An Investigation into the Spectrum Occupancy in Japan in the Context of TV White Space Systems

Soraya Contreras[1], Gabriel Villardi[2], Ryuhei Funada[2], Hiroshi Harada[2]
[1]Télécom Bretagne, Brest, France soraya.contreras@telecom-bretagne.eu
[2]National Institute of Information and Communications Technology, Yokosuka, Japan {gpvillardi, funada, harada}@nict.go.jp

***Abstract*—This paper presents the results of spectrum occupancy measurements carried out in three locations of Kanto area in Japan. Moreover, the collected data corresponding to DTV broadcasting service is analyzed to evaluate the possibilities of secondary systems operating in TV White Spaces (TVWS) in the framework of FCC regulations and Japanese standards. Appropriate propagation models are considered for analyzing the conditions of operation for both, fixed and portable unlicensed devices.**

***Index Terms*— Spectrum Occupancy, Cognitive Radio, White Space Communications, Digital TV.**

I. Introduction

THE apparent scarcity of the frequency spectrum and recent Federal Communications Commission (FCC) regulations allowing the operation of spectrum sharing technologies have motivated studies for determining the spectrum occupancy in different countries [1]–[4]. However, no publication evaluates the opportunities of spectrum sharing systems in digital TV (DTV) bands for specific markets using measured data and considering the FCC rules for unlicensed devices. This paper presents a measurement campaign carried out in three particular locations of Kanto area, Japan. The frequency range goes from 90 MHz to 3 GHz. The collected data is analyzed for determining the spectrum occupancy characteristics. Finally, the measurements are used to evaluate the opportunities of spectrum sharing devices operating in DTV band by taking into account the FCC rules as well as the Japanese regulation and DTV standard.

II. Spectrum Occupancy Measurements

In this section, the spectrum usage characteristics are evaluated for particular sites located in the most populated region of Japan; it does not intend to quantify the spectrum occupancy in the whole country. Spectrum usage is highly dependent of the location, measurement conditions and equipment.

A. *Measurements Setup*

Three sites with different characteristics have been chosen for data collection according to the possible location of TVWS devices. Site 1 corresponds to the rooftop of NICT facilities located in suburban Yokosuka. The antenna was installed at 33 meters height. The coordinates of this site are 35” 13’ 28 N (LA), 139” 40’ 30.64 E (LO). Site 2 is an indoor location in the NICT headquarters building situated in suburban Tokyo. The equipment was installed in a 12 square meters office at the 4th floor of the building. Site 3: Outdoor location situated close to Site 2. The equipment was installed at the floor level to simulate the conditions of a portable CR device operating on any street. The coordinates are 35” 42’ 40 N (LA), 139” 29’ 17.93 E (LO).

For the measurement campaign, a Tektronix Wireless Communication Analyzer WCA380, a discone antenna with omnidirectional pattern in the horizontal plane and a computer connected to the analyzer via Ethernet were used. The antenna was vertically polarized in all the sites and horizontal polarization was also used in site 3.

The data was collected in each site during a 24–hour period per each antenna configuration.

B. *Algorithm description*

Power threshold

During the measurement campaign, the power strength is the physical quantity measured. To evaluate whether a channel

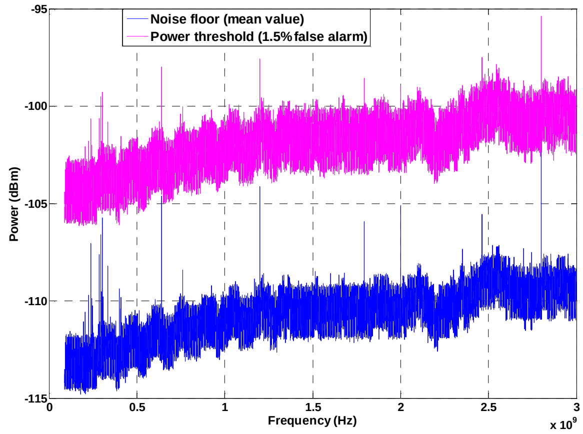


Fig. 1. Mean noise level and power threshold.

CROWNCOM 2011, June 01-03, Osaka, Japan

DOI 10.4108/icst.crowncom.2011.245857

is being used or not, the measured signal level is compared to a power threshold. In consequence, the selection of the threshold is essential for an accurate estimation of the spectrum occupancy.

For determining the threshold value, the equipment noise floor using the desired settings[1] was evaluated. Samples of noise were collected per frequency bin every 30 seconds during 8 hours; since bin width is 6.25 KHz more than 473 million samples were analyzed. The plot on the bottom of figure 1 shows the mean value of the noise floor calculated at each bin. The noise floor level drastically changes with the frequency.

In previous studies [2, 5], a margin of 3 to 5 dB above the mean noise power is set for establishing the decision threshold. This approach is adequate if the equipment noise floor is low compared to the minimum power of the signals to be measured, so that false alarm probability caused by the signal variations do not become a limitation. This is not the case of the results presented in this paper.

The noise statistical properties are highly variable all along the spectrum as shown in figure 1. Evaluating the noise characteristics per bin basis instead of averaging it along several sub bands is a more convenient approach. Different threshold is determined for each frequency point (bin) such that only a percentage of the noise samples overpasses it; in this case, only 1.5% of the samples do. This leads to false alarm probability of 0.015. Power threshold is plot in figure 1.

Frequency resolution

Reminding that the bin separation is 6.25 KHz, figure 2 shows that the bandwidth of several samples exceeding the threshold is not significant enough to be considered as a carrier of a system operating in VHF or UHF but more like random noise. For overcoming these noise effects, 16 bins are grouped and processed in order to make up 100 KHz–wide channels.

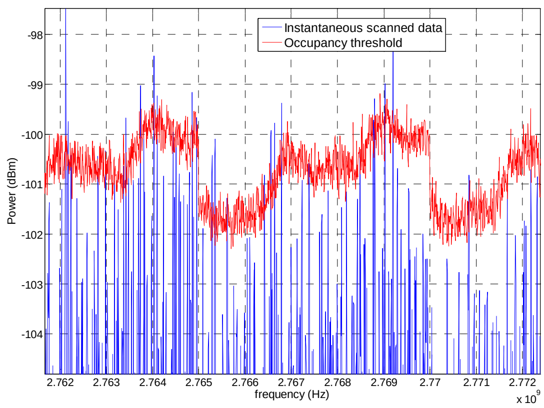


Fig. 2. Zoom on instantaneous PSD in site 1

Allow N to be the total number of power samples collected at time t; let $p_{f,t}$ to be the power level in frequency f at time t. The frequency separation between f and f+1 is 6.25 KHz. In order to group 16 bins, allow j to vary from 1 to the integer part of (N/16). The power threshold at frequency f is denoted by T_f; $b_{f,t}$ indicates whether the measured power at frequency f and time t is greater than the corresponding power threshold as defined by (1)

$$b_{f,t} = \begin{cases} 1\ if\ \ p_{f,t} < T_f \\ 0\ otherwise \end{cases} \qquad (1)$$

The status of each 100 KHz–channel is denoted by $B_{j,t}$; it is estimated by using the power values from $p_{f,t}$ to $p_{f+15,t}$. Busy channel corresponds $B_{j,t}$=1, and $B_{j,t}$=0 indicates idle channel. $B_{j,t}$ is defined by

$$B_{j,t} = \begin{cases} 1\ if\ \sum_{i=f}^{f+15} b_{i,t} \ge 8 \\ 0\ otherwise \end{cases} \qquad (2)$$

C. Occupancy Results

The spectrum usage has been evaluated through an occupancy rate determined by the percentage of time a channel was detected as occupied over a 24–hours period. Figure 3 illustrates the results for Site 1. Information on the services operating in the busiest frequency bands is included.

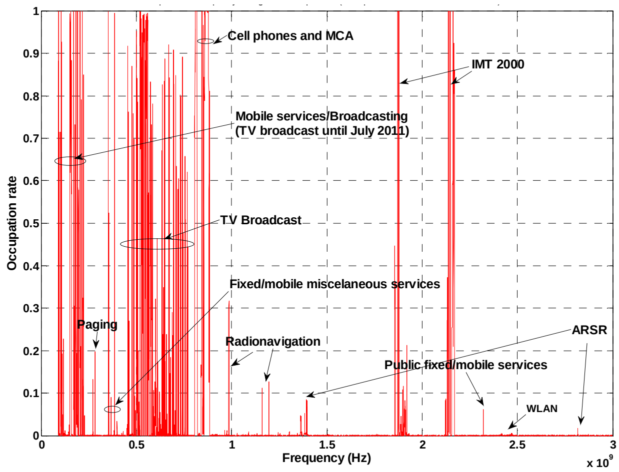


Fig. 3. Duty cycle calculated for the first 24-hour period in Site 1

It has been calculated that only 6.9% of the spectrum between 90 MHz and 3 GHz is used more than 10% of the time, which indicates great potential for deploying spectrum sharing systems in Japan all along the evaluated spectrum.

The spectrum usage is evaluated by establishing nine sub bands determined according to the provided services. The bandwidth and the amount of services provided per band are different in each case, for details on their usage, refer to [6]. Results are presented in Table I.

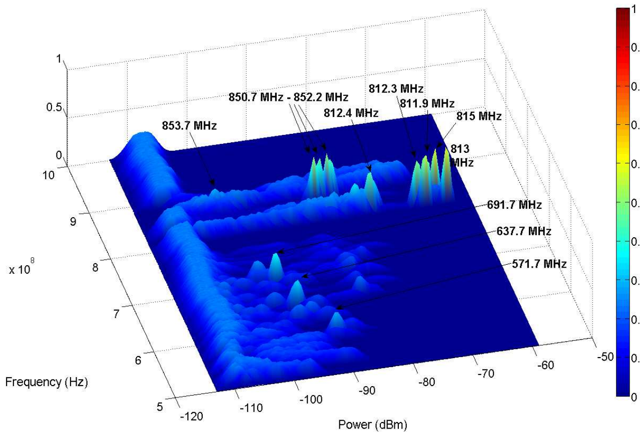


Fig. 4. APD for samples collected in site 1 from 500 MHz to 1 GHz

[1] Span= 3GHz, FFT size= 1024, Number of bins=480001, Reference Level= –50 dBm.

TABLE I
SPECTRUM OCCUPANCY IN SITE 1 CALCULATED FOR NINE SUB BANDS

Sub band	Bandwidth	Occupancy	Services
[90–108] MHz	18 MHz	23.58%	TV broadcast (until 07/11)
[108–170] MHz	62 MHz	12.91%	Miscellaneous Communications
[170–222] MHz	52 MHz	17.46%	TV broadcast (until 07/11)
[222–470] MHz	248 MHz	0.63%	Miscellaneous Communications
[470–810] MHz	340 MHz	13.9%	TV (until 07/12), Radio microphones
[810–958] MHz	148 MHz	28.55%	Cellular networks, disaster prevention, RFID
[958–1710] MHz	752 MHz	0.09%	Miscellaneous services
[1710–2300] MHz	590 MHz	5.9%	IMT 2K, spatial applications
[2300–3000] MHz	700 MHz	0.018%	Radar, IMT2K, ISM, public communications

A different type of analysis may be done by plotting the PDFs as a function of power and frequency. The resulting graphs are the Amplitude Probability Distribution (APD); they allow identifying active transmitters' properties and easily differentiate between several types of services. Figure 4 shows the APD for samples collected in Site 1 from 500 MHz to 1 GHz. To illustrate the utility of this method for service identification, observe in figure 4 the distribution shapes in the TV broadcasting frequencies (500 MHz–770 MHz); they are quite different from those corresponding to cellular service (810 MHz–901 MHz).

D. *Day/Night Comparison*

Spectrum usage during the day and night time has been compared through the occupancy rate and APD plots. The assumption about less occupied broadcasting bands during the night time has not been corroborated. Only significant variations were detected for frequencies dedicated to cellular services (uplink) and WLAN. The average power levels detected in site 2 are presented in figure 5 for the day and night time.

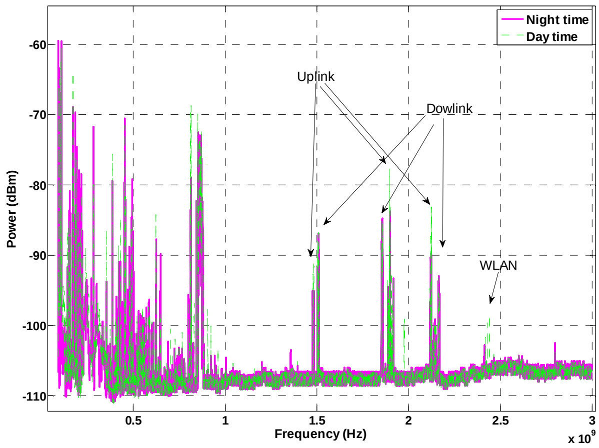
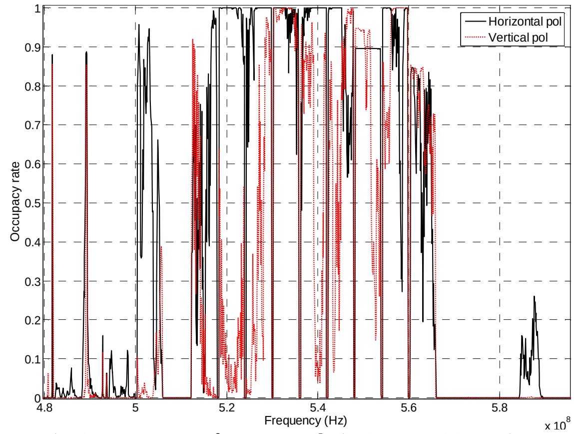


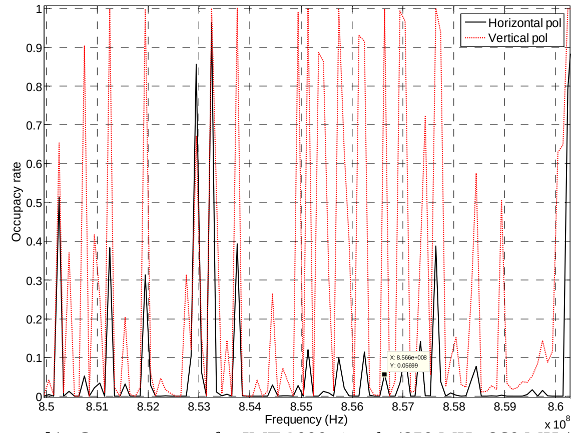
Fig. 5. Average PSD in site 2 during the day and night time

E. *Antenna polarization effect*

Figure 6 illustrates the duty cycle calculated in Site 3 using both, horizontal and vertical polarization; the differences are remarkable. Sensitivity highly improves for broadcasting services (95MHz—108MHz and 470MHz—700MHz) using horizontal polarization. In a similar way, vertical polarization is more convenient for sensing cellular networks, IMT 2000 and radar signals.



a) Occupancy rate for TV signals (470 MHz-590 MHz)



b) Occupancy rate for IMT 2000 signals (850 MHz-860 MHz)

Fig. 6. Comparison of vertical and horizontal polarization.

F. *Occupancy of Digital TV Band*

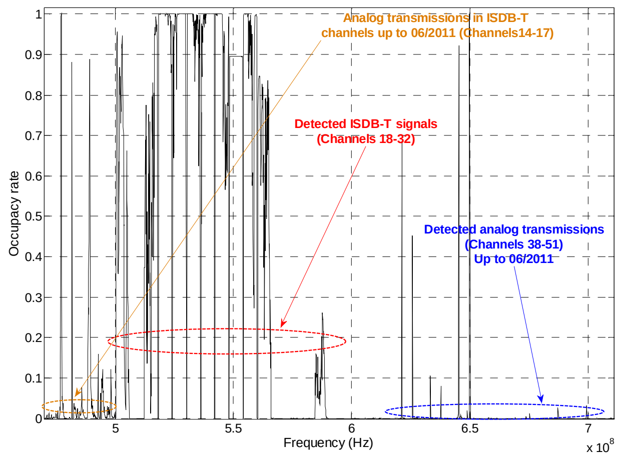


Fig. 7. Current use of frequency band exclusively dedicated to DTV from July 2011

Analog TV broadcasting in Japan is scheduled to finish in 2011. Currently, both, digital and analog transmissions are in service. After mid–2011, TV channels from 13 to 33 will be dedicated to ISDB-T[2] which implies a capacity increase for DTV transmissions of 300% respect to the number of broadcasted digital channels in 2010. These conditions lead to great perspectives for unlicensed devices operating in TV White Spaces, even in highly populated cities.

Figure 7 illustrates the current spectrum occupancy in Site 3 for TV broadcasting band from 470 MHz to 710 MHz. Power characteristics of current digital TV transmission were examined and found to be stable along 24–hour periods. Figure 8 presents the results for broadcasted DTV channels. Y axis identified as “sample” corresponds to the time evolution; sample 1 was taken on October 22nd at 2 pm; sample 2900 was measured the next day by 1:40 pm. Service interruption on channels 26 and 28 was detected from midnight to 4 am and 4:30 am, respectively.

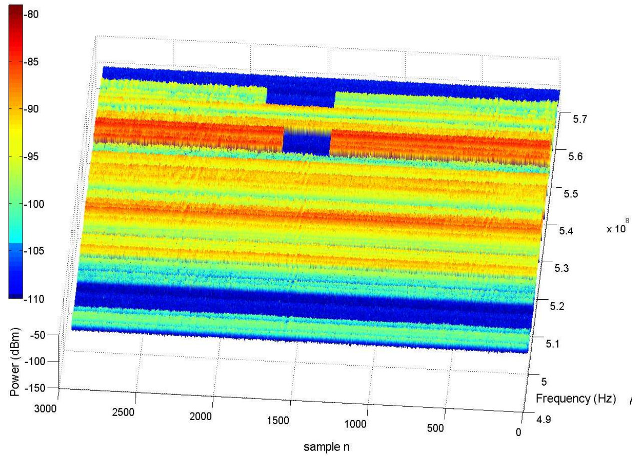


Fig. 8. Power level for DTV signals. TV channels 18 to 29

III. Opportunities for White Space Devices Operation in Japan

In this section, the opportunities for unlicensed devices to operate in the digital TV band are evaluated taking into account the measurements results, the FCC regulations and the dispositions of the Japanese Ministry of Internal Affairs and Communications.

A. FCC regulation

Table II summarizes the FCC proposed rules for protecting DTV service from interference by unlicensed devices [7].

TABLE II
PROPOSED OPERATION PARAMETERS FOR UNLICENSED DEVICES

FCC Proposed Rules	Fixed Devices	Portable Device
Peak EIRP	36 dBm	20 dBm. Limited to 16 dBm if adjacent channel is in use.
DTV field strength to be protected	41 dBμV/m[a]	
Co-channel transmission at edge of protected contour	Required D/U≥23 dB	

[a]Calculated by assuming the following conditions at the receiver system (UHF channels): Minimum signal level at the TV input terminal (TOV)= –84 dBm, Cable losses = 4dB, Antenna gain= 10dB.

[2] Integrated Services Digital Broadcasting-Terrestrial: Standard for digital television broadcasting developed and used in Japan.

B. Operation of fixed TVWS devices in Japan

A protected contour area around the DTV transmitter is defined by using F(50,90) curves and the minimum field strength level specified in Table II. However, 41dBμV/m corresponds to –84 dBm signal level at the receiver input, which is adapted to ATSC[3] standard. Typical sensitivity for receiver sets using ISDB–T standard is –90 dBm, corresponding to 35dBμV/m (considering the antenna gain and cable losses detailed in Table II).

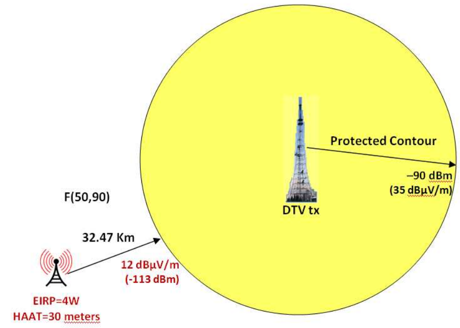


Fig. 9. Operation of fixed unlicensed devices in the framework of FCC regulations and ISDB–T standard.

Figure 9 illustrates the scenario for fixed unlicensed devices; F(50,90) curves were used to calculate the minimum distance between the CR device (operating at full power) and the protected area.

In order to avoid stringent scanning capabilities to be implemented in the unlicensed device, the access to the FCC database of protected radio services is assumed. The device is able to verify its position relative to the protected contours. If the distance is greater than 32.5 Km it may operate at full power; otherwise, power control mechanisms may be implemented for shorter range operation.

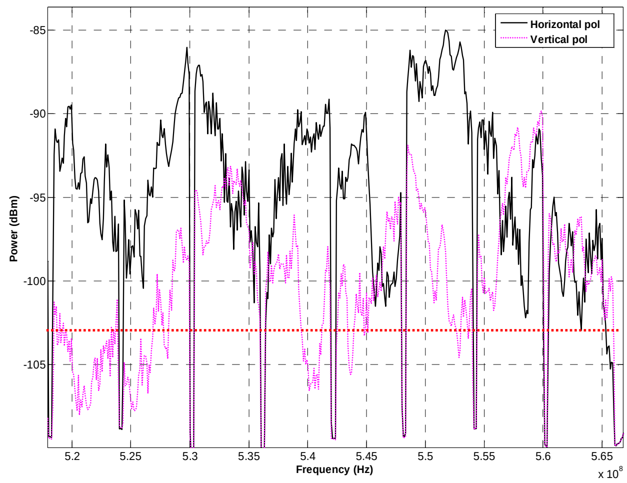


Fig. 10. Zoom on average PSD corresponding to currently used DTV channels (21 to 28) in Site 3.

Figure 10, presents the received power level for the DTV channels currently in service (518MHz to 566MHz). As previously considered, the TV receiver system includes a 10 dBi antenna; however, the measurements were done with a

[3] Advanced Television System Committee: US digital TV standard.

discone antenna (gain~0dBi); in consequence, the signal strength limiting the contour area is marked at –100 dBm in figure 10. The detected power levels measured in the outdoor locations are above the –100 dBm threshold for the DTV channels in service. As shown in figure 11, this is not valid for indoor locations. However, in this paper, we consider the DTV receiver's antenna to be installed outdoor.

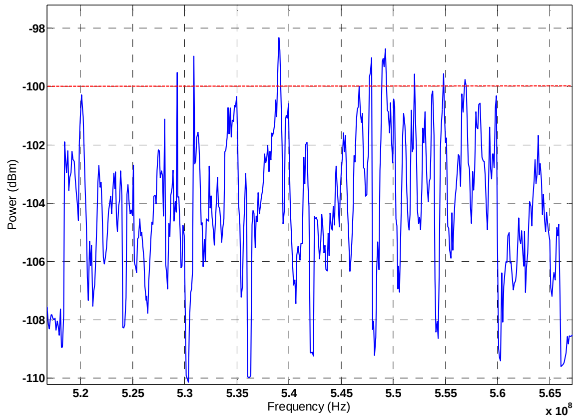


Fig. 11. PSD for TV channels 21–28 measured in Site 2 (indoor)

These results corroborate that statistical modeling for determining spectrum occupancy is not required under FCC regulations regarding the licensed systems database. Actually, the power levels detected and the implemented algorithm allow accurately estimate the occupancy status of each channel. Statistical models may be necessary when an important number of secondary systems will be in operation.

C. Opportunities for portable TVWS devices operation

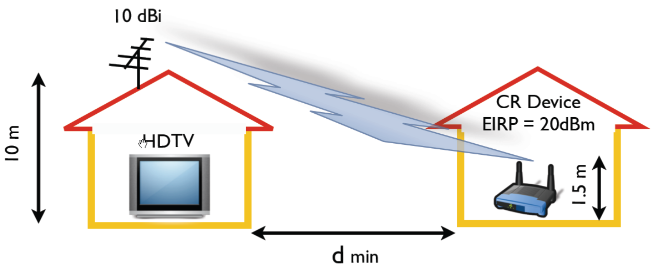


Fig. 12. Unlicensed portable device scenario for indoor operation at border of coverage of the primary system.

Figure 12 illustrates the scenario under consideration for the operation of an unlicensed portable indoor device.

By using an appropriate propagation model for indoor–outdoor or indoor–outdoor–indoor transmissions, it is possible to determine the minimum distance d_{min} that should be respected to avoid interfering with the primary system. In this paper, the propagation model considered is extracted from a internal report of NICT. Such model is based on indoor–outdoor measurements carried out at different frequencies and locations and takes into account the antennas heights and attenuation factors according to the clutter. Random components for modeling shadowing effects have not been used for the calculations presented in this paper.

As previously stated, at the border of the protected area, the desired signal strength at the DTV receiver input is –90 dBm; the co–channel undesired signal strength generated by the unlicensed device should not be greater than –113 dBm. By using these values and the propagation model previously described for a sub urban area, the minimum distance d_{min} is 1.7 Km. If the same calculation is done for an urban zone, d_{min} is reduced to 680 meters.

Results presented in figure 11, show the effect of attenuation losses in areas covered by the primary service. The power levels detected by an indoor device are much lower than those received by the DTV terminals due to the penetration losses, the difference of antenna gain and height. This confirms the necessity for secondary devices to have access to the primary systems database; otherwise, the required sensitivity is extremely high.

IV. Conclusion

We have shown the great potential for deploying spectrum sharing systems in Japan all along the evaluated spectrum, from 90 MHz to 3 GHz.

Through real measurements, we have also demonstrated that statistical modeling for determining spectrum occupancy is not required if the licensed systems data base is implemented and accessible by unlicensed devices.

By considering the FCC regulations and Japanese standards, we have determined a "keep out distance" from the protected area for a TVWS device to operate at full power.

Finally, through the collected data, we have corroborated the necessity for secondary devices to have access the primary systems database; otherwise, required sensitivity is extremely high.

References

[1] A. Petrin and P. G. Steffes, "Analysis and Comparison of Spectrum Measurements performed in Urban and Rural Areas to Determine the Total Amount of Spectrum Usage" in *Proc. of International symposium on Advanced Radio Technologies*, Boulder, 2005, pp. 9–12.

[2] M. Wellens, J. Wu and P. Mähönen, "Evaluation of Spectrum Occupancy in Indoor and Outdoor Scenario in the Context of Cognitive Radio", Dept. Wireless Networks, RWTH Aachen University.

[3] M. López, A. Umbert and F. Casadevall, "Evaluation of Spectrum Occupancy in Spain for Cognitive Radio Applications", Dept. Signal Theory and Comm., UPC, Barcelona, Spain.

[4] M. Habibul, et al, "Spectrum Survey in Singapore: Occupancy Measurements and Analyses", Institute for Infocomm Research, Info-communication Development Authority (IDA) of Singapore, Singapore.

[5] R. Chiang, G. Rowe, and K. Sowerby, "A Quantitative Analysis of Spectral Occupancy Measurements for Cognitive Radio", Dept. Electrical and Computer Eng., University of Auckland, New Zealand.

[6] Ministry of Internal Affairs and Communications, "Frequency Assignment Plan", amended on 31 March 2008. Available: http://www.tele.soumu.go.jp/e/adm/freq/search/share/plan.htm

[7] FCC 08-260, Second Report and Order and Memorandum Opinion and Order, OET bulletin 69.