Channel Propagation Models for 1900.7 Medium to Long Range Applications

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</table>

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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
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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>150 MHz to 1.5 GHz</td>
<td>30 MHz to 3 GHz</td>
<td>30 MHz to 3 GHz</td>
<td>30 MHz to 3 GHz</td>
</tr>
<tr>
<td>Transmission range</td>
<td>1 to 20 km</td>
<td>&lt;100 km</td>
<td>1 to 1000 km</td>
<td>0.25 to 3000 km</td>
</tr>
<tr>
<td>BS antenna height</td>
<td>30 to 200 m</td>
<td>&lt;200 m</td>
<td>&lt; 3000 m; interpolation for &lt; 10 m</td>
<td>1 to 3000 m</td>
</tr>
<tr>
<td>MS antenna height</td>
<td>1 to 10 m; with correction factor</td>
<td>&lt;200 m</td>
<td>≥ 1 m and &lt; 3000 m; with correction for clutter height</td>
<td>1 to 3000 m</td>
</tr>
<tr>
<td>Computation complexity</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Environment</td>
<td>Mid/Small Urban, Large Urban, Suburban, Rural (Open)</td>
<td>Urban, Suburban, Open space</td>
<td>Dense Urban, Urban, Suburban, Rural, Warm Sea, Cold Sea, Mixed Land-Sea</td>
<td>Dense Urban, Urban/Trees, Suburban, Open, Coastal, Sea</td>
</tr>
</tbody>
</table>

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.

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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
- \( \Delta x \) is the distance between two observation locations
- \( R \) is the correlation coefficient

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 $\Delta x$ 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.

RMS Delay Spread

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.

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

Table 1

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

Table 2

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

Channel Impulse Response Model

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

1. $d \leq 3$ km
2. $3$ km $< d \leq 9$ km
3. $9$ km $< d \leq 16$ km

<table>
<thead>
<tr>
<th>Path Delay</th>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
<th>Path 5</th>
<th>Path 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path A (P6) Urban</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d=2.7$ km</td>
<td>0</td>
<td>0.9</td>
<td>1.7</td>
<td>3.1</td>
<td>3.8</td>
<td>7.5</td>
</tr>
<tr>
<td>Avg PathGain</td>
<td>0</td>
<td>-18.2</td>
<td>-20.6</td>
<td>-25</td>
<td>-26.5</td>
<td>-19.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Path Delay</th>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
<th>Path 5</th>
<th>Path 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path B (P14) Suburban</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d=6.1$ km</td>
<td>0</td>
<td>0.6</td>
<td>5.3</td>
<td>6.2</td>
<td>7.5</td>
<td>19.5</td>
</tr>
<tr>
<td>Avg PathGain</td>
<td>0</td>
<td>-12.1</td>
<td>-25.2</td>
<td>-22.2</td>
<td>-18.5</td>
<td>-21.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Path Delay</th>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
<th>Path 5</th>
<th>Path 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path C (P11) Suburban</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d=13.6$ km</td>
<td>0</td>
<td>3.0</td>
<td>6.5</td>
<td>8.1</td>
<td>21.7</td>
<td>26.0</td>
</tr>
<tr>
<td>Avg PathGain</td>
<td>0</td>
<td>-8.2</td>
<td>-8.2</td>
<td>-7.7</td>
<td>-7.8</td>
<td>-9.2</td>
</tr>
</tbody>
</table>

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


Appendix
Revised Hata Model

\[ p_l = f_{\text{propag}}(f, h_1, h_2, d, \text{env}) = L + T(G(\sigma)) \]

where:
- \( L \) = median propagation loss (in dB)
- \( \sigma \) = 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.
- \( \text{env} \) = (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: $d \leq 0.04$ km

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

Case 2: $d \geq 0.1$ 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

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

$$\alpha = \begin{cases} 
\alpha = 1 & d \leq 20 \text{ km} \\
\alpha = 1 + (0.14 + 0.000187 f + 0.00107 H_b) \left( \log \frac{d}{20} \right)^{0.8} & 20 \text{ km} < d \leq 100 \text{ km}
\end{cases}$$
Revised Hata Model (Cont. 2)

Sub-case 1: Urban

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

- $150 \text{ MHz} < f \leq 1500 \text{ MHz}$
  \[ L = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) + \left[44.9 - 6.55 \log(\max\{30, H_b\})\right] \log(d)^\alpha - a(H_m) - b(H_b) \]

- $1500 \text{ MHz} < f \leq 2000 \text{ MHz}$
  \[ L = 46.3 + 33.9 \log(f) - 13.82 \log(\max\{30, H_b\}) + \left[44.9 - 6.55 \log(\max\{30, H_b\})\right] \log(d)^\alpha - a(H_m) - b(H_b) \]

- $2000 \text{ MHz} < f \leq 3000 \text{ MHz}$
  \[ L = 46.3 + 33.9 \log(2000) + 10 \log(f / 2000) - 13.82 \log(\max\{30, H_b\}) + \left[44.9 - 6.55 \log(\max\{30, H_b\})\right] \log(d)^\alpha - a(H_m) - b(H_b) \]
Revised Hata Model (Cont. 3)

**Sub-case 2: Suburban**

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

**Sub-case 3: Open area**

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

**Case 3: 0.040 km < d < 0.1 km**

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

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

<table>
<thead>
<tr>
<th></th>
<th>Fixed Base Station</th>
<th>Mobile Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Freq.</td>
<td></td>
<td>190MHz</td>
</tr>
<tr>
<td>Occupied Bandwidth</td>
<td></td>
<td>10 MHz</td>
</tr>
<tr>
<td>Tx Power</td>
<td>20W</td>
<td>5W</td>
</tr>
<tr>
<td><strong>Antenna</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>3-Stage Collinear Array</td>
<td>Whip</td>
</tr>
<tr>
<td>Heights</td>
<td>45m</td>
<td>2m</td>
</tr>
<tr>
<td>Gain</td>
<td>6dBi</td>
<td>2.4dBi</td>
</tr>
</tbody>
</table>

Site Measurement Map at Japan Numazu City

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