

# AN OVERVIEW AND COMPARISON OF TV WHITE SPACE REGULATIONS WORLDWIDE

Ser Wah Oh, Yugang Ma, Ming-Hung Tao, Edward Chu Yeow Peh

Institute for Infocomm Research, A\*STAR, 1 Fusionopolis Way, Singapore 138632  
Emails: (swoh, mayg, taomh, cyepeh)@i2r.a-star.edu.sg

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## Abstract

The use of unlicensed wireless devices in TV White Spaces (TVWS) is gaining traction worldwide as a mean to increase spectrum utilization of TV bands. Regulators around the world have released or preparing the regulation frameworks for unlicensed wireless devices operating in TVWS to regulate these white space devices (WSDs). As the use of WSDs is still mostly in trial stages and the switchover from analogue to digital TV is not completed worldwide, the regulators have regular updates to the regulations of WSDs after accumulating more knowledge from the trials. In this paper, we provide an overview and comparisons of the latest TVWS regulations in major regions such as North America, Europe and Asia Pacific. We will point out the rationale for some of the differences so that readers are aware of the various parameters to watch out for when using TVWS.

## 1 Introduction

TV White Spaces (TVWS) are the unused TV channels assigned to TV broadcasting. As digital TV has higher spectrum efficiency than analogue TV, the worldwide trends of switching from analogue to digital TV have free up more spectrums in TV bands for TVWS. Spectrum sharing through TVWS is an important topic as it is the first step towards efficient use of spectrum in an opportunistic and dynamic manner.

TVWS has superior propagation characteristics as it is in the Very High Frequency (VHF) and Ultra High Frequency (UHF) spectrum bands. This results in longer communication distance and better penetration through obstacles. The long communication distance makes TVWS an attractive option for rural connectivity while the better penetration gives TVWS an edge over other technologies for machine-to-machine applications in dense areas. Due to urbanization, TVWS provides a good option as the connectivity backbone for Smart Cities.

In order for white space devices (WSDs) to utilize TVWS, they must not cause excessive interference to primary users (PUs). There are many proposed techniques to protect PUs

from WSDs such as spectrum sensing, beacon and White Space Database (WSDB). While each technique has its own pros and cons technically, there was no consensus on which is the most suitable technique for determining TVWS channels.

To understand which technology is the most suitable for TVWS, the Federal Communications Commission (FCC) conducted their first test of TVWS in 2007. The test concluded that spectrum sensing based approaches had not reached the acceptable accuracy and reliability on detecting PUs. In 2008, FCC released another report, which pointed out that the TVWS prototypes submitted by Adaptrum, Institute for Infocomm Research (I2R), Motorola and Philips had met the burden of "proof of concept" in their ability to detect and avoid PUs' transmissions.

However, FCC finally decided that the current spectrum sensing technologies are not reliable enough to be used solely as a mean to determine vacant TVWS. In 2010, FCC released a Memorandum Opinion and Order that determined the rules for TVWS which are fine-tuned several times subsequently with WSDB as the main method for determining vacant TVWS. After USA, Singapore also finalized its TVWS regulation in 2014. Besides USA and Singapore, Ofcom, CEPT, Canada, New Zealand and other countries have released their draft standards or regulatory frameworks for TVWS. WSDB remains as the main choice for determining TVWS.

Although TVWS applications rely mainly on WSDB, there are other requirements such as protection contour, self-positioning, out-of-band (OOB) limits, update cycle, etc., which are important parameters to be aware of when implementing TVWS in specific countries as these parameters differ for different territories. Thus, analyzing regulations and comparing them over the world become valuable for prospecting TVWS applications.

The rest of this paper is organized as follows. We will first introduce various TVWS regulations in the world in Section 2 which includes representative regulations in three large continents, i.e., North America, Europe and Asia Pacific. These regulations will be compared in Section 3 which covers typical regulation parameters such as frequencies, power and emissions. Finally, some concluding remarks will be given in Section 4.

## 2 TVWS Regulations around the World

### 2.1 North America

#### 2.1.1 United States of America (USA), FCC

In 2004, the FCC of USA became the first regulator in the world to propose the use of unlicensed devices to operate in TV bands at locations where the TV bands are not being used [1]. The purpose is to provide more efficient and effective use of TV bands which may lead to development of new services or increasing the range of existing services. In the latest development, incentive auction, which TV broadcasters will be paid if they allow some of their spectrum to be auction for licensed wireless services, will affect spectrum available for WSDs. Hence, FCC has released a new notice of proposed rulemaking for WSDs in 2014 [2]. The new proposed rules will be covered in this paper. However, the proposed rules are still subjected to changes after feedbacks from relevant stakeholders.

The FCC classifies WSDs into two main categories which are fixed devices and personal portable devices. Fixed devices, which their locations are fixed, are able to operate up to 4W of effective isotropic radiated power (EIRP). Fixed devices that use lesser powers are able to operate at locations closer to the protection contours of PUs in the latest ruling [2]. Fixed devices must access WSDB at least once every 20 minutes to determine the availability of the TV bands. This is an update from the previous requirement of daily query.

Portable WSDs are able to operate up to 100mW of power unless they are operating within protection contours of an adjacent TV broadcast channel which will limit them to 40mW. The personal WSDs are further sub-categorized into Mode I, Mode II and sensing-only devices. The main difference between Mode I and Mode II devices is that Mode II devices have the capability to determine the available channels at their locations while Mode I devices do not have that capability and need to be controlled by fixed or Mode II devices. Mode I devices need to receive signals from fixed or Mode II devices at least once every minute to ensure the continuity of channel availability. For Mode II devices, they need to re-check their locations at least once every minute and have to re-determine the available channels if they move more than 100m. Mode II devices need to access WSDB at least once every 20 minutes to determine the availability of the TV bands even if they have not moved more than 100m.

The FCC has decided that fixed, Mode I and Mode II devices only require WSDB access to determine the availability of TV channels without the need of spectrum sensing in 2010 [3]. Sensing-only devices are able to operate up to 50mW of power but must be able to sense TV signals at -114dBm and wireless microphone signals at -107dBm at least once every minute.

#### 2.1.2 Canada, Industry Canada

In 2011, the regulator of Canada, Industry Canada, released a consultation paper on the policy and technical framework for the use of non-broadcasting applications in the TV bands [4]. The objectives are to seek comments on the possibility of introducing WSDs in TV bands and the possibility changes to rules for licensed rural broadband systems and licensed low-power apparatus such as wireless microphones. After receiving feedbacks from relevant shareholders, Industry Canada has proposed to allow TVWS operations in Canada and the framework for TVWS operations is finalized and released in 2012 [5].

Similar to other parts of the world, Industry Canada will develop initial rules and regulations of WSDs based on WSDB. Spectrum sensing will be considered when the technology is more matured. The WSDs in Canada will generally harmonize with the WSDs in USA and hence the classifications of WSDs will be the same as USA. However, Industry Canada will determine its own technical rules for WSDs with its own established processes and consultations with stakeholders.

### 2.2 Europe

#### 2.2.1 United Kingdom (UK), Ofcom

In 2005, the regulator of UK, Ofcom, announced a Digital Dividend Review to examine the use of TV spectrum free up by the digital switchover programme. The digital switchover programme, which is the switching of analogue to digital TV broadcast, will release a large amount of spectrum for new services. Ofcom released a consultation paper on the use of this free spectrum in 2006 [6] and issued a statement to allow unlicensed WSDs to use interleaved spectrum in TV bands in 2007 [7]. In the first statement on technical parameters of WSDs, which was published in 2009, WSDs will determine the availability of spectrum by sensing, and/or WSDB with WSDB as the more important method in the short to medium term [8]. Beacon technique is determined as the least appropriate and hence being dropped out. Since WSDB is deemed to be more important in the short to medium term, Ofcom has released further details on the parameters for WSDB [9-10].

The Ofcom classifies WSDs into two main categories which are master and slave devices. Master WSDs will contact WSDB for available channels while slave WSDs will receive relevant information from their master WSDs without the need for them to contact WSDB directly. The master WSDs need to determine the location information with 95% certainty which includes the maximum area that the slave WSDs may be located in. If the slave has a different model number from the master WSD, the master WSD has to report the slave model number to WSDB as well. The master WSDs need to access a list of WSDBs from Ofcom at least once every 24 hours and access one of the WSDBs at least once every 2 hours. If a master WSD moves out of its valid area, it needs to re-access WSDB. A slave WSD has to stop operation

whenever the master WSDs request it to or if the slave WSD does not receive a response from the master WSDs within 5 seconds.

### 2.2.2 Europe, CEPT

In 2011, Electronic Communications Committee (ECC) under the European Conference of Postal and Telecommunications Administrations (CEPT) released a report on technical and operational requirements for cognitive radio systems in TVWS in 2011 [11]. In this report, it concluded that sensing alone is not reliable enough to guarantee the protection of co-channel Digital Terrestrial Television (DTT) receivers and PMSE and WSDB is the most feasible method either alone or combined with sensing. The report provides details on the procedure for WSDB to calculate available channels and their maximum powers allowable by WSDs. The deployment of WSDs will be based on the master and slave architecture similar to the one proposed by Ofcom.

In 2013, the ECC released a report [12] to enhance the details of implementing the WSDB. The general principles of: 1) location accuracy, 2) master-slave operations, 3) database management, 4) translation process in WSDB and 5) combination of sensing and WSDB, are provided in this report. At the same time, the ECC also released another report [13] to enhance and facilitate the development of the regulation for WSDs. The technical investigations in this report included: 1) classification of WSDs, 2) collaborative spectral sensing, 3) protection parameters of DTT, 4) protection parameters of PSME, 5) protection of aeronautical radio-navigation service system, 6) impact of WSD interference on services operating at adjacent channels, 7) potential amount of spectrum available for WSDs.

## 2.3 Asia Pacific

### 2.3.1 Singapore, IDA

Singapore is active in promoting TVWS. In 2012, Singapore white space pilot group (SWSPG) was established with the support of Infocomm Development Authority (IDA), the nation regulator for Telecommunications. The members of SWSPG include I<sup>2</sup>R, Microsoft, StarHub, Neul, NICT, Power Automation and so on. In the past two years, SWSPG has conducted various TVWS pilot projects and has led Singapore to be an innovation zone and test-bed of advanced TVWS technologies. IDA also organizes a TVWS regulation taskforce under Telecommunications Standards Advisory Committee (TSAC) to set TVWS standardization in Singapore. In 2014, IDA released TVWS regulatory framework based on public feedbacks from its TVWS consultation paper.

IDA welcomes and intends to attract global TVWS companies come into Singapore market. Thus, Singapore’s TVWS regulation is friendly and compatible to major TVWS standards in the world such as that of FCC, Ofcom and CEPT. However, Singapore’s TVWS regulation has also unique points which are suitable for a city country. For example,

since Singapore is a small urban city, a single TV tower could cover the whole city; there are no separation distances defined for co-channel and adjacent channels. Since Singapore is a dense city, the out-of-band (OOB) emission is also strict. To avoid the interference to the neighboring country, Malaysia, IDA regulates that a WSD signal propagating at the border should be smaller than -115dBm [14].

The Singapore TVWS regulation also introduces a special type of channel called High Priority Channel (HPC). With HPC, WSDs could potentially have Quality of Service (QoS) differentiations even among WSDs. The detail operation of HPC is currently under investigation with potential WSDB operators together with IDA.

### 2.3.2 New Zealand, Radio Spectrum Management

The Radio Spectrum Management of New Zealand has decided to create an interim licensing scheme to allow trials of WSDs in the UHF TV bands. In 2014, it released a consultation paper for certification and licensing rules of TVWS devices [15]. A long term regime that suit New Zealand will be investigated only after international frameworks and regulations are developed. Under the current interim licensing scheme, WSDs have to follow either FCC Part 15, Subpart H standard or the standard “ETSI EN 301 598 V1.1.1” published by European Telecommunications Standards Institute (ETSI). In the consultation paper, it is proposed that WSDs are able to transmit a maximum EIRP of 10dBW.

## 3 Regulation Comparison

In this section, we compare the regulatory specifications, in particular, spectrum usage, power limit, protection level, and WSDB requirements among different countries.

### 3.1 TVWS Frequency Range

FCC (MHz)	Canada (MHz)	Ofcom (MHz)	CEPT (MHz)	IDA (MHz)	New Zealand (MHz)
Fixed WSDs: 54-72, 76-88, 174-216.	54-72, 76-88, 174-216, 470-608, 614-698.	470-550, 614-790.	470-790.	181-188, 209-223, 502-518, 614-622, 630-710, 718-742, 750-774, 790-806.	510-606.
Fixed & portable WSDs: 470-698.*					

\*Except areas where part 27 600MHz band wireless licensees operate.

Table 1: TVWS frequency ranges for different regulations

The recommended frequency ranges for TVWS regulations in different countries are listed in Table 1. From the table, one could see that the frequency ranges are similar for countries in the same region. This is probably due to history of TV band frequency usage. From the table, it can be observed that the TVWS frequency ranges of USA, Canada and Singapore are

very wide which span from VHF to UHF. While in Europe and New Zealand, the TVWS frequency ranges are only in the UHF. Large frequency range may be a challenge for antenna design and size if a WSD is to cover the whole frequency range. Hence, it is important for manufacturers and users of WSDs to select the appropriate antenna for the frequency range they intend to operate.

### 3.2 Number of Channels

FCC	Ofcom	CEPT	Canada	IDA	New Zealand
50 channels 2-51.	32 channels 21-30, 39-60.	40 channels 21-60.	49 channels 2-36, 38-51.	24 channels	12 channels 26-37.

Table 2: The numbers of available channels for different regulations

The comparison of the number of available channels in different regulations is shown in Table 2. From the table, it may seem that North America countries like USA and Canada have more available TVWS spectrum than European countries. However, from Table 3, the channel bandwidth of each TV channel in North America countries is 6 MHz while in Europe it is 8MHz. Hence, the total available TVWS spectrum in North America and Europe are actually quite close.

Singapore seems to have lesser TVWS spectrum compared to North America and Europe based on Tables 2 and 3. However, it is important to note that the number of TVWS channels provided in Singapore is excluding all operating TV broadcast channels since a single TV broadcast channel will cover the whole island, thus, losing the opportunity to use this frequency as interleave spectrum. While the TVWS channels provided in North America and Europe include operating TV broadcast channels since different parts of the countries may have different number of operating TV broadcast channels. Hence, it is hard to conclude whether Singapore has more or less available TVWS spectrum compared to North America and Europe.

New Zealand has a small number of available TVWS channels as these TVWS channels are set aside for trials. It is still not known how many TVWS channels will be released if its TVWS framework is finalized.

### 3.3 Channel Bandwidth

FCC	Ofcom	CEPT	Canada	IDA	New Zealand
6MHz	8MHz	8MHz	6MHz	7MHz (VHF) 8MHz (UHF)	8MHz

Table 3: The TVWS channel bandwidths in different regulations

The channel bandwidth comparison between different regulations is shown in Table 3. This bandwidth is consistent with the current bandwidth used by TV broadcasting.

### 3.4 Types of Devices

FCC	Ofcom	CEPT	Canada	IDA	New Zealand
Fixed WSD, Mode I WSD, Mode II WSD, Sensing only WSD	Master WSD, Slave WSD	Master WSD, Slave WSD	Fixed WSD, Mode I WSD, Mode II WSD	Fixed WSD, Mode I WSD, Mode II WSD	Fixed, Base station, Mobile

Table 4: The device types defined in different regulations

The device types defined in each regulation are shown in Table 4. In general, the types are similar although the naming might be slightly different except for sensing-only WSDs where currently only FCC supports this type of device. The fixed and Mode II WSDs are similar to master WSDs while Mode I WSDs are similar to slave WSDs.

### 3.4 In-Channel and OOB Power Limits

In this section, we provide and compare the in-band and OOB power limits of WSDs in various countries. In USA, Canada and Singapore, the in-band powers (within whole TV band) allowed by WSDs are pre-determined and then based on these pre-determined in-band powers, the OOB power limits (per 100kHz) are determined respectively. Hence, their values are fixed. However, for Europe and UK, the maximum in-band powers of WSDs are determined by WSDB for different TV channels and then the OOB limits are computed based on the provided maximum in-band powers together with the ACLR of different classes of WSDs with a minimum OOB limit set at -84dBm/100kHz. Hence, their values are dynamic and different across different TV channels.

#### 3.4.1 United States of America

Type of WSD	Conduct power limit (6 MHz)	PSD limit (100 kHz)	OOB limit (100 kHz)
Fixed	30dBm (1W)	12.6dBm	-42.8dBm
	26dBm (0.4W)	8.6dBm	-46.8dBm
	22dBm (158mW)	4.6dBm	-50.8dBm
	18dBm (63mW)	0.6dBm	-54.8dBm
	14dBm (25mW)	-3.4dBm	-58.8dBm
	10dBm (10mW)	-7.4dBm	-62.8dBm
Personal/portable (adj. channel)	16dBm (40mW)	-1.4dBm	-56.8dBm
Sensing only	17dBm (50mW)	-0.4dBm	-55.8dBm
All other personal/portable	20dBm (0.1W)	2.6dBm	-52.8dBm

Table 5: The power limit, PSD limit, and adjacent channel limit proposed by the US FCC [16-17]

The power limit, power spectral density (PSD) limit, and the adjacent channel limit for each device type under FCC regulation are listed in Table 5.

### 3.4.2 United Kingdom

The WSDB should specify the maximum permitted in-block EIRP spectral density in term of both per 100 kHz and 8 MHz for each 8MHz DTT channel to WSDs.

The out-of-block (OOB) EIRP spectral density,  $P_{OOB}$ , of a WSD is as follows [18]

$$P_{OOB(dBm/0.1MHz)} < \max\{P_{IB(dBm/8MHz)} - AFLR(dB), -84\} \quad (1)$$

where  $P_{IB}$  is the WSD's in-block EIRP spectral density and AFLR is the WSD's adjacent frequency leakage ratio. AFLR is equivalent to ACLR, adjacent channel leakage ratio, which is defined as in-band emission power versus peak power spectrum density per 100 kHz. The values of ACLR can be found in Table 6.

Where $P_{OOB}$ falls within the $n^{th}$ adjacent DTT channel	ACLR (dB)			
	Class 1	Class 2	Class 3	Class 4
$n = \pm 1$	74	74	64	54
$n = \pm 2$	79	74	74	64
$n \geq \pm 3$	84	74	84	74

Table 6: The recommended ACLR values in UK Ofcom regulation [18]

### 3.4.3 Europe

European Telecommunications Standards Institute (ETSI) is a standardization organization that develops standards for radio communication systems and equipment. It works closely with ECC and is officially recognized by the European Union as a European standards organization. The WSDs' ACLR set by ETSI follows the same limitations as the UK Ofcom except adding class 5 [19].

Where $P_{OOB}$ falls within the $n^{th}$ adjacent DTT channel	ACLR (dB)				
	Class 1	Class 2	Class 3	Class 4	Class 5
$n = \pm 1$	74	74	64	54	43
$n = \pm 2$	79	74	74	64	53
$n \geq \pm 3$	84	74	84	74	64

Table 7: Recommended ACLR values in ETSI standard.

### 3.4.4 Canada

In keeping with Industry Canada's proposal to broadly harmonize with the USA, the co-channel and adjacent-channel separation distances relative to the TV protected contours specified in Table 8 would form a starting point for

discussion of interference protection criteria for TV receivers [5].

TV WSD Characteristics			Required Separation (km) from Analog or DTV Protected Contour	
Type	Maximum EIRP	Antenna height	Co-channel	Adjacent-channel
Mobile (Mode I or II)	16dBm	not applicable	6.0 km	[Note 1]
	20dBm	not applicable	6.0 km	0.1 km
Fixed	36dBm	less than 3 metres	6.0 km	0.1 km
		3 to less than 10 metres	8.0 km	0.1 km
		10 to 30 metres	14.4 km	0.74 km

**Note 1:** Due to the low potential for interference, mobile WSDs with an EIRP of 16dBm or less would be permitted to operate within or outside broadcast coverage areas with no minimum separation distance from the protected contour of a TV broadcast station when using the adjacent channel

Table 8: The separations suggested for different forms of devices by the Canada regulation.

### 3.4.5 Singapore

In Singapore, the upper power limits for fixed and portable WSDs are similar to the FCC. The main exception is for WSDs operating at an adjacent channel to broadcast TV signals where Singapore allows up to 100mW while FCC only allows 40mW transmission with the same OOB of -56.8dBm. There is no OOB limit if WSDs are operating in TV channels that are not adjacent to any TV broadcasting channels. The in-band and OOB power limits proposed by IDA are provided in Table 9. For cross-border protection, WSDB needs to ensure the signal level propagated from a WSD reaching the Singapore borders will be at the noise floor level of -115dBm [14] to protect Malaysia's TV receivers. This is 9dB more stringent than the requirement from New Zealand which only requires -106dBm to protect their DTT receivers (see Section 3.4.6).

Type of WSD	EIRP limit (8 MHz)	Adjacent channel limit (100 kHz)
Fixed	36dBm (4W)	-56.8dBm
Mode I/II	20dBm (0.1W)	-56.8dBm

Table 9: The in-band and OOB power limits regulations set by IDA.

### 3.4.6 New Zealand

In New Zealand, the signals from WSDs arriving at a DTT receiver within the  $48dB\mu V/m$  coverage contour must be lower than -106dBm. This is based on the thermal noise floor calculated based on a 7.77MHz bandwidth and a noise figure of 6dB for DTT receivers.

It is also required to conduct calculations to prove that any signals produced by WSDs operating under the proposed

TVWS licenses are 6dB or more below the noise floor of a DTT receiver anywhere within the coverage of a DTT transmitter. In addition, to consider adjacent channel leakage from WSD and adjacent channel selectivity of DTT, the unwanted emission limits are given as in Table 10.

Limits within DTV bands (dBm /100 kHz, EIRP)		
Fixed (conducted +6dBi antenna gain)	Personal / portable adjacent to occupied TV channels	Other personal / portable
-36.8	-56.8	-52.8

Table 10: The unwanted emission limit proposed in the New Zealand regulation [15].

### 3.7 WSDB Requirements

	FCC	Ofcom	CEPT	Singapore
Min. WSDB output data	Avail. TV channels	1) Start and end frequencies of available bands, 2) Maximum power levels, 3) Time validity of data 4) Notification of any sensing requirement	1) Start and end frequencies of available bands, 2) Maximum power levels, 3) Time validity of data, 4) Maximum number of contiguous DTT channels, 5) Maximum number of DTT channels that WSDs can transmit	Avail. TV channels
WSD access freq.	20 minutes	2 hours	-	6 hours
Default time validity of data	1 hour	2 hours	-	6 hours
Location accuracy	50 meters	100 meters	100 meters	50 meters
Reserve channels for WSDs	1	0	0	2

Table 10: WSDB requirements in various regulations

In general, the more frequent the WSDB is being accessed, the more efficient is the spectrum utilization. However, there is a tradeoff between complexity and efficiency. Moving forward in the future, the frequency of access might be increased.

## 4 Conclusion

The introduction of dynamic spectrum access such as TVWS increases the efficiency of spectrum utilization. Many countries are actively promoting it as a way to solve spectrum

crunch issues. Due to early stage of development, TVWS regulations from around the world are not harmonized yet. It is therefore important to understand the differences of the different regulations and the rationale behind them so that better WSDs can be designed to tackle the needs of various regions and applications.

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