Wideband Directional Radio Propagation  
Channel Analysis inside an Arched Tunnel

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Outline

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Cross Polarization Ratio
Introduction

To achieve uninterrupted communications, the radio propagation channel inside tunnels is important especially in mountainous areas or highway networks with many tunnels.

Experiments inside tunnels involve measuring the path gain (to predict coverage), or delay spread (to predict capacity) among others.

In this paper, we used a wideband channel sounder with an array on the Rx with dual polarized elements to learn more about the propagation mechanism inside tunnels.
RUSK-DoCoMo channel sounder

Table 1: Measurement Parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>5.2 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Delay resolution</td>
<td>10 ns</td>
</tr>
<tr>
<td>Tx signal</td>
<td>multitone</td>
</tr>
<tr>
<td>Tx power</td>
<td>40 dBm</td>
</tr>
<tr>
<td>Tx antenna</td>
<td>sleeve dipole (vertically oriented)</td>
</tr>
<tr>
<td>Tx antenna height</td>
<td>8 m (Tx1), 2.5 m (Tx2 and Tx3)</td>
</tr>
<tr>
<td>Rx antenna</td>
<td>cylindrical, 4 rings × 24 dual polarized patched elements</td>
</tr>
<tr>
<td>Rx antenna height</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Synchronization</td>
<td>Cesium clocks</td>
</tr>
</tbody>
</table>

Wideband Directional Radio Propagation Channel Analysis inside an Arched Tunnel
Scenario

- 2\textsuperscript{nd} Tomei highway, Shizuoka prefecture, Japan
- semi-circular cross section; for 3 car lanes
Scenario

Experiment was performed in 3 rounds:

Tx1: Rx1 to Rx18

Tx2 and Tx3: Rx2, Rx4 ... Rx14

Top view

Side view

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Parameter Estimation

A multidimensional gradient based maximum likelihood parameter estimator was used.*

The channel model for SIMO case:

\[ \mathbf{H}(\tau, \varphi, \vartheta) = \sum_{l=1}^{L} \begin{bmatrix} \gamma_{H,l} \\ \gamma_{V,l} \end{bmatrix} \delta(\tau - \tau_l) \delta(\varphi - \varphi_l) \delta(\vartheta - \vartheta_l) \]

Estimates:
- Complex path weights for cross and co polarization
- Time of arrival
- Angle of arrival (azimuth and coelevation)

Residual power is around 12 % of the total received power.

*provided together with the channel sounder

Wideband Directional Radio Propagation Channel Analysis inside an Arched Tunnel
Scatterer Identification

Using the AoA and path length information, scattering points can be derived assuming single-bounce.

Based on path length and AoA

If the scattering points lie beyond the surface of the tunnel, it's a multibounce path, and the AoA information is used to detect the last scattering point.
Scatterer Classification

Point 1: wall
Point 2: light-frame
Points 3, 5: sidewalk
Point 4: ground
Point 6: ceiling

light-frame scatterers are generally single-bounces, while the others can either be single-bounce or multibounce

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Resolvability of LoS path

Estimated LoS path may not be composed only of a distinct ray if it is too close to other paths.
Path gain of similar scatterer class are combined in each Rx.

Estimated LoS (strongest path) path gain differs from theoretical LoS because Tx1 is located near ceiling.

High power contribution from ground, sidewalk and light-frame scatterers.
Ground scatterers again dominate.

Wall scatterers maybe due to double-bounces from wall to wall before reaching Rx.

Detected ceiling and ground specular reflection only at Rx <= 50 m
No ceiling scatterers.

If both Tx and Rx are in the middle of the tunnel, paths can scatter to ground then ceiling before reaching Rx.

Since Tx3 is at the side, paths that scatter to the ground may scatter to the walls (instead of the ceiling).
XPR: Tx1

Mean in dB of similar scatterers was taken in each Rx.

Polarization rotation occurs when scattering point is from
For single-bounce ground or sidewalk scatterers, polarization is maintained because of the flat surface of the scatterer.

For multi-bounce scatterers, XPR depends on all interactions.
XPR: all Rx points per Tx

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Number of Paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx1</td>
<td>5.8  dB</td>
<td>8.2  dB</td>
<td>77</td>
</tr>
<tr>
<td>Tx2</td>
<td>9.6  dB</td>
<td>9.5  dB</td>
<td>37</td>
</tr>
<tr>
<td>Tx3</td>
<td>11.2 dB</td>
<td>8.9  dB</td>
<td>28</td>
</tr>
</tbody>
</table>

More rotation for Tx1 maybe because of its location on upper portion of tunnel such that more energy is bouncing the curved portion of the tunnel.
Conclusion

The spatio-temporal radio propagation channel inside an arched tunnel was analyzed utilizing a wideband directional measurement data.

Majority of the scatterers are from the ground.

When the Tx antenna is near the ceiling, the rotation of the wave polarization is observed especially for ceiling scatterers.

When Tx antenna is positioned on the side of the tunnel, the contribution of ceiling scatterers is less observable.
Thank You