Submission Title: [NLOS residential channel model based on TSV model]
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Abstract: [This contribution describes NLOS residential channel model based on TSV model.]

Purpose: [Contribution to mmW TG3c meeting.]

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NLOS residential channel model based on TSV model

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Agenda

- Background
- Measurement procedure and results
- Extracted TSV model parameters
Background

- TG3c requires NLOS residential channel model

- Tx and Rx are set up in different room but the antennas will be aligned in most likely NLOS residential environment to be considered (UM2)
Measurement environment

Distance: 1-3 m
Door: obstacle between Tx and Rx
Antenna Height: 1.1 m
Ceiling Height: 2.47 m
Window: 3.57 m
Floor plan of NLOS residential environment

Floor plan of NLOS residential environment
### Measurement conditions

<table>
<thead>
<tr>
<th>Instrument</th>
<th>HP8510C VNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>62.5 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>3 GHz</td>
</tr>
<tr>
<td>Time resolution</td>
<td>0.333 ns</td>
</tr>
<tr>
<td>Distance resolution</td>
<td>19.1 cm</td>
</tr>
<tr>
<td># of frequency points</td>
<td>801</td>
</tr>
<tr>
<td>Frequency step</td>
<td>3.75 MHz</td>
</tr>
<tr>
<td>Times of average</td>
<td>128 times</td>
</tr>
</tbody>
</table>

- Calibration performed with 1m reference separation
- Time resolution and distance resolution were determined by bandwidth
Measurement conditions (cont’)

- **Antenna:** Conical horn antenna
- **Polarization:** Vertical
- **Beam-width:** Tx:30 and Rx 30

Conical horn antenna
Beam-width 30 deg
Example PDPs (Power delay profile) in NLOS residential environment (Beam width: Tx=30, Rx=30)

- Direct-path component remains in NLOS measurement
- TSV model can model NLOS residential channels
Impulse response

NLOS direct-path component with penetration loss of obstacle

Cluster Rician factor ($\Delta K$)

Ray Rician factor ($\Delta k$)

S-V model response $\Gamma, \Lambda, \gamma, \lambda$

TSV model can generate channel response for NLOS environment by setting $\Gamma_0 = 0$
**TSV model for NLOS residential environment**

- For LOS desktop environment (06/297)

  TSV model = Statistical two-path component + S-V components

  \[
  h(t) = \beta \delta(t) + \sum_{l=0}^{L-1} \sum_{m=0}^{M_l-1} \alpha_{l,m} \delta(t - T_l - \tau_{l,m}) \delta(\varphi - \Psi_l - \psi_{l,m})
  \]

  \[
  \beta [\text{dB}] = 20 \cdot \log_{10}\left[\left(\frac{\mu_d}{d}\right)\sqrt{G_r G_i} + \sqrt{G_r G_2} \Gamma_0 \exp\left(\frac{2\pi h_2}{\lambda} \frac{2h_1 h_2}{d}\right)\right] - PL_d(\mu_d)
  \]

  Statistical factors in both two-path and S-V

- For NLOS residential environment

  Reflection coefficient: \( \Gamma_0 \triangleq 0 \)

  Modified TSV model = Direct-path component + S-V components

  \[
  h(t) = \beta \delta(t) + \sum_{l=0}^{L-1} \sum_{m=0}^{M_l-1} \alpha_{l,m} \delta(t - T_l - \tau_{l,m}) \delta(\varphi - \Psi_l - \psi_{l,m})
  \]

  \[
  \beta [\text{dB}] = 10 \cdot \log_{10}(G_r G_i) - PL_d(\mu_d)
  \]

  Statistical factors in only S-V

  Refer to Appendix A for each parameter
**Extracted TSV model parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TSV Model</th>
<th>Small Rician effect</th>
<th>S-V model oriented parameter</th>
<th>Number of cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Omega_0(d)$ [dB]</td>
<td>$k$ $(\Delta k)$</td>
<td>$\Gamma$ [ns]</td>
<td>$1/\Lambda$ [ns]</td>
</tr>
<tr>
<td>Tx:30</td>
<td>-7.55 d (22.4 dB)</td>
<td>5.16</td>
<td>6.49</td>
<td>7.58</td>
</tr>
<tr>
<td>Rx:30</td>
<td>-81.9</td>
<td>(22.4 dB)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Channel model for NLOS residential environment is available**

*Refer to Appendix B and C for each parameter*
Path loss in direct-path component in NLOS residential environment

\[
PL_d(\mu_d)[dB] = PL_d(d_0) + 10n_d \log_{10}(\mu_d / d_0)
\]

Path loss in direct-path component

- Path loss at \(d_0=1\)m distance

\[
PL_d[dB] = 20\log_{10}\left(\frac{4\pi d_0}{\lambda_f}\right) + 6.19 \approx 74.6
\]

\(\lambda_f \approx 4.8\text{mm} (f = 62.5\ \text{GHz})\)

- Path loss exponent

\(n_d = 2.78\)

- \(PL_d\) includes the penetration loss of door (Attenuation for NLOS residential environment: \(A_{NLOS} = 6.19\) dB)
Summary

- We observed direct-path components still remains although NLOS measurement

- We confirmed TSV model can express NLOS environment

- NLOS residential channel model based on TSV model is now available
Appendix A: Definition of TSV model (modified)

CIR: \( h(t) = \beta \delta(t) + \sum_{l=0}^{L-1} \sum_{m=0}^{M_{l}-1} \alpha_{l,m} \delta(t-T_l - \tau_{l,m}) \delta(\varphi - \Psi_l - \psi_{l,m}) \)

(Complex impulse response)

\[
|\alpha_{l,m}|^2 = \Omega_0 e^{-T_l / \Gamma} e^{-\tau_{l,m} / \gamma - k[1 - \delta(m)]} \sqrt{G_r(0, \Psi_l + \psi_{l,m})}, \angle \alpha_{l,m} \propto \text{Uniform}[0, 2\pi]
\]

Two-path response
\[
\beta [\text{dB}] = 20 \cdot \log_{10} \left( \frac{\mu_0}{d} \right) \sqrt{G_g G_r} + \sqrt{G_s G_r}, \exp \left[ \frac{2 \pi 2h \mu_0}{\lambda d} \right] - PL_{f}(\mu_0)
\]

\[
PL_{f}(\mu_0)[\text{dB}] = PL_{f}(\mu_0)[\text{dB}] + 20 \cdot \log_{10} \left( \frac{d}{\lambda} \right) \quad PL_{f}(\mu_0)[\text{dB}] = 20 \log_{10} \left( \frac{4G_s \mu_0}{\lambda^2} \right) + A_{\text{NLOS}}
\]

Path number of \( G_g \) and \( G_r \) (1: direct, 2: reflect)

Two-path parameters (4)
\[
d \propto \text{Uniform: Distance between Tx and Rx}
\]
\[
h_1 \propto \text{Uniform: Height of Tx}
\]
\[
h_2 \propto \text{Uniform: Height of Rx}
\]
\[
\mu_0 \propto \text{Average of distance between Tx and Rx}
\]
\[
|\Gamma_0|: \text{Reflection coefficient}
\]
\[
|\Gamma_0| \approx 1: \text{LOS Desktop environment}
\]
\[
|\Gamma_0| \approx 0: \text{Other LOS/NLOS environment}
\]

Arrival rate: Poisson process
\[
p(T_l | T_{l-1}) = \Lambda \exp[-\Lambda(T_l - T_{l-1})], \quad l > 0
\]
\[
p(\tau_l | \tau_{l,(m-1)}) = \lambda \exp[-\lambda(\tau_l - \tau_{l,(m-1)})], \quad m > 0
\]

S-V parameters (7)
\[
\Gamma: \text{cluster decay factor}
\]
\[
1/\Lambda: \text{cluster arrival rate}
\]
\[
\gamma: \text{ray decay factor}
\]
\[
1/\lambda: \text{ray arrival rate}
\]
\[
\sigma_{r_1}: \text{cluster lognormal standard deviation}
\]
\[
\sigma_{r_2}: \text{ray lognormal standard deviation}
\]
\[
\sigma_{\psi} : \text{Angle spread of ray within cluster}
\]
\[
\text{(Laplace distribution)}
\]

Antenna parameters (2)
\[
G_r(\theta, \phi): \text{Antenna gain of Tx}
\]
\[
G_t(\theta, \phi): \text{Antenna gain of Rx}
\]

Rician factor (2)
\[
k: \text{Ray Rician effect in each cluster}
\]
\[
K = \frac{b^2}{\bar{K}} = \sum_{l=0}^{L-1} \sum_{m=0}^{M_{l}-1} |\delta(t-T_l - \tau_{l,m}) \delta(\varphi - \Psi_l - \psi_{l,m})| \bar{G}(0, \Psi_l + \psi_{l,m})
\]
Appendix B: Results of data analysis

Antenna beamwidth
Tx: 30 deg, Rx: 30 deg

Cluster decay factor ($\Gamma$)
Cluster arrival rate ($1/\Lambda$)
Ray decay factor ($\gamma$)
Ray arrival rate ($1/\lambda$)

Angle of arrival in cluster ($\propto$ Uniform)
Angle spread of ray ($\sigma_\phi$)
Standard deviation of cluster ($\sigma_1$)
Standard deviation of ray ($\sigma_2$)
Appendix C: Averaged power of the first ray of S-V response

\[ y = -7.55 \times -81.9 \]

Antenna beamwidth
Tx: 30 deg, Rx: 30 deg

\( \Omega_0 [\text{dB}] = -7.55 \times d - 81.9 \)

- \( \Omega_0 \) slightly decreases according to distance