Radio Propagation Measurement and Modeling in Wireless Communication Environments

Soo Yong LIM (Grace)

• Outline:
  — Introduction
  — Four distinct environments
    • Indoor Stairwell
    • Periodic Building Façade
    • Open-trench Drain
    • Cave
  — Conclusion
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• EM waves – the carrier of wireless information.
• Propagation prediction - for successful wireless communication systems design.
What should we know about it?
- Large-scale path loss
- Small-scale multipath fading
- Angle of arrival/departure (e.g. for MIMO systems)

What should we consider about it?
- Environment
  - Geometry
  - Materials
- Frequency
  - Bandwidth
- Antenna
  - Radiation pattern

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• In an indoor stairwell, the propagation environment is like a leaky waveguide with inhomogeneous fillings (stairs) inside.
• This unique propagation environment is different from multifloor and other indoor scenarios, hence, deserves careful studies.
• Reliable communication in indoor stairwell is crucial to law enforcement and firefighting safety.
VV - Pol. at 2.4 GHz

Mean dif. = 0.24 dB
Stddev/dif. = 1.50 dB
To determine one-reflection ray, on the left-hand side of the wall from Tx to Rx, the image of Tx due to the wall is first determined as Tx'.

Then connect Tx' and Rx; the intersection point on the left wall (P1) is the reflection point.

The red line (all rays) include hybrid rays.

Big drop in (a), (b), and (c) are due to:
- a: LOS is lost.
- b: Double transmission.
- c: Blockage of Tx power by the front wall.

When horizontal polarization is concerned, the receive antenna can assume two different orientations on the rotation arm when measurement is being done.

- Case (a) is when the main beam occurs.
- Case (b) is when the null occurs.

For HH-Pol., the Tx antenna was oriented with the null of the radiation pattern facing the entry door.

- For VH-Pol.: 
  - Tx antenna was placed vertically.
  - Rx antenna was placed horizontally.
a) Dog-Leg Stairwell

1) PO
2) HA
3) MS
4) HL

b) Stairwell Around a Square Well

1) PO
2) HA
3) MS
4) HL
• Typical received signals at different locations when the Rx antenna rotates a complete revolution.
• The sampling signals are recorded over a 30-second period when the Rx antenna is rotated around the post an entire revolution.
• These sampling signals are then averaged offline to yield the mean path gain at each stair step.

Path loss is an indication of power loss in the channel: 
\[ P(d) = 10 \log_{10} \left( \frac{P_t}{P_r} \right) \]

The mean power predicted above is a random variable, which can be characterized by adding an extra term, a log-normal distribution for both outdoor and indoor propagation environments:
\[ P(d)[dB] = \bar{P}(d)[dB] + X_\sigma[dB] \]
<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>Pol.</th>
<th>$\eta$-Values</th>
<th>$\sigma_m$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>HL/VV</td>
<td>8.93</td>
<td>5.75</td>
</tr>
<tr>
<td></td>
<td>HL/HH</td>
<td>7.48</td>
<td>4.83</td>
</tr>
<tr>
<td></td>
<td>PO/VV</td>
<td>9.64</td>
<td>5.79</td>
</tr>
<tr>
<td></td>
<td>PO/HH</td>
<td>8.57</td>
<td>4.97</td>
</tr>
<tr>
<td></td>
<td>PO/VH</td>
<td>7.77</td>
<td>4.62</td>
</tr>
<tr>
<td></td>
<td>HA/VV</td>
<td>8.76</td>
<td>5.73</td>
</tr>
<tr>
<td></td>
<td>HA/HH</td>
<td>7.62</td>
<td>5.01</td>
</tr>
<tr>
<td></td>
<td>MS/VV</td>
<td>8.17</td>
<td>6.53</td>
</tr>
<tr>
<td></td>
<td>MS/HH</td>
<td>7.33</td>
<td>5.82</td>
</tr>
<tr>
<td></td>
<td>PO/HH (II)</td>
<td>8.75</td>
<td>4.83</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>8.30</td>
<td>5.39</td>
</tr>
<tr>
<td>5.8</td>
<td>HL/VV</td>
<td>10.12</td>
<td>6.36</td>
</tr>
<tr>
<td></td>
<td>HL/HH</td>
<td>7.49</td>
<td>4.89</td>
</tr>
<tr>
<td></td>
<td>PO/VV</td>
<td>12.94</td>
<td>7.45</td>
</tr>
<tr>
<td></td>
<td>PO/HH</td>
<td>8.74</td>
<td>5.06</td>
</tr>
<tr>
<td></td>
<td>MS/VV</td>
<td>10.96</td>
<td>8.58</td>
</tr>
<tr>
<td></td>
<td>MS/HH</td>
<td>8.16</td>
<td>6.16</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>9.74</td>
<td>6.42</td>
</tr>
</tbody>
</table>

The $\sigma$ value shows how severe the variation of path loss is about the mean of a normal distribution. A low value of $\sigma$ will indicate less variation and the path loss model can predict more accurately.

S. Y. Lim, Z. Yun, and M. F. Iskander, “Propagation measurement and modeling for indoor stairwells at 2.4 and 5.8 GHz,” IEEE Transactions on Antennas and Propagation, accepted.
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To investigate by means of measurement and simulation how much accuracy would be compromised in a ray tracing simulation when the complex building façade is approximated by a simpler structure.

1) Moore Hall
2) Sakamaki Hall
3) Hale Kuahine
4) Idealized façade
Simplified Version of Moore Hall

Façade: $\varepsilon_r = 2.0$; $\sigma = 0.0001$ S/m; Ground: $\varepsilon_r = 7.0$; $\sigma = 0.0001$ S/m

Flat surface = 4.4 dB, Knife-edge = 3.3 dB

Signal propagation is weaker at 5.8 GHz than that at 2.4 GHz by approximately 10 dB.
The reflection from the flat surface is stronger (~15dB) than the diffraction from the knife edges.

Facade: $\varepsilon_r = 3.3317; \sigma = 0.0001 \ S/m$

Flat surface = 2.6 dB; Knife-edge = 2.5 dB
Idealized Façade (2.4 & 5.8 GHz)

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Bangkok, 2013

Palembang, 2012
To investigate how differently EM waves would propagate inside the open-trench drain, compared to where the drains were covered.
Scenarios/Frequency Bands

<table>
<thead>
<tr>
<th></th>
<th>Inside Drain</th>
<th>Atop Drain/Inside Drain with Increased Height</th>
<th>Atop Nearby Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 MHz</td>
<td>Strong Signal Strength</td>
<td>Weak Signal Strength</td>
<td>Strong Signal Strength</td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>Strongest Signal Strength</td>
<td>Medium Signal Strength</td>
<td>Weakest Signal Strength</td>
</tr>
<tr>
<td>5.8 GHz</td>
<td>Weakest Signal Strength</td>
<td>Medium Signal Strength</td>
<td>Medium Signal Strength</td>
</tr>
</tbody>
</table>


To tackle a practically important problem because in reality the open-trench drain environment is not always dry and empty.

To utilize an interactive full 3D ray tracing software package for running simulation in an open-trench drain.


To integrate research into teaching (an intervention to teach EM as an appetizer course for CS and IT undergraduates).

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Mulu National Park, Sarawak, Malaysian Borneo, March 2012. A UNESCO World Heritage Site that encompasses caves and karst formation in a mountainous equatorial rainforest setting.
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• Fundamental propagation mechanisms in the following environments have been investigated at several frequencies, e.g. 900 MHz, 2.4 and 5.8 GHz:
  – Indoor stairwell
  – Periodic building facade
  – Idealized periodic structure
  – Open-trench drain
• Future work: cave environment