IEEE 1900.7 White Space Radio

Regulatory and propagation conditions in the TVWS

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Authors:

Name	Company	Address	Phone	Email
Vincent BERG	CEA-LETI	17 rue des Martyrs 38054 Grenoble FRANCE		vincent.berg@cea.fr
Dominique NOGUET	CEA-LETI	idem		dominique.noguet@cea.fr

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

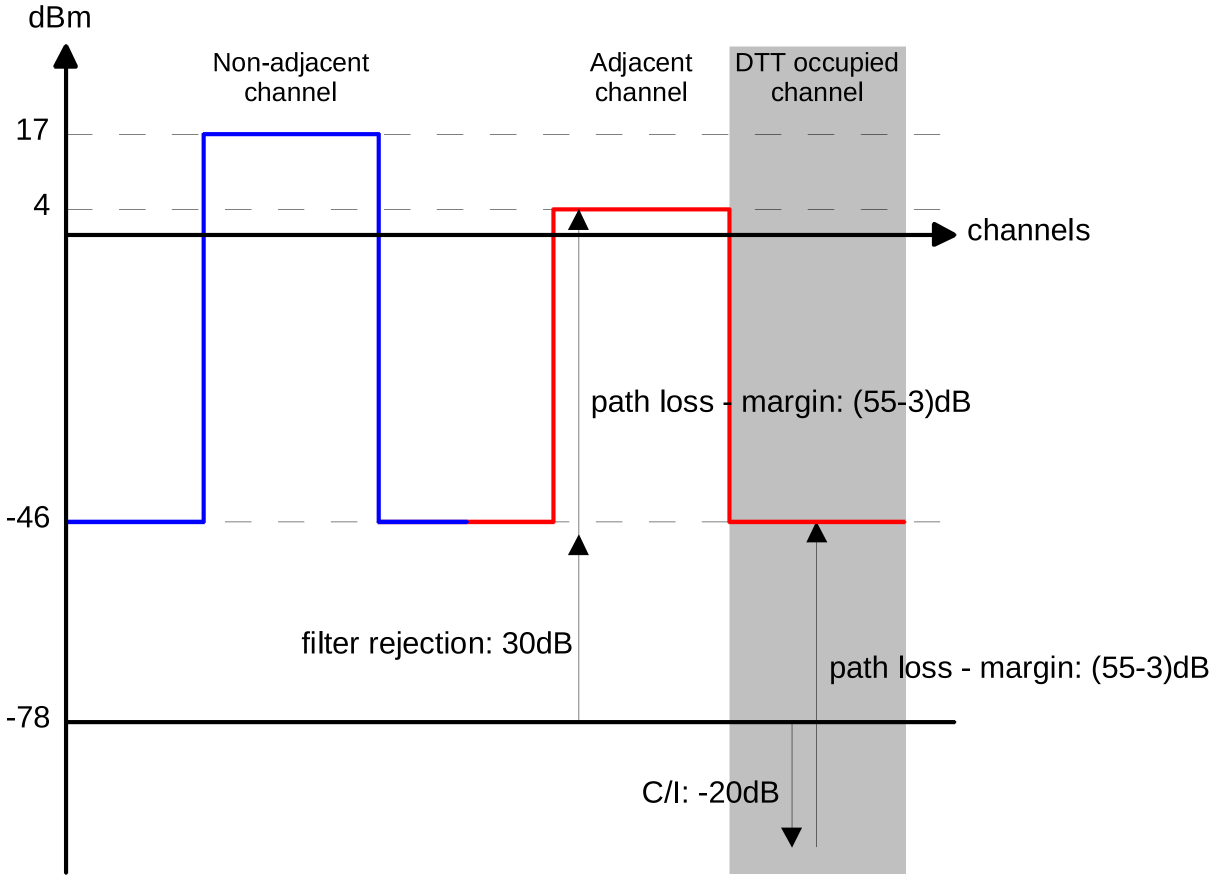
FD: Fixed Device
PPD: Personal Portable Device

- 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

$$L(r) = -10\log_{10}\left(r^{-\alpha}\right) + 10\log_{10}\left(G_t G_r \left[\frac{\lambda_0}{4\pi}\right]^2\right)$$

- 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

TX	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	-104,97 dBm				
Rx Noise Figure	6 dB		Rem 7 dB max for SiTuner DVB-T		
Required SNR	12 dB		Includes Digital Implementation 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				
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
- h_m mobile station antenna height
- h_b base station antenna height
- d distance in km

Outdoor FD to PPD case - link budget

TX	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	-104,97 dBm			
Rx Noise Figure	6 dB		Rem 7 dB max for SiTuner DVB-T	
Required SNR	12 dB		Includes Digital Implementation 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			
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
			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 μs
  - 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 μs to 25 μs
- 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 an d 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

TX	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	-104,97 dBm				
Rx Noise Figure	6 dB		Rem 7 dB max for SiTuner DVB-T		
Required SNR	12 dB		Includes Digital Implementation Loss		
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	
			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	3,62 km	2,82 km	1,34 km	
Free Space Loss	1009,88 km	160,05 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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