Effect of Antenna Placement in Vehicle-to-Vehicle Communication Systems

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Background

\( \text{A Position of antenna is expected to have large impact} \)

\( \text{i} \quad \text{Both TX and RX antennas are at same height} \)

\( \text{i} \quad \text{Relatively close to ground level (1-2m above ground)} \)

\( \text{i} \quad \text{Shadowing effects are expected} \)

\( \text{A Measurements in the past have been conducted with same type of antenna arrangements} \)

\( \text{i} \quad \text{Usually roof mounted antenna} \)

\( \text{i} \quad \text{Single exception exists with antenna placed Inside-windscreen} \)
Background

- No measurement results are available to compare the impact of antenna placement on different positions of car.
- Roof antenna is sensitive to roof inclination.
Objective

Å Obtain a **basic understanding** of impact of antenna placement in vehicle-to-vehicle communications

- Antenna positions/Channel Interaction

Å For different antenna positions is there any difference?

- Overall channel gain
- Delay and Doppler spreads
- Visibility of scatterers

Å Find a diversity arrangement with complementary antennas,

- Signal strength can be increased using diversity combining
# Measurement Setup

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Sounder</td>
<td>RUSK Lund</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>5.6 GHz</td>
</tr>
<tr>
<td>Measurement Bandwidth</td>
<td>200 MHz</td>
</tr>
<tr>
<td>Number of TX Antennas</td>
<td>4</td>
</tr>
<tr>
<td>Number of RX Antennas</td>
<td>4</td>
</tr>
<tr>
<td>Cars</td>
<td>Volvo V70</td>
</tr>
<tr>
<td>Cars Height</td>
<td>1.47 m</td>
</tr>
<tr>
<td>Number of Snapshots</td>
<td>49,152</td>
</tr>
<tr>
<td>Recording Time</td>
<td>25 s</td>
</tr>
<tr>
<td>Snapshot Time Duration</td>
<td>102.4 μs</td>
</tr>
<tr>
<td>Snapshot Repetition Time</td>
<td>0.51 ms</td>
</tr>
<tr>
<td>Supporting Data</td>
<td>Site Maps, GPS Coordinates Videos</td>
</tr>
</tbody>
</table>
Antennas used are omni-directional.

TX

RX
Measured Traffic Scenarios

Three type of environments were chosen,
- Highway
- Urban
- Rural

Due to their differences in,
- Traffic density
- Roadside environment
- Number of scatterers and Pedestrians
- Houses along the road side

Measurements were conducted in cities of Lund and Malmö, in Sweden
Measured Traffic Scenarios

Highway Measurements:

- Two lane highway
- Direction of travel was separated by 0.5m high wall
- TX/RX speed (80-90km/h)
- Many moving vehicles
- LOS and non-LOS conditions
- Only convoy measurements
Measured Traffic Scenarios

Urban Measurements Lund:
- Width 9-14 m
- Single lane
- Parked cars along street
- Some traffic

Urban Measurements Malmö:
- Width 14-40 m
- Two lanes and turn lanes
- Parked Cars along street
- Busy traffic

Measurements while driving in **Convoy** and in **Opposite** direction
Measured Traffic Scenarios

Rural Measurements:

- Single lane country road
- TX/RX speed (60-70km/h)
- No moving vehicles
- Always LOS conditions
- Measurements while driving in *Convoy* and in *Opposite* direction

Rural measurements can be treated as reference; where no or very few scatterers are around.
Analysis

Å Channel Gain

- We derive PDPs for each link over 10MHz of bandwidth
- To eliminate the effect of small scale fading we average PDPs over several time samples

\[ P_h(t, \tau) = \frac{1}{N_{avg}} \sum_{n=0}^{N_{avg}-1} |h(t + n\Delta t, \tau)|^2 \]

- The attenuation due to cables is measured and compensated
- Signals, except ones with power 3dB above noise power, are set to zero
- From this averaged PDP we get channel gain,

\[ G_h(t) = \frac{1}{N_\tau} \sum_\tau P_h(t, \tau) \]

Note:
We focus only on the links between same antenna mounts, e.g., roof-roof
Analysis

Å RMS Delay and Doppler spread

- RMS delay-spread is normalized second central moment of APDP given as,

\[
\tau_{RMS} = \sqrt{\frac{\sum_{k=0}^{L-1} \tau_k^2 P_h(\tau_k)}{G_h} - \mu_{RMS}^2}
\]

\[
\mu_{RMS} = \frac{\sum_{k=0}^{L-1} \tau_k P_h(\tau_k)}{G_h}
\]

- Similarly, normalized second central moment of ADDP gives RMS Doppler-spread
Analysis (Example)

**APDP**

**ADDP**

**RMS delay-Spread**

**RMS Doppler-Spread**
Channel Gain $[\text{dB}]$ as Function of Time $[\text{s}]$

**Rural - Convoy**

- Roof
- Bumper
- Windscreen
- Left-Side Mirror

**Urban - Convoy**

- Roof
- Bumper
- Windscreen
- Left-Side Mirror

**Leftside-mirror** antenna has stronger gain

**Roof** antenna has stronger gain

**Leftside-mirror** antenna is sensitive to alignment of cars
Channel Gain [dB] as Function of Time [s]

Rural - Opposite

Urban - Opposite

**Bumper** antenna has strongest gain before cars cross each other

**Roof** antenna has strongest gain after cars cross each other
Channel Gain [dB] as Function of Distance [m]

Highway - Convoy

Results from 2 measurement runs are shown with different colors

Signal level falls below noise level most of the time
Channel Gain [dB] as Function of Distance [m]

Urban - Convoy

Urban - Opposite

Results from 4 measurement runs are shown with different colors
Channel Gain [dB] as Function of Distance [m]

Rural - Convoy

Rural - Opposite

Results from 4 measurement runs are shown with different colors
RMS delay-spread and Doppler-spread

- Calculated over full 200MHz of bandwidth
- RMS delay/Doppler spread is affected by antenna placement,
  - Roof; higher gain in backward direction
  - Bumper and Windscreen; higher gain in forward direction
  - Leftside-mirror; higher gain in both forward and backward direction

Even though it is the same type of antenna
Highway Measurements

- Both line-of-sight (LOS) and non-LOS conditions
- Distant scatterers were visible sometimes
- RMS delay and doppler spreads are effected by antenna positions even though we have same type of antennas
Urban Measurements

- Both line-of-sight (LOS) and non-LOS conditions
- Multi-path propagation, relatively large number of scatterers
- RMS delay and doppler spreads are effected by antenna positions even though we have same type of antennas
Rural Measurements

- line-of-sight (LOS)
- Few scatterers
- RMS delay and doppler spreads are affected by antenna positions even though we have the same type of antennas

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Conclusion from above discussion

Â Antennas can be categorized into two complementary groups,
  ï Group 1: Roof and Left-mirror antenna
  ï Group 2: Bumper and Windscreen antenna
Â Diversity arrangements with complementary antennas seems to be a preferred solution
Â Based on overall performance one can choose 2 out of 4, e.g.,
  ï Roof or Left side mirror
  ï Bumper
Diversity Combining (MRC)

Roof Only
Roof+Bumper
Roof+Bumper +WindScreen
All four
Diversity Combining (MRC)
Summary and Conclusions

- The impact of antenna placement on V2V communications is studied and results are presented.
- Four antenna mounts were used; roof, bumper, inside-windscreen and leftside-mirror.
- Bumper and windscreen antennas do not have good coverage in backward direction.
- Roof and left side mirror antennas are sensitive to shadowing caused by the body of TX/RX.
- Results suggest, diversity arrangements with complementary antennas seems to be preferred solution.
  - For example, roof or leftside-mirror together with bumper antenna.
Thank you!