Channel Propagation Models for 1900.7 Medium to Long Range Applications

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Introduction

- Background
- Proposed Channel Propagation Models
  - Path Loss Model
  - Log-normal Shadowing Model
  - RMS Delay Spread
  - Channel Impulse Response Profile
- Summary

Background

- Presently, the standardization activities for TV White Space applications are ongoing for different area networks including WPAN, WLAN, and WRAN. PAN and LAN cover the ranges from a few meters to a few hundreds meters, while RAN supports the communications range of about 30 to 100 km.
- One possible application range has yet been considered for TV White Space applications is Metropolitan Area Network with medium to long range.
- In this presentation, we discuss the channel propagation models for the range of about 0.1 to 15km for urban/sub-urban area by VHF band measurement results in order to assist corresponding system design and be used for performance evaluation.

Proposed Channel Propagation Models

- The following four aspects will be covered in this presentation
  - Path Loss Model
  - Log-normal Fading Model
  - RMS Delay Spread
  - Channel Impulse Response Profile

to assist the PHY/MAC design, link budget calculation, system level simulation and data link simulation

Path Loss Model

	Okumura-Hata [1]	Revised Hata [2]	ITU-R P.1546-4 [3]	ITU-R P.1812-1 [4]
Frequency	150 MHz to 1.5 GHz	30MHz to 3GHz	30 MHz to 3 GHz	30 MHz to 3 GHz
Transmission range	1 to 20 km	<100km	1 to 1000 km	0.25 to 3000 km
BS antenna height	30 to 200 m	<200m	< 3000 m; interpolation for < 10 m	1 to 3000 m
MS antenna height	1 to 10 m; with correction factor	<200m	≥ 1 m and < 3000 m; with correction for clutter height	1 to 3000 m
Computation complexity	Low	Low	Medium	High
Environment	Mid/Small Urban, Large Urban, Suburban, Rural (Open)	Urban, Suburban, Open space	Dense Urban, Urban, Suburban, Rural, Warm Sea, Cold Sea, Mixed Land-Sea	Dense Urban, Urban/Trees, Suburban, Open, Coastal, Sea

Based on the comparison, revised Hata model is able to support longer transmission range and BS antenna heights less than 30m and offer relatively low complexity compared to the other two ITU models shown in Table. It is hence recommended as the selected path loss model for link budget calculation.

[1] M. Hata, “Empirical formula for propagation loss in land mobile radio services,” *IEEE Trans. Vehicular Technol.*, vol. 29, pp. 317–325, Aug. 1980.
[2] ERC Report 68, “Monte-Carlo Simulation Methodology for the Use in Sharing and Compatibility Studies Between Different Radio Services or systems”
[3] ITU-R, “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz,” *Recommendation ITU-R P.1546-4*, Oct. 2009.
[4] ITU-R, “A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands,” *Recommendation ITU-R P. P.1812-1*, Oct. 2009.

Log-normal Shadowing Model

- A revised auto-correlation model [5][6] as used in ITU-R M.1225 is recommended for the shadow fading effect of same radio link

  - The autocorrelation function is defined as

$$R(\Delta x) = e^{-\frac{|\Delta x|}{d_{cor}}\ln 2},$$

where

d_{cor} is the decorrelation distance where the correlation coefficients reduce to 0.5

Δx is the distance between two observation locations

R is the correlation coefficient

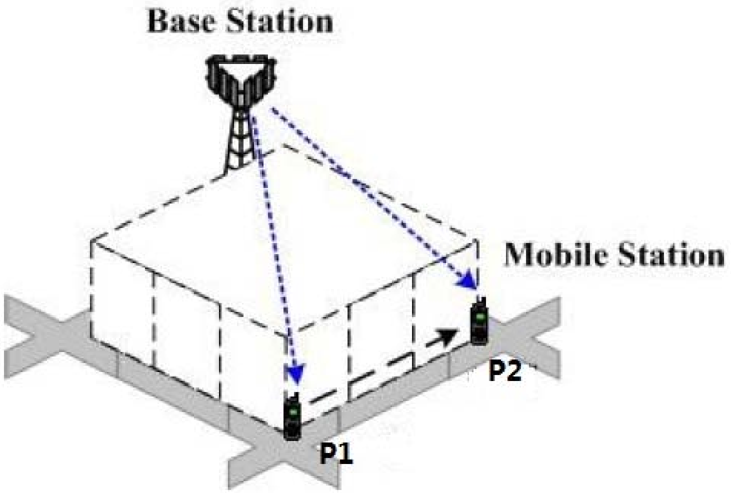
[5] M. Gudmundsun, “Correlation model for shadow fading in mobile radio systems”, Electronic Letters, 1991, Page 2145-2146
[6] Rec. ITU-R M.1225, “Guidelines For Evaluation of Radio Transmission Technologies for IMT-2000”

Log-normal Shadowing Model

- Decorrelation length is dependent on the environment, the values obtained based on measurement results are as follows [5][6]
  - 5m for urban, 300m for suburban[5]
  - 20m for vehicular test environment and rural area [6]
- Simulation methodology[7]

If L_1 is the log-normal component at position P_1, L_2 is for P_2 which is Δx away from P_1. Then L_2 is normally distributed in *dB* with mean $R(\Delta x)L_1$ and variance $(1-R(\Delta x)^2)\sigma^2$.

The logarithmic standard deviation is dependent on the frequency and environment



[5] M. Gudmundsun, "Correlation model for shadow fading in mobile radio systems", Electronic Letters, 1991, Page 2145-2146
[6] Rec. ITU-R M.1225, "Guidelines For Evaluation of Radio Transmission Technologies for IMT-2000"
[7] I. Fu, C.F Li, T. C. Song, and W. H. Sheen, "Correlation Models for Shadow Fading Simulation", Document S802.16m-07/060

RMS Delay Spread

Table 1

Index of Measured Point	Distance(km)	RMS Delay Spread (μs)
P16	1.4	0.61
P5	1.5	0.29
P4	1.6	0.45
P1	1.8	0.4
P3	1.8	1.4
P6	2.7	0.82
P15	2.8	0.29
P2	3.2	7.9
P7	4.7	0.74
P14	6.1	1.79
P8	7.7	20.6
P13	9.6	12.2
P12	12.3	10.9
P11	13.6	8.4
P10	15.6	6.5
P9	16	17.8

The RMS delay spread is recommended based on VHF band measurement results for Japan Public broadband network [8][9](See Appendix slide for experiment setting and site map). Table 1 shows the calculated RMS Delay Spread for 16 measured points. The average RMS delay spread highly depends on the terrain type. Some additional measured results from reference are shown in Table 2.

Table 2 [10]

Environment	Frequency (MHz)	RMS Delay Spread (σ_τ)	Notes
Urban	910	1300 ns avg. 600 ns st. dev. 3500 ns max.	New York City
Urban	892	10–25 μs	Worst case San Francisco
Suburban	910	200–310 ns	Averaged typical case
Suburban	910	1960–2110 ns	Averaged extreme case
Indoor	1500	10–50 ns 25 ns median	Office building
Indoor	850	270 ns max.	Office building
Indoor	1900	70–94 ns avg. 1470 ns max.	Three San Francisco buildings

Worse case RMS delay can have a major impact on system performance, RMS delay spread of 20μs is recommended.

[8] M. OODO, N. SOMA, R. FUNADA and H. HARADA, "Channel Model for Broadband Wireless Communication in the VHF-band", IEICE Technical Report
[9] M. Oodo, N. Soma, and H. Harada, "Radio Propagation Experiments for Broadband Wireless Communication System in the VHF Band", Proc. WPMC 2008, Sept. 2008
[10] Theodore S. Rappaport, Wireless Communications: Principles and Practice (2nd Edition), Prentice Hall, 2007

Channel Impulse Response Model

Three channel impulse response profiles are selected for outdoor medium to long range [8][9] communications based on measurement results. The selected profiles represent three different communication ranges d:

(1) d ≤ 3km
(2) 3km < d ≤ 9km
(3) 9km < d ≤16km

	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6
d=2.7 km Profile A (P6) Urban						
Path Delay	0	0.9	1.7	3.1	3.8	7.5
Avg PathGain	0	-18.2	-20.6	-25	-26.5	-19.6
d=6.1 km Profile B (P14) Suburban						
Path Delay	0	0.6	5.3	6.2	7.5	19.5
Avg PathGain	0	-12.1	-25.2	-22.2	-18.5	-21.8
d=13.6 km Profile C (P11) Suburban						
Path Delay	0	3.0	6.5	8.1	21.7	26.0
Avg PathGain	0	-8.2	-8.2	-7.7	-7.8	-9.2

[8] M. OODO, N. SOMA, R. FUNADA and H. HARADA, "Channel Model for Broadband Wireless Communication in the VHF-band", IEICE Technical Report
[9] M. Oodo, N. Soma, and H. Harada, "Radio Propagation Experiments for Broadband Wireless Communication System in the VHF Band", Proc. WPMC 2008, Sept. 2008

Summary

- The presentation proposes channel propagation models for medium to long range TV White Space communications.
- The following Channel Models / parameters are recommended
  - Path Loss Model: Revised Hata Model
  - Log-normal Shadowing Model: Revised auto-correlation model as used in ITU-R M.1225
  - RMS Delay Spread: 20μs
  - Channel Impulse Response Profile: selected based on VHF band measurement results representing three distance ranges
- Additional measurement may be needed to cope with several use cases

References

[1] M. Hata, “Empirical formula for propagation loss in land mobile radio services,” *IEEE Trans. Veh. Technol.*, vol. 29, pp. 317–325, Aug. 1980.

[2] ERC Report 68, “Monte-Carlo Simulation Methodology for the Use in Sharing and Compatibility Studies Between Different Radio Services or systems”, revised in June 2002

[3] ITU-R, “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz,” *Recommendation ITU-R P.1546-4*, Oct. 2009.

[4] ITU-R, “A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands,” *Recommendation ITU-R P. P.1812-1*, Oct. 2009.

[5] M. Gudmundsun, “Correlation model for shadow fading in mobile radio systems”, Electronic Letters, 1991, Page 2145-2146

[6] Rec. ITU-R M.1225, “Guidelines For Evaluation Of Radio Transmission Technologies For IMT-2000”, 1997

[7] I. Fu, C.F Li, T. C. Song, and W. H. Sheen, “Correlation Models for Shadow Fading Simulation”, Document S802.16m-07/060, 13 March 2007

[8] M. Oodo, N. Soma, R. Funada and H. Harada, “Channel Model for Broadband Wireless Communication in the VHF-band”, IEICE Technical Report, June 2010

[9] M. Oodo, N. Soma, and H. Harada, “Radio Propagation Experiments for Broadband Wireless Communication System in the VHF Band”, Proc. WPMC 2008, Sept. 2008

[10] Theodore S. Rappaport, Wireless Communications: Principles and Practice (2nd Edition), Prentice Hall, 2007

Appendix

Revised Hata Model

$$pl = f_{propag}(f, h_1, h_2, d, env) = L + T(G(\sigma))$$

where:

L	=	median propagation loss (in dB)
σ	=	standard deviation of the slow fading distribution (in dB)
f	=	frequency (in MHz)

$H_m = \min\{h_1, h_2\}$

$H_b = \max\{h_1, h_2\}$

d	=	distance (in km), preferably less than 100 km.
env	=	(outdoor/outdoor), (rural, urban or suburban), (propagation above or below roof).

If H_m and/or H_b are below 1 m, a value of 1 m should be used instead. Antenna heights above 200 m might also lead to significant errors. Propagation below roof means that both H_m and H_b are above the height of roofs. Propagation is above roof in other cases (H_b above the height of roofs).

Revised Hata Model(Cont. 1)

Formulas for calculation of Median Path Loss

Case 1: $d \le 0.04$ km

$$L = 32.4 + 20\log(f) + 10\log(d^2 + (H_b - H_m)^2 / 10^6)$$

Case 2: $d \ge 0.1$ km

$$a(H_m) = (1.1\log(f) - 0.7)\min\{10, H_m\} - (1.56\log(f) - 0.8) + \max\{0, 20\log(H_m / 10)\}$$

$$b(H_b) = \min\{0, 20\log(H_b / 30)\}$$

Note that in the "SE24-model" for short range devices in the case of low base station antenna height,

H_b, $b(H_b) = \min\{0, 20\log(H_b / 30)\}$ is replaced

$$b(H_b) = (1.1\log(f) - 0.7)\min\{10, H_b\} - (1.56\log(f) - 0.8) + \max\{0, 20\log(H_b / 10)\}$$

$$\alpha = \begin{cases} \alpha = 1 & d \le 20 \text{ km} \\ \alpha = 1 + \left(0.14 + 0.000187\, f + 0.00107\, H_b\right)\left(\log\dfrac{d}{20}\right)^{0.8} & 20 \text{ km} < d \le 100 \text{ km} \end{cases}$$

Revised Hata Model(Cont. 2)

Sub-case 1: Urban

- 30 MHz < f ≤ 150 MHz

$$L = 69.6 + 26.2\log(150) - 20\log(150/f) - 13.82\log(\max\{30, H_b\}) + \left[44.9 - 6.55\log(\max\{30, H_b\})\right](\log(d))^{\alpha} - a(H_m) - b(H_b)$$

- 150 MHz < f ≤ 1500 MHz

$$L = 69.6 + 26.2\log(f) - 13.82\log(\max\{30, H_b\}) + \left[44.9 - 6.55\log(\max\{30, H_b\})\right](\log(d))^{\alpha} - a(H_m) - b(H_b)$$

- 1500 MHz < f ≤ 2000 MHz

$$L = 46.3 + 33.9\log(f) - 13.82\log(\max\{30, H_b\}) + \left[44.9 - 6.55\log(\max\{30, H_b\})\right](\log(d))^{\alpha} - a(H_m) - b(H_b)$$

- 2000 MHz < f ≤ 3000 MHz

$$L = 46.3 + 33.9\log(2000) + 10\log(f/2000) - 13.82\log(\max\{30, H_b\}) + \left[44.9 - 6.55\log(\max\{30, H_b\})\right](\log(d))^{\alpha} - a(H_m) - b(H_b)$$

Revised Hata Model (Cont. 3)

Sub-case 2: Suburban

$$L = L(\text{urban}) - 2\{\log[(\min\{\max\{150, f\}, 2000\})/28]\}^2 - 5.4$$

Sub-case 3: Open area

$$L = L(\text{urban}) - 4.78\ \{\log[\min\{\max\{150, f\}, 2000\}]\}^2 + 18.33\ \log[\min\{\max\{150, f\}, 2000\}] - 40.94$$

Case 3: 0.040 km < d < 0.1 km

$$L = L(0.04) + \frac{[\log(d) - \log(0.04)]}{[\log(0.1) - \log(0.04)]}\ [L(0.1) - L(0.04)]$$

When L is below the free space attenuation for the same distance, the free space attenuation should be used instead.

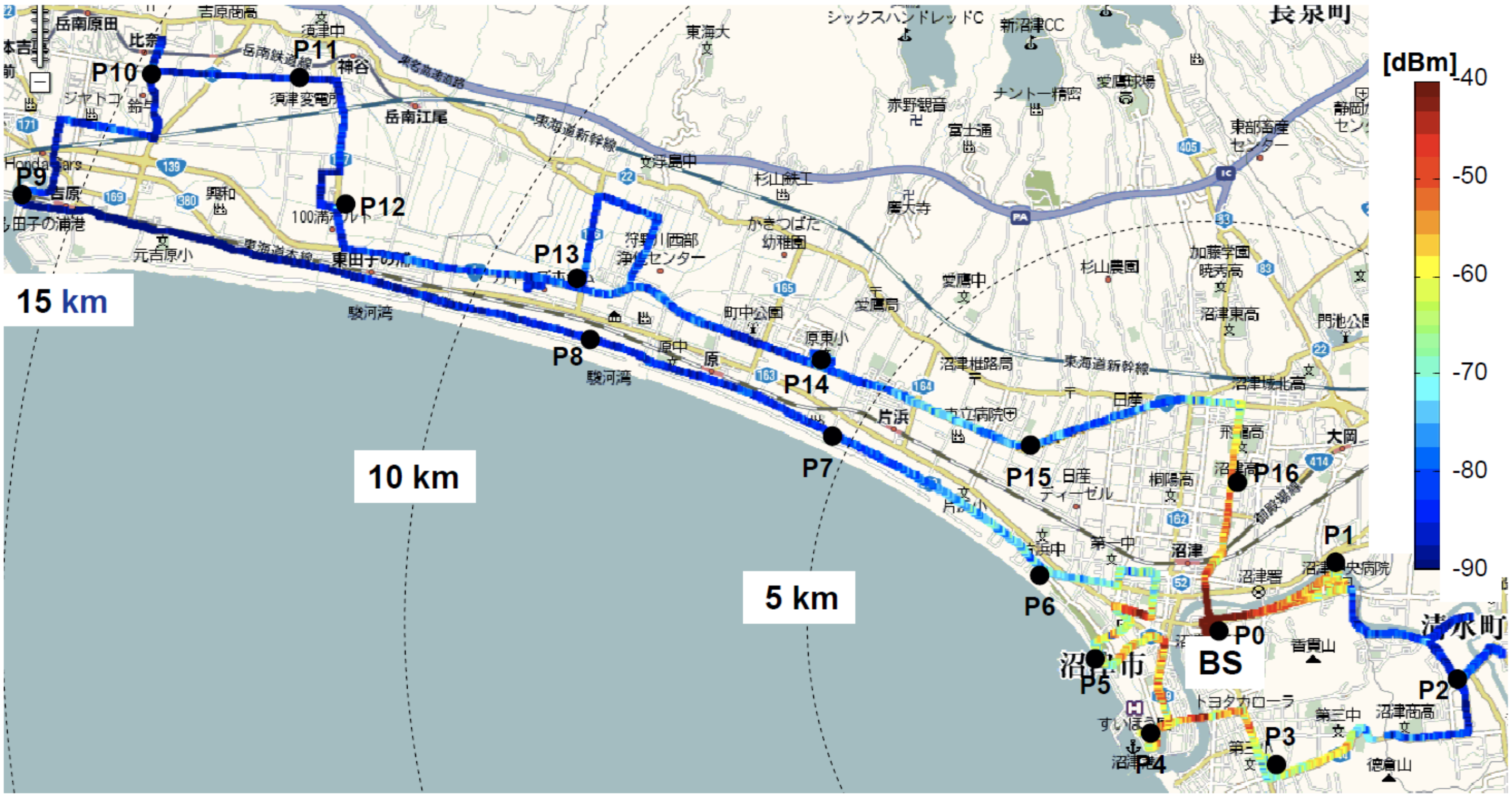
Experiment Setting for VHF Band Site Measurement

- Measurement site: Numazu city, Japan
- Measured Range: with radius up to 16km

	Fixed Base Station	Mobile Station
Centre Freq.	190MHz	
Occupied Bandwidth	10 MHz	
Tx Power	20W	5W
Antenna		
Type	3-Stage Collinear Array	Whip
Heights	45m	2m
Gain	6dBi	2.4dBi

[8] M. Oodo, N. Soma, R. Funada and H. Harada, "Channel Model for Broadband Wireless Communication in the VHF-band", IEICE Technical Report
[9] M. Oodo, N. Soma, and H. Harada, "Radio Propagation Experiments for Broadband Wireless Communication System in the VHF Band", Proc. WPMC 2008, Sept. 2008

Site Measurement Map at Japan Numazu City



•Site measurement of received power vs. distance with base station antenna height: 45m

[8] M. Oodo, N. Soma, R. Funada and H. Harada, "Channel Model for Broadband Wireless Communication in the VHF-band", IEICE Technical Report

[9] M. Oodo, N. Soma, and H. Harada, "Radio Propagation Experiments for Broadband Wireless Communication System in the VHF Band", Proc. WPMC 2008, Sept. 2008