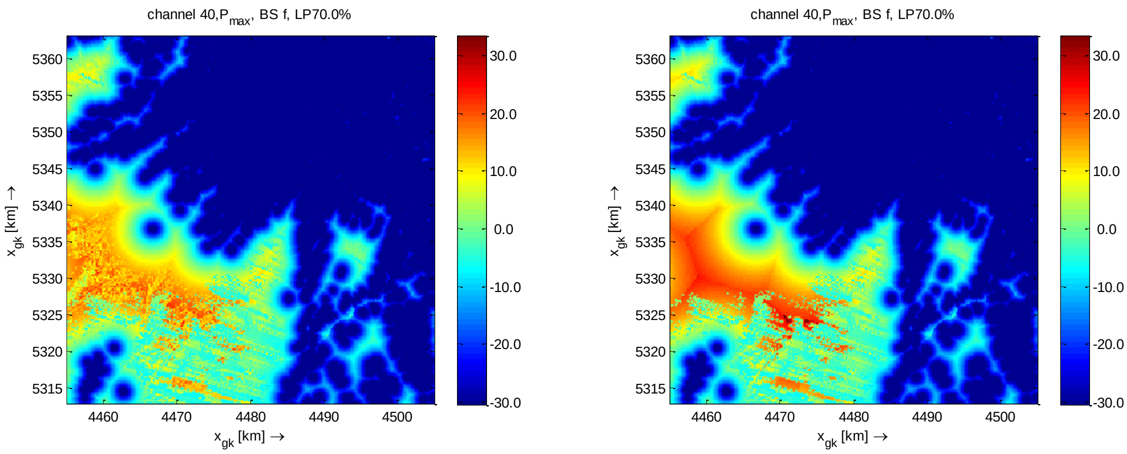

Figure 29 Difference in Pwsd,max for $N_{adj} = 9$ (left) and $N_{adj} = 2$ (right)

In the West of the area the channels N-2, N-1, N, N+1 and N+2 are free and it can easily be seen that in the right picture where only these channels are considered the WSD transmit power can be higher.

It is to notice that the power distribution is also smoother there. This is because the wanted field strength in the adjacent channels which have to be considered sometimes changes quite fast over the area and so the acceptable $P_{wsd,max}$ is varying a similar way. Here at these locations the relevant channels are free and so the limitation is caused by the almost location independent overload threshold.

An interesting parameter to describe the TVWS situation at a given location is the number of available channels for a demanded power. If for example in channel 40 in Munich area (Figure 29) the required WSD power is 20 dBm, then only the red pixels are available. This is a binary threshold (0/1) and counting (for each location) the values for all channels under consideration results in the number of available channels for this power. The frequency range considered by COGEU is from 626 MHz to 786 MHz (channels 40 to 60).

In Munich area in this frequency range 5 channels are used for DVB-T transmission. In addition 2 trial channels are (temporarily) used for DVB-T2 tests.

Figure 30 left shows the number of available channels for the ‘more restrictive’ situation when the required WSD transmit power is 20 dBm, the right side is for the ‘less restrictive’ scenario but with a WSD transmit power 30 dBm.

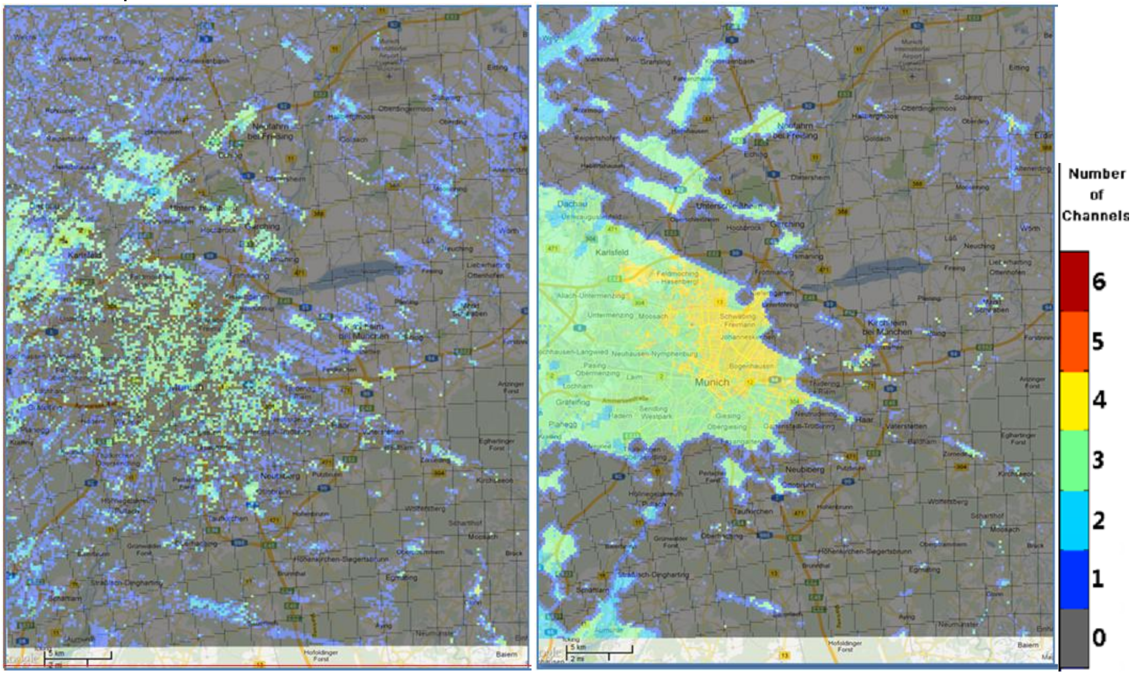

Figure 30 Available channels in Munich area for ‘more restrictive’ and ‘less restrictive’ protection of DVB-T.

Usually two contiguous channels are not used by broadcast operators due to possible interference, so the occupied channels are spread over the whole band (see D4.1 section 2.3.2). Within N-9 and N+9 there are several channels used and so may influence the $P_{wsd,max}$. Due to poorer protection ratios (PR) some channels e.g. N±1 or N+9 may cause more restrictions. Figure 30 shows that although the requested WSD transmit power for the left picture is 10 dB lower, the large number of adjacent channels severely reduces the number of available channels.

The right picture in Figure 30 describes the scenario with 30 dBm wanted WSD power but with N_{adj} = 2 only. The number of available channels is not higher than in favorable locations of the case before which indicates that the dominating effect is caused by the directly adjacent channels.

As mentioned before, the wanted field strength can strongly vary over small areas and so, having to take into account many channels more locations can be found where for one or more adjacent channels the signal strength is high enough for belonging to a coverage area but such low that the calculated $P_{wsd,max}$ is affected.

This also explains the distribution of the available channels. Some of the DTT channels are transmitted from transmitters in Munich, so the signals are stronger in the Munich area. Strong wanted signal allow higher WSD transmit power, so close to the transmitter more channels (higher transmit power) are available for WSD operation. With increasing distance the wanted DTT signal drops and so does the $P_{wsd,max}$. If $P_{wsd,max}$ drops under the threshold, the number of available channels decreases by one.

In general, in Slovakia less multiplexes are in the air than in the Munich area. In Bratislava two multiplexes are on air and some other channels are used by foreign transmitters.

Figure 31 shows the results for Bratislava when the required WSD transmit power is 20 dBm (left picture) and 30 dBm (right picture). Six or even more channels are available in most of the locations. Comparing both pictures it can easily be seen that in case of higher required WSD transmit power, the number of channels decreases. The number decreases at those locations, where the strength of the wanted DTT signals is such that 20 dBm WSD power are possible (left picture) but not 30 dBm (right picture).

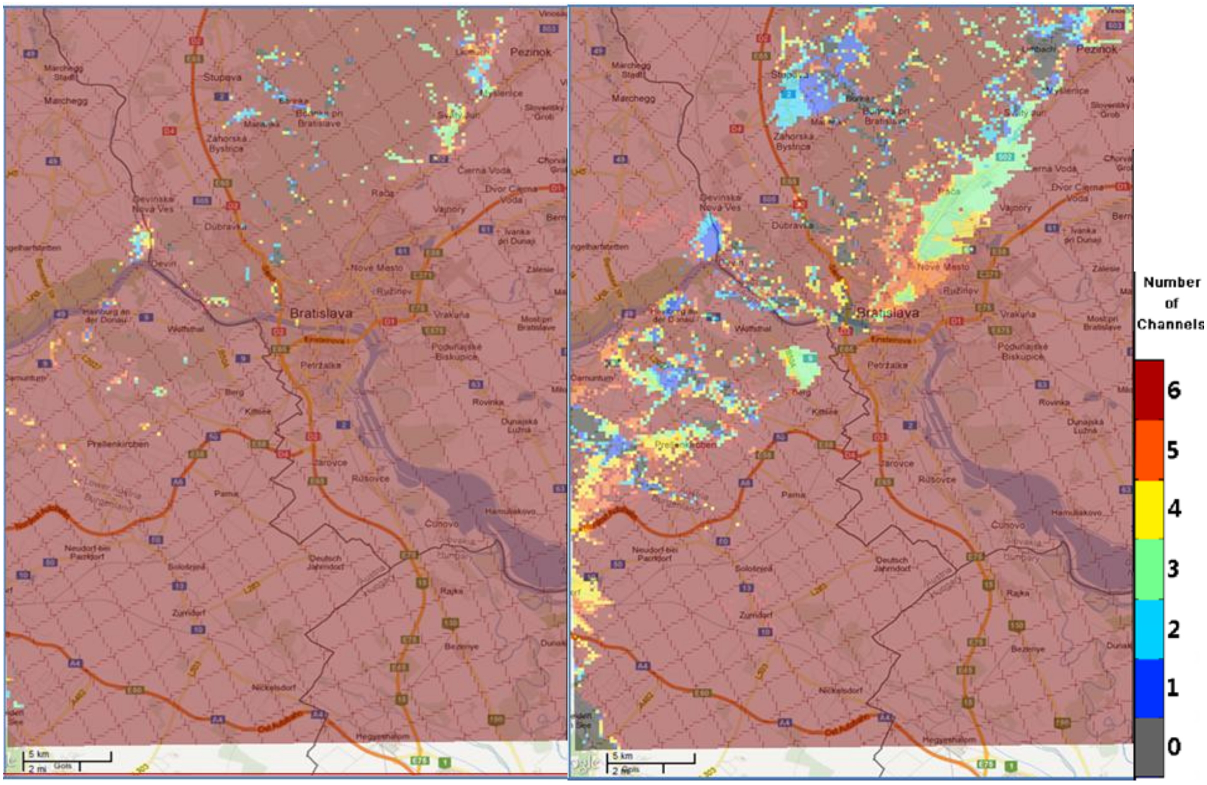

Figure 31 Available channels in Bratislava for max WSD 20 dBm (left) and 30 dBm (right)

In the Banksa Bytrica region, as shown in Figure 32 there are as well many channels available but here the picture looks much less homogeneous. The reason for this is again found in the wanted signal strength and the number of adjacent channels that are taken into account: N_{adj} = 9. There are some channels used by incumbents in the Banska Bystrica region but the signal strength is low and varying, so the possible WSD transmit power is correspondingly low and may drop below the threshold (30dBm). The effect is clearly seen in the valleys which are shaded by the mountains, e.g. East of Zvolen or North West of Bansky Bystrica.

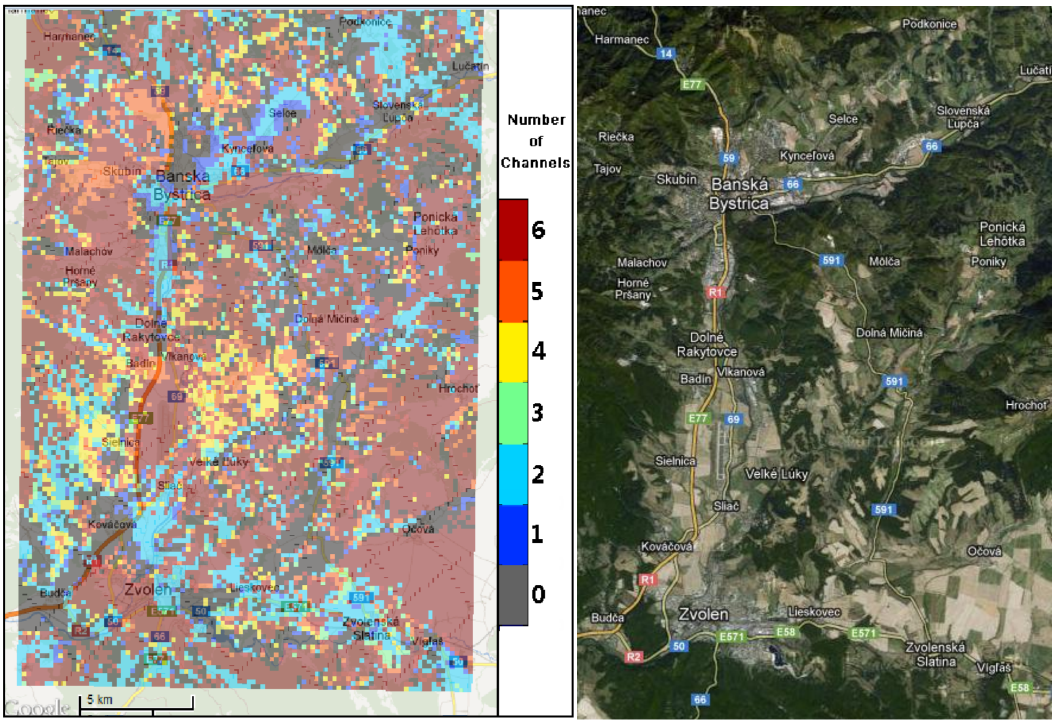

Figure 32 Number of available channels where the max allowed power is higher than 30 dBm for the mountain area of Banska Bystrica.

The investigations made in the chapter before and the comparison of Munich and Slovakian results indicate that:

- If many channels are used by incumbents then the number of channels available for WSD is mainly determined by those adjacent channels where the Pr_{adj} is poor. In general this is the case for N = ±1, (N = ±2) and N = 9.
- In a densely populated spectrum if less adjacent channels are taken into account, the number of available channels does not increase globally, but the local variations become less.
- Strong wanted signals allow higher WSD transmit power. With increasing distance to the transmitter for a required WSD transmit power the number of available channels decreases.

4- Extension of COGEU geo-location database for Slovakian scenarios

The COGEU geo-location database is described in detail in the Chapter 3 of D7.2. Initially planned for a area with 50x50 km around Munich, thanks to the addition of the new partner TOWERCOM, the geo-location database was extended with TVWS maps for the Slovakian areas of Bratislava and Banska Bystrica. This extension is needed for the validation of COGEU demonstrator in Slovakia (T7.4). The COGEU geo-location database provides a User Web interface for visualization of white space maps in several formats and is public available at http://projectos.est.ipcb.pt/cogeu2/index.php. The geo-location database communicates with the WSDs through a protocol (draft-PAWS) developed in T6.4, this allows external researches to use and exploit COGEU white space maps.

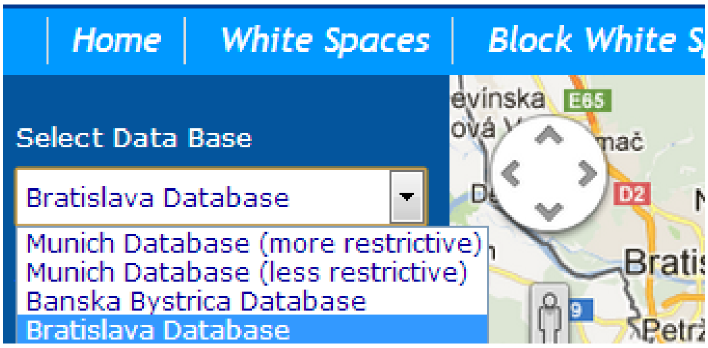

Figure 33 Show White Spaces tool in the online COGEU database including the Slovakian areas of Bratislava and Banska Bystrica.

A summary of the protection criteria and the methodology used to compute the TVWS maps in Slovakia is available for download from the ‘White Spaces’ menu.

To illustrate the extension of the COGEU database for Slovakian scenarios a set of prints screens are showed in the following figures:

- Figure 34 shows the maximum power for a WSDs operating in channel 56 in the Bratislava region. Channels 56 is used by broadcast services and hence the maximum transmit power is very low in most of the area.
- Figure 40 shows the maximum power for a WSDs operating in channel 50 in the Bratislava area. Channel 50 in the Bratislava region is not used and also adjacent channels are free (Table 1). In this case WSD transmit powers up to 30 dBm are possible.
- Figure 36 shows TVWS maps for channel 50 in a black-and-white format. The white colour area represents the locations where secondary users can operate with power up to 30 dBm, the black areas are forbidden for this amount of power. The database automatically computes the % of white spaces for a given power, in this case is 79% of the area.
- Figure 37 shows the chart point map for the Bratislava database. In the geo-pixel marked with red color 12 vacant channels allow more than 30 dBm for WSD operation, i.e. a total of 96 MHz are free.
- Figure 38 shows the maximum power for a WSDs operating in channel 40 in the Banska Bystrica region (20x30 Km). Channel 40 in the Banska Bystrica region is not used and also adjacent channels are free (Table 1). In this case WSD transmit powers up to 40 dBm are possible.
- Figure 39 shows the feature that allows the user to automatically download a pdf file with the summary of the methodology and protection criteria used in the computation of the TVWS maps in Slovakia.

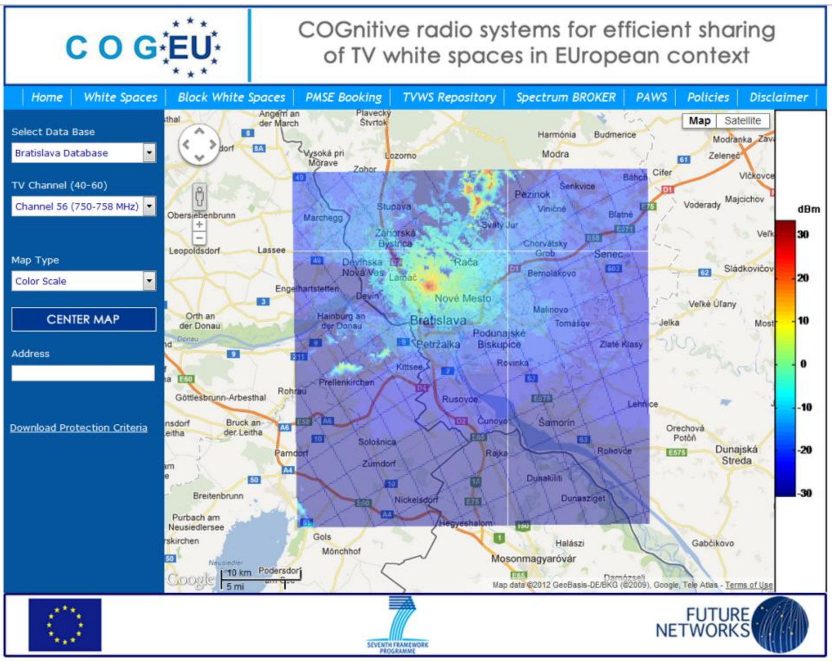

Figure 34 $P_{wsd,max}$ for channel 56 in the Bratislava region (50x50 Km).

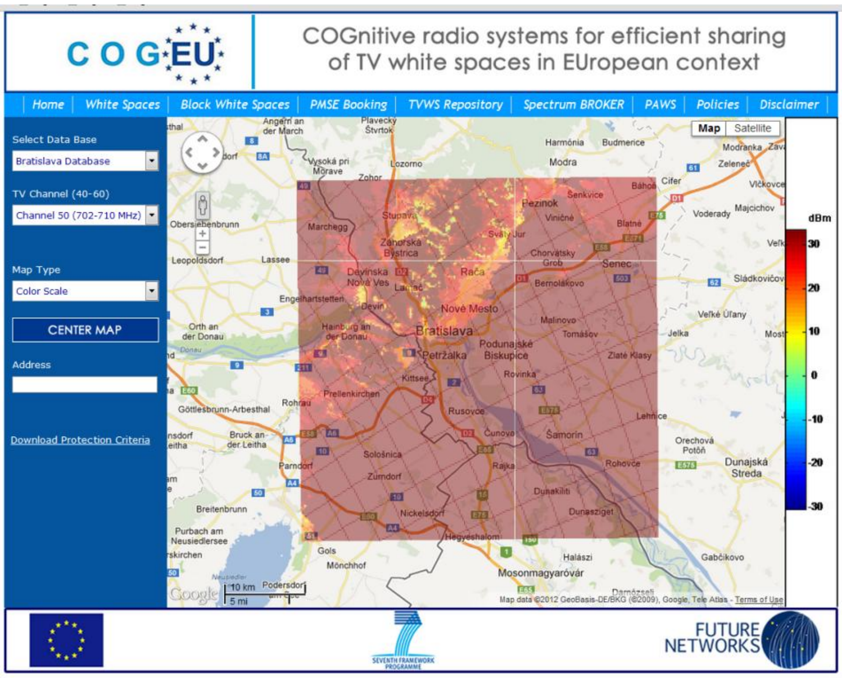

Figure 35 $P_{wsd,max}$ for channel 50 in the Bratislava region (50x50 Km).

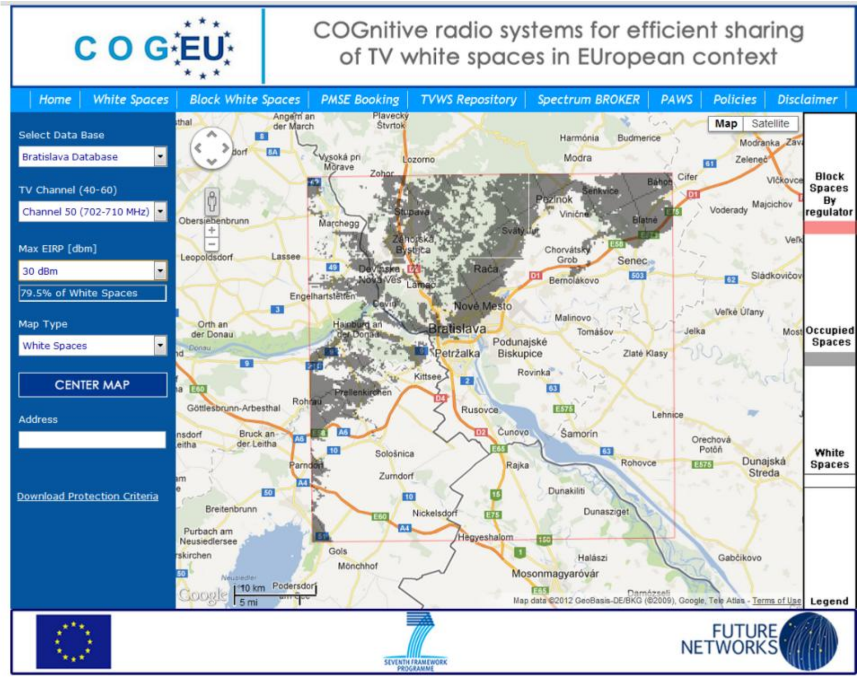

Figure 36 White spaces map for channel 50 in the Bratislava region. The white areas inside the red square are locations where WSDs transmission is possible with transmit power higher than 30 dBm (meaning 79% of the considered area).

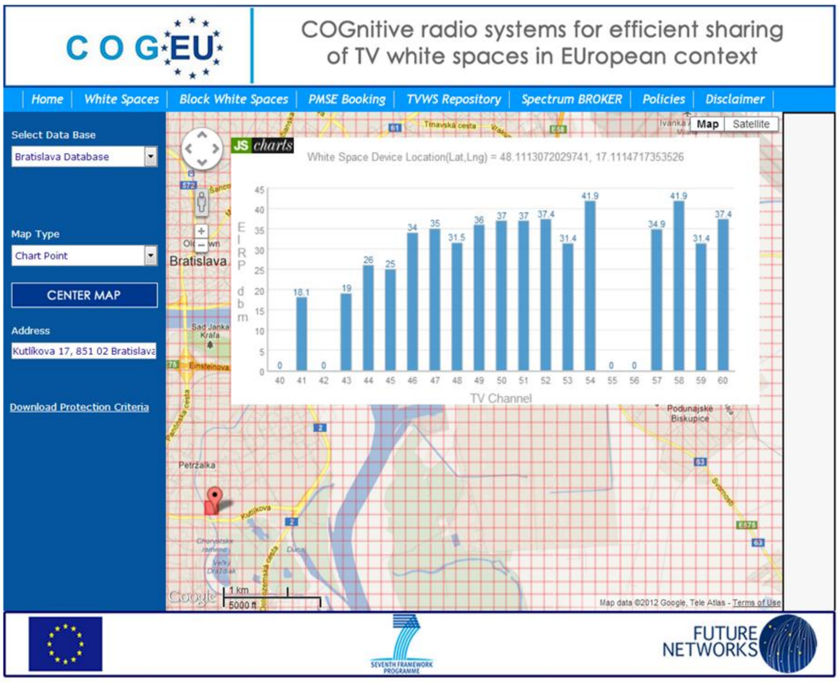

Figure 37 Chart point map for the Bratislava database. In the geo-pixel marked with red 13 vacant channels allow more than 30 dBm for WSD operation, total of 104 MHz are free.

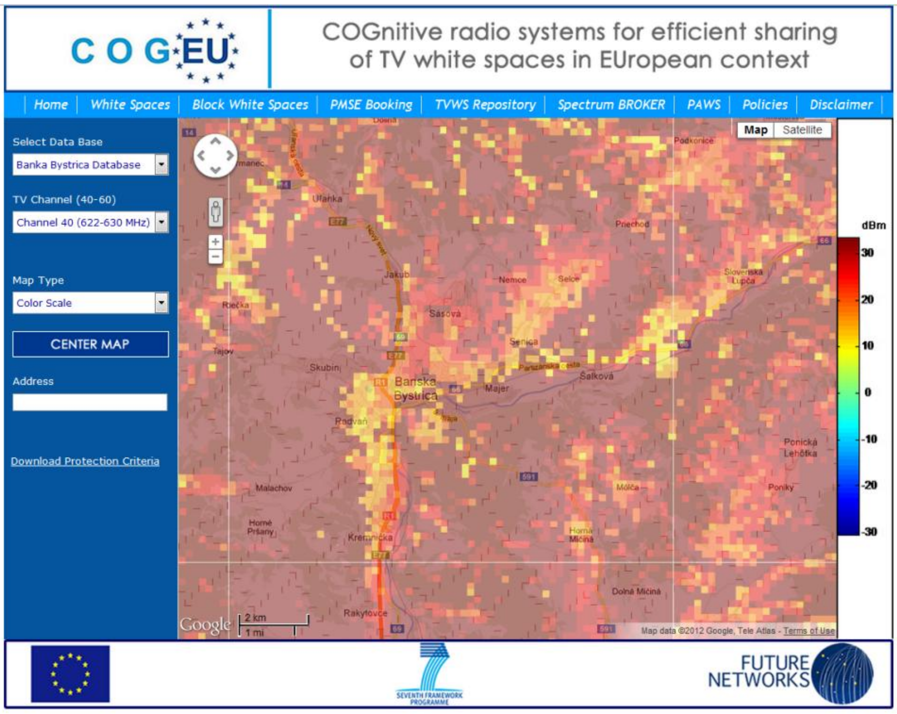

Figure 38 $P_{wsd,max}$ for channel 40 in the Banska Bystrica region (20x30 Km).

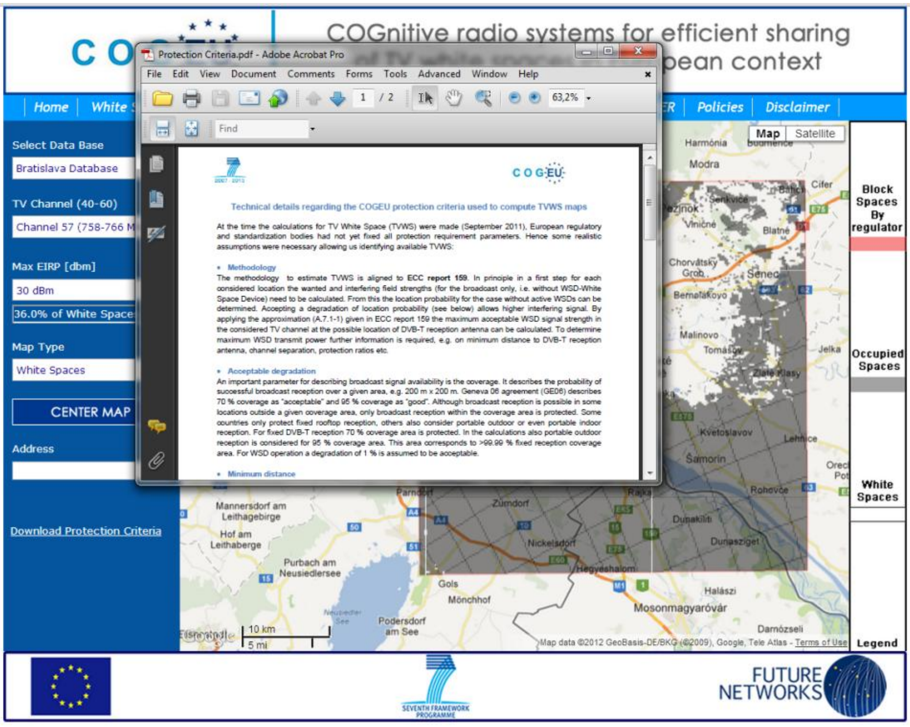

Figure 39 A file with the protection criteria used in the computation of TVWS maps in Slovakia is available for download from the COGEU geo-location database.

5- Conclusions

This Deliverable, D4.6, reported the results of T4.5, spectrum measurements and propagation modelling was utilised to identify the available TVWS in two Slovakian scenarios: Bratislava and Banska Bystrica.

The maximum transmission power for each location on a 200m x 200m grid was calculated for UHF channels 40 to 60. Also, a comparison was performed between the TVWS availability in Munich and Bratislava. Despite the cross-border context of Bratislava, TVWS are more abundant in Bratislava than in the Munich area, this is due to the lower number of multiplexers and the no-protection of portable broadcast reception in Slovakia.

When calculating the maximum WSD transmit power several assumptions were required. The scenarios and values were chosen aligned to CEPT SE43 discussion. To learn about the influence of the parameters we underwent them a sensitivity analysis. One parameter which has a significant influence on WSD transmit power and who lies completely in the hand of WSD equipment manufacturer is the more restrictive WSD's spectrum mask and it is recommended to use this as a first step for optimization.

The COGEU geo-location database was extended with TVWS maps for the Slovakian areas of Bratislava and Banska Bystrica. This extension is needed for the validation of COGEU demonstrator in Slovakia (T7.4). The availability of TVWS reported in this deliverable will also impact the COGEU business models developed for the Slovakian scenarios in WP2. The Main interconnections between the work reported in this deliverable and further tasks of the project are showed in Figure 40.

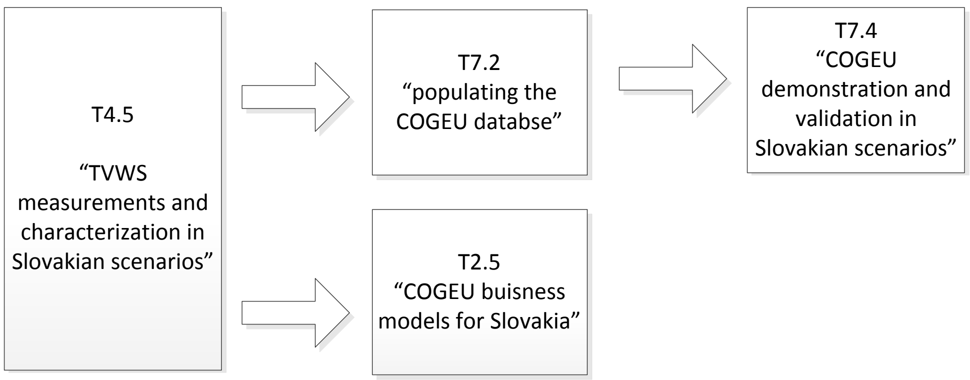

Figure 40: Main interconnections between the work reported in D4.6 (T4.5) and further tasks of the project.

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Abbreviations

CEPT	Conference of European Postal & Telecommunications
DVB-T	Digital Video Broadcasting - Terrestrial
DTV	Digital Television
DTT	Digital Terrestrial Television
ITU	International Telecommunication Union
LTE	Long Term Evolution
OFDM	Orthogonal Frequency Division Multiplexing
TV	Television
TVWS	TV White Spaces
UHF	Ultra High Frequency
US	Unites States of America
WP	Work Package
WSD	White Space Device