IEEE 1900.7 White Space Radio Regulatory and propagation conditions in the TVWS

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Abstract

- UHF TV bands is a prime option where White Space Radio (WSR) is applicable
- Opportunities for WSR depend on parameter values set by regulators (spectrum mask, transmit power) and propagation properties
- Potential scenarios require estimates of link budget and propagation conditions
- This presentation highlights US and UK TVWS operation parameters, and the propagation models that can be envisaged
- ➡ It concludes on estimated communication range in the TVWS

Key parameters from regulation (1)

- → FCC has approved communication parameters in the TVWS in 2009 [1]
- → OFCOM is setting up parameters in the UK [2]

Parameter	FCC [1]	OFCOM [2]	Note
Power for FD in adjacent band	Not allowed	Not applicable	
Power for FD in non-adjacent band with geo-location	30dBm (1W)	Not applicable	FCC: 36dBm EIRP with a gain
capability			antenna
Power for PPD in adjacent band	16dBm (40mW)	4dBm	Gain antenna not allowed
Power for PPD in non-adjacent band with geo-location	20dBm (100mW)	17dBm	Gain antenna not allowed
capability			
Power for PPD in non-adjacent band without geo-location	17dBm (50mW)		
capability			
Out-of-band performance	<55dB	<-46dBm	Relative to in-band power in the
			case of the FCC

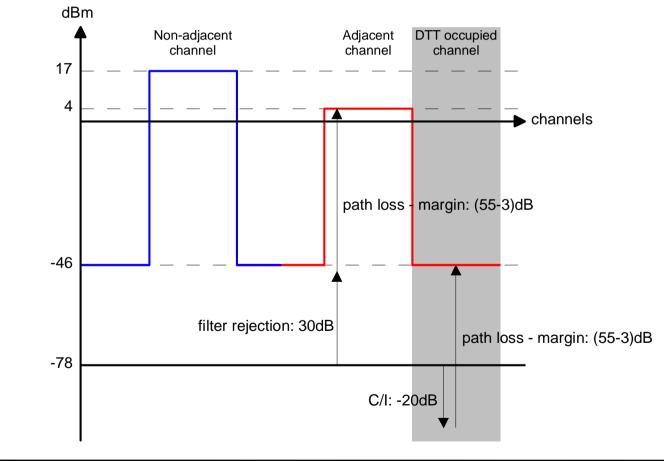
FD: Fixed Device PPD: Personal Portable Device

CEPT SE43 is harmonizing TVWS operation across Europe (not considered in this presentation)

[1] FCC final rule, "Unlicensed Operation in the TV Broadcast Bands", US Federal Register Vol. 74, No.30, pp 7314-7332, Feb. 17 2009 [2] Digital dividend: cognitive access, statement on licence-exempting cognitive devices using interleaved spectrum, OFCOM, July 2009

Key parameters from regulation (2)

➡ Spectrum mask suggested by OFCOM in the UK



Assuptions for this study

- Maximum allowed Power: power level at output of TX antenna in EIRP
 - Fixed: 4 W EIRP
 - Portable: 100 mW EIRP
 - Adjacent: 40 mW (FCC) /2.5 mW EIRP (OFCOM)
 - Bandwidth: 8 MHz bandwidth
- Assumption on Receiver
 - Rx noise figure set to 6 dB (from UHF TV tuners)
 - SNR requirement set to 12 dB (4b.s⁻¹.Hz⁻¹ theoretical)

Propagation scenarios

- ➡ Frequency of propagation set to UHF 470MHz-790MHz
- Scenarios in terms of propagation may be grouped into 3 categories
 - 1. Indoor PPD (expected: 1 100m) e.g. WLAN
 - 2. Outdoor FD to PPD (expected: 0.1 10km) e.g. cellular
 - 3. Outdoor FD to FD (expected: 1-10km) e.g. backhauling
- For each channel scenario, the following parameters should be derived:
 - Path Loss model: used to derive a link budget
 - Coherence bandwidth of the channel: Time Delay Spread
 - Coherence time of the channel: Doppler Spread

Indoor PPD case

- Corresponds to wlan or femtocell scenario
 - Ranges from 1 to 100 m
 - Indoor propagations
- Path Loss
 - Saleh and Valenzuela [1] propose Path Loss of type

$$L(r) = -10 \log_{10}(r^{-\alpha}) + 10 \log_{10}\left(G_{t}G_{r}\left[\frac{\lambda_{0}}{4\pi}\right]^{2}\right)$$

• Lots of variation over alpha in the literature. Number between 1.5 (hallways) and 6 (wc NLOS) depending on layout of building – Typical case between 3 to 4 – Confirmed in [2] – When crossing multiple floors, typical values vary from 4 to 6.

[1] A. A. M. Saleh and R. L. Valenzuela, « A Statistical Model for Indoor Multipath Propagation », IEEE Journal on Selected Areas in Comms, vol. 5, 1987, pp 128-137

[2] T. K. Sarkar, and al., « A survey of Various Propagation Models for Mobile Communications », IEEE Antennas and Propagation Magazine, vol. 45, No. 3, June 2003

Indoor PPD case – link budget

тх	4 W	100 mW	40 mW	2.5 mW
Tx Allowed Maximum Power	36 dBm	20 dBm	16 dBm	4 dBm
Tx Cable Loss	0 dB	0 dB	0 dB	0 dB
Tx Antenna Gain	0 dBi	0 dBi	0 dBi	0 dBi
Tx Band	8 MHz	8 MHz	8 MHz	8 MHz
Tx Power Spectral Density	-33,03 dBm/Hz	-49,03 dBm/Hz	-53,03 dBm/Hz	-65,03 dBm/Hz
EIRP	36,00 dBm	20,00 dBm	16,00 dBm	4,00 dBm
RX				
Rx Noise Power Density (Thermal Noise)	-174,00 dBm/Hz		at 290K	
Rx Noise Power Density (mermar Noise)	-104,97 dBm		ai 2301	
Rx Noise Figure	-104,97 dBm 6 dB		Rem 7 dB max fo	or SiTuper D\/B_T
Required SNR	12 dB			mplementation Loss
Rx Antenna Gain	0 dBi		includes Digital II	
Cable and Connector Loss	1 dB			
Rx Power Spectral Sensitivity	-155,00 dBm/Hz			
Rx Sensitivity	-85.97 dBm			
	00,07 0011			
Propagation Loss	121.97 dB	105,97 dB	101,97 dB	89,97 dB
Propagation Margin	0 dB	0 dB	0 dB	0 dB
Cell Propagation	121,97 dB	105,97 dB	101,97 dB	89,97 dB
Carrier Frequency	470 MHz			
Cell Range				
Indoor, Gamma = 4	252,43 m	100,49 m	79,82 m	40,01 m
Indoor, Gamma = 6	39,94 m	21,62 m	18,54 m	11,70 m
Free Space Loss	63,72 km	10,10 km	6,37 km	1,60 km

•Link Budget matches expected range

• Max. propagation range: 10 m to 100 m

Indoor PPD channel profile

- Delay Spread for indoor channels have been measured
 - Typical RMS delay spread expected to be larger for UHF than larger carrier frequencies (ISM 2.4 GHz or even 900 MHz) expecting 15-20% larger delay spread @ 900 MHz than @ 2.4 GHz [3]
 - Typical delay spreads range from 5-10ns for residential, 10-100ns for office spaces and 50-200 ns for large halls for 2.4GHz / 5GHz carrier frequency
 - Expected Delay spread for indoor: up to 300 ns, typical 60 ns
- Doppler Spread, Propose classical (Jake's) Doppler spread with terminal speed of 2 m/s (~7 km/h)

•Propose to use hyperlan channel models and spread time scale by 20% to take frequency scaling into account [4]

Channel Type	Typical	Open Space	Large Open Space	Very Large Open Space
Average RMS Delay				
Spread	60 ns	120 ns	150 ns	300 ns

•[3] Devasirvatham, D.M.J.; Banerjee, C.; Murray, R.R.; Rappaport, D.A.; , "Four-frequency radiowave propagation measurements of the indoor environment in a large metropolitan commercial building," *GLOBECOM '91. 'Countdown to the New Millennium.* Dec 1991.

▶[4] Medbo, J.; Schramm, P., "Channel Models for HIPERLAN/2 in Different Indoor Scenarios,", Ericsson Radio Systems AB, ETSI EP BRAN 3ERI085B, March 1998

Outdoor FD to PPD case – propagation model

•Propose to use Okumara - Hata model of propagation

• Urban

 $L_{Urban}(r) = 69.55 + 26.16 \cdot \log(f) - 13.82 \cdot \log(h_b) - C_H + [44.9 - 6.55 \cdot \log(h_B)] \log d$ $C_H = 0.8 + (1.1 \cdot \log(f) - 0.7)h_m - 1.56 \log(f)$

Suburban

$$L_{Suburban}(r) = L_{Urban}(r) - 2\left(\log(\frac{f}{28})\right)^2 - 5.4$$

- f frequency in MHz
- ${\boldsymbol{\cdot}}\ h_m$ mobile station antenna height
- \cdot h_b base station antenna height
- d distance in km

Outdoor FD to PPD case - link budget

тх	4 W	100 mW	40 mW	2.5 mW
Tx Allowed Maximum Power	36 dBm	20 dBm	16 dBm	4 dBm
Tx Cable Loss	0 dB	0 dB	0 dB	0 dB
Tx Antenna Gain	0 dBi	0 dBi	0 dBi	0 dBi
Tx Band	8 MHz	8 MHz	8 MHz	8 MHz
Tx Power Spectral Density	-33,03 dBm/Hz	-49,03 dBm/Hz	-53,03 dBm/Hz	-65,03 dBm/Hz
EIRP	36,00 dBm	20,00 dBm	16,00 dBm	4,00 dBm
P Y				
RX		1		
Rx Noise Power Density (Thermal Noise)	-174,00 dBm/Hz		at 290K	
Rx Noise Power	-104,97 dBm			
Rx Noise Figure	6 dB			or SiTuner DVB-T
Required SNR	12 dB		Includes Digital I	mplementation Loss
Rx Antenna Gain	0 dBi			
Cable and Connector Loss	1 dB			
Rx Power Spectral Sensitivity	-155,00 dBm/Hz			
Rx Sensitivity	-85,97 dBm	3	,	
Propagation Loss	121,97 dB	105,97 dB	101,97 dB	89,97 dB
Propagation Margin	0 dB	0 dB	0 dB	0 dB
Cell Propagation	121,97 dB	105,97 dB	101,97 dB	89,97 dB
		heigth Mob	Hm	1,5
Carrier Frequency	470 MHz	Height Base	Hb	15
Camer Frequency	470 10112	Teight Dase	CH	-0,01
				-
Cell Range				
Okamura-Hata Urban	0,93 km	0,34 km	0,27 km	0,13 km
Okamura-Hata Suburban	1,56 km	0,58 km	0,45 km	0,21 km
Free Space Loss	63,72 km	10,10 km	6,37 km	1,60 km

Link Budget gives a rather short range for cellular application 0.1 - 1.6 km

Outdoor FD to PPD case - propagation model

- Typical RMS delay spread of the order of 2-3 μs
- Greenstein model remains valid [5]

 $\tau_{RMS} = T_1 d^{\varepsilon} y$ T_1 is the median value of τ_{RMS} at 1 km. ε is an exponent between 0.5 and 1 y is a lognormal distribution

- T1 is found to be between 0.4 and 1 μ s
- Standard deviation of *y* is between 2 and 6 (4 typical)
- Value for ε is equal to 0.5 or 1 (for mountainous areas)
- Worst case, 90% of delay spread are between 10 μ s to 25 μ s
- Typical case wc 4 μs to 10 μs
- Doppler Spread, Propose classical (Jake's) Doppler spread with terminal speed up to 100 m/s (360 km/h)
- Corresponds to ITU Vehicular B, COS207, hilly terrain HTx6
- Some Channel models with larger spread?
- When taking link budget into consideration delay spread between 0.5 and 1.3 μs
 - Channels proposed in microcell channel environment (ITU Pedestrian and Vehicular A+B channel models)

^[5] Greenstein, L.J.; Erceg, V.; Yeh, Y.S.; Clark, M.V.; , "A new path-gain/delay-spread propagation model for digital cellular channels," Vehicular Tech., IEEE Trans. , May 1997

Outdoor FD to FD case

- Static reception 1 10 km
- Assume at least one Antenna with small aperture
- ITU-R P.1546 path loss model well adapted
- Okumara-Hata easier to use and close

$$L(r) = 69.55 + 26.16 \cdot \log(f) - 13.82 \cdot \log(h_b) - C_H + [44.9 - 6.55 \cdot \log(h_B)] \log d$$

$$C_H = 0.8 + (1.1 \cdot \log(f) - 0.7)h_m - 1.56 \log(f)$$

• Rx Antenna Gain larger than 0 dBi

Outdoor FD to FD case – link budget

ТХ	4 W	100 mW	40 mW	2.5 mW	
Tx Allowed Maximum Power	36 dBm	20 dBm	16 dBm	4 dBm	
Tx Cable Loss	0 dB	0 dB	0 dB	0 dB	
Tx Antenna Gain	0 dBi	0 dBi	0 dBi	0 dBi	
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Tx Power Spectral Density	-33,03 dBm/Hz	-49,03 dBm/Hz	-53,03 dBm/Hz	-65,03 dBm/Hz	
EIRP	36,00 dBm	20,00 dBm	16,00 dBm	4,00 dBm	
RX					
Rx Noise Power Density (Thermal Noise)	-174,00 dBm/Hz	1	at 290K		
Rx Noise Power	-104,97 dBm				
Rx Noise Figure	6 dB		Rem 7 dB max fo	or SiTuner DVB-T	
Required SNR	12 dB		Includes Digital Implementation Lo		S
Rx Antenna Gain	24 dBi				
Cable and Connector Loss	1 dB				
Rx Power Spectral Sensitivity	-179,00 dBm/Hz				
Rx Sensitivity	-109,97 dBm				
Propagation Loss	145,97 dB	129,97 dB	125,97 dB	113,97 dB	
Propagation Margin	0 dB	0 dB	0 dB	0 dB	
Cell Propagation	145,97 dB	129,97 dB	125,97 dB	113,97 dB	
		heigth Mob	Hm	4	
Carrier Frequency	470 MHz	Height Base	Hb	15	
carrier rioquonoy			CH	5,59	
Cell Range					
Okamura-Hata Urban	5,79 km	2,15 km	1,68 km	0,80 km	
Okamura-Hata Suburban	9,73 km	, ,	,	1,34 km	
	1009,88 km	,	100,99 km	25,37 km	

Range up to 10 km possible assuming significant gain at Rx antenna

Outdoor FD to FD case – propagation model

- Propose to use WiMAX fixed channels as reference [6]
 - Reflects both RMS delay spread and Doppler statistics
- Extend to UHF frequencies?
- Propose to use Stanford University Interim (SUI) Channel models
 - LOS path dominated by Ricean fading
 - Rounded Doppler spectrum (Frequencies reduced by factor 8)
- RMS delay spread varies between 0.1 µs to 2.4 µs depending on terrain type (hilly or flat), up to 7 km cell size
- Coherence Time > 200 ms

[6] V. Erceg and al., "Channel Models for Fixed Wireless Applications", IEEE 802.16 Broadband Wireless Access WG, IEEE 802.16a-03/01

Conclusion

Channel Scenario	Tx EIRP	Max Link Budget Range	RMS Delay	Max Doppler	Max Speed
Indoor	100 mW	100 m	150 ns	5.9 Hz	7 km/h
Outdoor FD to PPD	4 W	1.56 km	1.30 us	105.3 Hz	144 km/h
Outdoor FD to FD	4 W	10 km	2.4 us	2.6 Hz	4 km/h

- Cellular (outdoor) FD to PPD in the TVWS is limited to 1.6 km range
- Indoor (indoor PPD to PPD) and outdoor FD to FD are most promising scenarios for TVWS applications

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