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Measurement-Based Analysis: The Effect of Complementary Antennas and Diversity on Vehicle-to-Vehicle Communication

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***Abstract*—In vehicle-to-vehicle (V2V) communication systems the antennas are prone to shadowing and the antenna gain is dissimilar even for same antenna elements if mounted at different positions on the car. This paper investigates the impact of antenna placement based on channel measurements performed with four omni-directional antennas mounted on the roof, bumper, windscreen and left-side mirror of the transmitter and receiver cars. Results suggest to use antennas with complementary characteristics, e.g., antennas on each side, mounted on the roof and bumper, to exploit diversity and decrease the effect of shadowing.**

I. INTRODUCTION

The research interest in vehicle-to-vehicle (V2V) communications has recently increased and is continuously flourishing due to the diversified scope of applications of V2V communications for improving the traffic safety and management. The effectiveness of these applications require low latency communication with high reliability. In order to obtain a high reliability, it is necessary to have a stable radio link. In cellular communications the base station antenna is at an elevated position with a circular (sectorized) coverage around it. This is not the case in V2V communications; both the transmit (TX) and receive (RX) antennas are at the same height relatively close to ground level, at some $1-2$ m above ground. In V2V systems, the position of the antenna is expected to have a large impact on the radio link performance. Therefore some of the experiences gained from cellular communications [1] are not directly applicable to V2V communications. Above all, by having antennas close to the ground level, shadowing effects from other vehicles and surrounding buildings are expected. Therefore, experimental studies employing real-time-measurement are essential to understand how antennas mounted at different positions on a car affect the behavior and performance of the radio link.

In the past, a number of measurement campaigns have been conducted for V2V systems, e.g., [2]–[7]. These measurements have almost exclusively been conducted with the same type of antenna mounting: a roof-mounted antenna (array). However, a small number of exceptions exist. In [4], an antenna was placed inside the vehicle, next to the windshield. In [3] and [8], the effects of five and three different roof positions, respectively, were tested. In, [9] and [10], ray tracing based simulations have been applied for analyzing impact of three and six antenna positions, respectively. To the authors' best knowledge, though, no (measurement-based) investigations to study the impact of antenna placement at different positions on the car, other than on the roof and windscreen, have been presented in the literature.

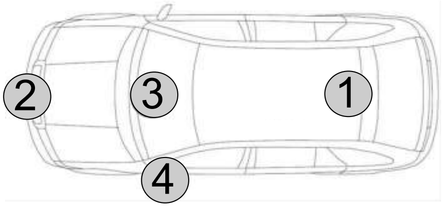

Fig. 1. The antennas were taped on a Styrofoam block that, in turn, was mounted in the following way: 1) Roof antenna (R), was mounted at the shark fin on the center of the roof, side wise, and 360 mm from the back edge of the roof: 2) Bumper antenna (B), was mounted 70 mm ahead of the registration plate; 3) Inside Windscreen antenna (W), was centered at the instrument board/dashboard at distance 1600 mm from the front of the car; 4) Left-side mirror antenna (M), was mounted at the outer edge of the mirror about 290 mm from the car side.

In order to meet the need for measurement-based investigations, as described above, a measurement campaign was conducted with four antennas mounted at four different positions on each TX and RX car (see Fig. 1): roof (R), bumper (B), inside-windscreen (W) and left-side mirror (M). Alternative antenna mounts include the rear bumper as well as the right side mirror, but those antenna positions are not measured in this campaign. The main goal is to investigate whether there is any antenna combination that is especially suitable for a diversity based system, i.e., if there are any two antenna elements that complement each other well in different propagation environments.

This letter contributes to the knowledge of the impact of distributed antennas in V2V communication and helps to develop a better understanding by characterizing the propagation channel properties for antennas mounted at different positions on a car. This is achieved in four steps. First, we analyze how the overall channel gain varies over time for different antenna positions in different environments. Second, we perform the diversity combining, and present diversity gain from different antenna combinations using selection combining (SC) and maximum ratio combining (MRC). Third, we select the best antenna pair among four antennas for the TX/RX vehicles based on the maximum diversity gain. Finally, we present

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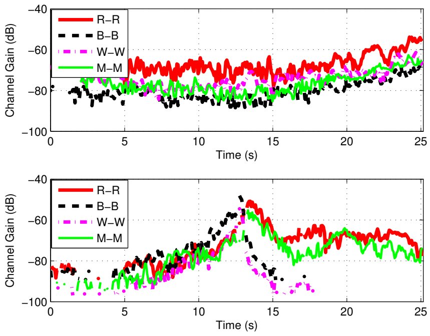

Fig. 2. Example of channel gains for four SISO links between same antenna mounts in urban convoy (top) where R-R links have higher gain. In urban opposite (bottom) the B-B and W-W links are the stronger as long as the vehicles are approaching, whereas R-R and M-M links have higher gain after the cars have passed each other.

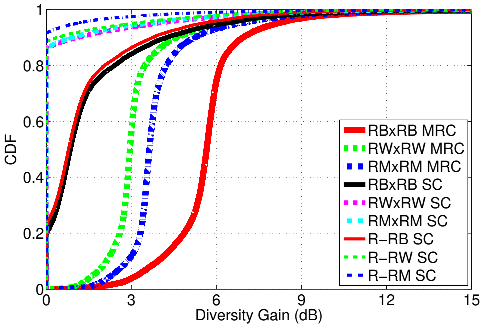

Fig. 3. Highway convoy: The diversity gain shown above is relative to the R-R SISO link. MRC has significant gain for all antenna combinations whereas SC does not provide any diversity gain for more than 80% of the time because the R-R link is better than the other links except for the RB×RB and R-RB links.

delay and Doppler spread for these antenna positions.

II. MEASUREMENTS

A. *Measurement setup*

For the measurement campaign we measure the gain of different links between two standard Volvo V70 cars, 1.47 m high station wagons, used either as TX or RX. Each vehicle was equipped with four omni-directional (in azimuth) vertically polarized SkyCross meander line antennas mounted at four different positions (see Fig. 1), SMT-2TO6MB-A, having a frequency range between 2.3 to 5.9 GHz and an antenna gain of around 3 dBi in the used frequency band. Channel measurements were performed using the RUSK-LUND channel sounder [11], which performs multiple-input multiple-output (MIMO) measurements based on a switched array principle. The complex time-varying channel transfer function $H(f,t)$ was measured for each TX/RX link over 200 MHz of bandwidth at 5.6 GHz, the highest carrier frequency on which our channel sounder can operate. Since 5.6 GHz is very close to 5.9 GHz, the standard frequency for 802.11 p, it is believed that the channel characteristics remain same. Moreover, the 200 MHz bandwidth is chosen to achieve the high delay resolution which is beneficial for the channel analysis. During the analysis the transmitted power was assumed constant and was switched over the multiple transmitted antennas. Moreover, to secure additional support in post processing, videos were taken through the windscreen of each car and GPS data were logged during each measurement run.

All measurements were conducted in and between the cities of Lund and Malmö, in the south of Sweden. Three typical propagation environments were chosen due to differences in the traffic densities, road-side environments, number of scatterers, pedestrians, and houses along the road side:

- **Highway** - Measurements were performed on a $4-$lane highway (E22) where TX/RX vehicles were moving in a convoy at a speed of $22-25$ m/s over a 10 km long stretch of the road. The direction of travel was separated by a (≈ 0.5 m tall) concrete wall whereas the outer boundary of road was guarded by a metallic rail.
- **Urban** - Measurements were performed in densely populated areas in Lund and Malmö where the streets were $12-20$ m wide, either single or double lane, lined with $2-4$ storied buildings. The vehicles were driven over $4-6$ km long loops and on a 3 km long stretch at varying speeds ranging $0-14$ m/s while moving as a convoy or in opposite directions.
- **Rural** - Measurements were performed on a patch of road with open surroundings just outside the city of Lund at an approximate speed of $17-20$ m/s. There were no moving scatterers but a couple of houses at some 300 m distance from the measurement site. The rural scenario was measured as a reference to analyze the case when there are no or very few scatterers around.

Moreover, along the roadside there were trees, vegetation, road signs, street lights, bicycles, parked cars and often buildings situated at random distances, where the concentration of these objects depends upon the scenarios. There were other vehicles which occasionally obstructed the line-of-sight (LOS), partially or completely, for all or only for a subset of antenna combinations. In the urban environment, vehicles experience additional attenuation when buildings around the corner block the LOS. For more details on measurement set up, see [12].

III. RESULTS AND DISCUSSION

Before the measurements the cable losses and the gain of the low-noise-amplifier (LNA) were explicitly measured and their effect is removed from the measured channel gains. Hence the channel gains presented here are the gains experienced from TX antenna connector to the RX antenna connector of the measurement equipment without further cables.

V2V antennas are sensitive to the shadowing effects either from other vehicles or from the body of the car itself. This means, e.g, due to the shadowing caused by the curved surface and the size of the roof of a car that the R-antenna (roof) experiences stern degradation in the azimuth gain in the forward direction [13] whereas it has higher gain in the backward direction. The M-antenna (left-side mirror) has the higher channel gain both in forward and backward direction but it

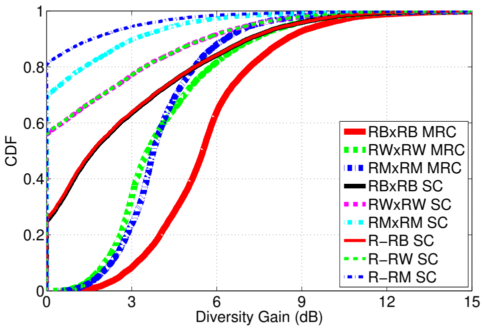

Fig. 4. Urban convoy: For more than 50% of the time the SC diversity gain is at least 2 dB and 6 dB for the RB×RB and R-RB links, respectively. MRC performs well in all situations since it uses dominant eigen mode transmission.

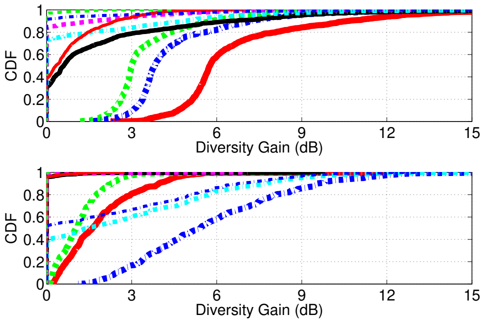

Fig. 5. Urban opposite: Vehicles approaching (top) and moving away (bottom). The R and B antenna combination has the strongest gain when vehicles are approaching whereas R and M antenna combination has better gain when moving away. However, for more than 50% of time there is no diversity gain with SC for both the RB and RM combinations because the bumper or mirror antennas were often obstructed by other vehicles. Legend is the same as in the above figure.

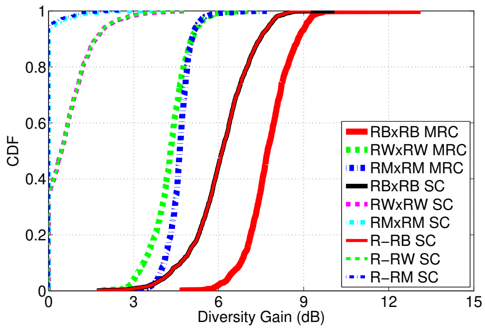

Fig. 6. Rural convoy: Both TX/RX vehicles are well aligned so the RWxRW and RMxRM links provide diversity gain also with SC. However, the RB×RB combination has the best performance since it provides 6 dB and 8 dB gain for SC and MRC, respectively, for more than 50% of the time.

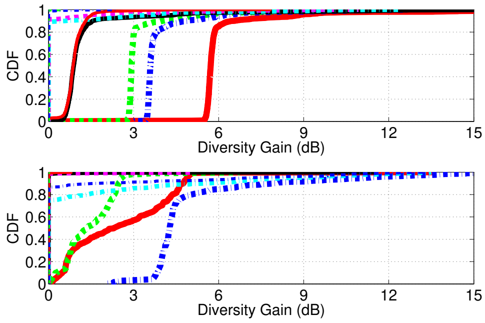

Fig. 7. Rural opposite: Vehicles approaching (top) and moving away (bottom). Similar to the urban opposite case, the R and B antenna combination has best performance when vehicles are approaching, whereas the R and M antenna combination has higher gain when moving away. Legend is same as in above figure.

is sensitive to the exact alignment of the two vehicles, as also stated in [14]. Finally, the W and B antennas, mounted next to the windscreen and bumper respectively, are completely shadowed by the car body thus they only have good gain in the forward direction. Thus, it is interesting to notice that the antenna gain is dissimilar even by similar antenna elements if mounted at different positions on the car [3].

These differences in channel gain for the links associated to same antenna positions on the TX and RX, i.e., link for; R-R, B-B, W-W, and M-M, in urban environment are highlighted in Fig. 2, while TX and RX are moving in a convoy as well as in the opposite directions. It can be observed in Fig. 2 that the R-R link has higher gain since all other antennas are somehow under the shadow of the car body itself. On the contrary, in an opposite setting when both the TX and RX cars are moving towards each other, the LOS between the B-B and W-W antenna pairs will enhance the received power compared to other links. This gain in power by the B-B link will make us detect vehicles 2 s before other antenna pairs as if the TX/RX vehicles are moving at speed of around 17 m/s. In other words, by having an additional antenna on the bumper, we can detect other cars from slightly larger distance relative to the roof only antenna (see Fig. 2). Moreover, when TX/RX are moving away from each other, we gain similar amount of time with the roof antenna.

A. *Diversity Gains*

The performance differences in antenna gain for each position suggests to use multiple antennas that complement each others performance by exploiting diversity gain [10]. We thus investigate MIMO and single-input multiple-output (SIMO) diversity methods by using selection combining (SC) and maximum ratio combining (MRC) [14]. We first compute the diversity gain using both methods for all possible MIMO and SIMO combinations, i.e. 1x1, 2x2, 3x3, 4x4 and 1x2, 1x3, 1x4 antenna systems, and for all antenna mounts in all measurement scenarios, respectively. We then short list and analyze the most interesting cases, that are 2x2 MIMO diversity with SC and MRC, and 1x2 SIMO diversity with SC only. The cumulative distribution function (CDF) of the diversity gain for 5 measurement scenarios: highway convoy, urban convoy, urban opposite, rural convoy and rural opposite, are shown in Figs. 3-7. The diversity gains presented here are relative to the R-R single-input single-output (SISO) link.

As a first observation, for the given antenna arrangement the R-antenna together with the B-antenna outperform all other antenna combinations (in particular, 1x2 SIMO and 2x2 MIMO). From the results it is evident that the diversity gain for RB-RB MRC is $4-5$ dB higher than that for RB-RB SC.

It is because there are two channels which are almost equally strong in both settings, either moving in convoy (R-B and R-R) or in opposite direction (B-B and R-R). MRC gives the best system performance [14] but for V2V systems SC could be a preferred solution. Mounting an antenna on the roof and on the bumper require $2-4\,\mathrm{m}$ long cables connections from the on-board units (OBU), and this long RF cables will introduce $3.5-7\,\mathrm{dB}$ extra attenuation, as a typical cable loss is $1.7\,\mathrm{dB/m}$. This loss can be avoided if the processing units are placed near the antennas and the data is transfered to the OBU via an Ethernet cable. For such a setup, the SC diversity scheme could be more useful than MRC. The antenna gain can be increased $4-5\,\mathrm{dB}$ by using antennas with directional beam patterns, such that the bumper antenna has its main beam in the forward direction and the roof antenna having a somewhat omni-directional antenna pattern.

B. Delay and Doppler Spreads

The delay and Doppler spreads are measures of the channel dispersion in time and frequency. The mirror antenna has good gain in both the forward and backward directions, whereas the roof antenna has a somewhat higher gain in the backward direction in the horizontal plane. Similarly, the bumper and windscreen antenna has a very low gain in the backward direction, thus reducing the experienced delay spread and Doppler spreads. It means that the rms delay and Doppler spreads are affected by the antenna placement even though it is the same kind of antenna elements that are used for all antenna positions. Therefore, it is important to include realistic antenna patterns in simulations, which is inherent in models such as geometry based stochastic channel models (GSCM) [15]. From the above diversity based analysis the roof antenna together with the bumper antenna appears to be the best pair in current settings. In Table I the 90^{th} percentile of rms-delay and rms-Doppler spread is given for all 4 links of the RB×RB antenna combinations. The 90^{th} percentile is the value for which 90% of the data points are smaller.

IV. SUMMARY AND CONCLUSIONS

In this letter we have presented a measurement based analysis of the impact of antenna placement on vehicle-to-vehicle communications. This investigation suggests that a pair of antennas with complementary properties, e.g., a roof mounted antenna together with a bumper antenna is a good solution for obtaining the best reception performance, in most of the propagation environments. It is because when vehicles are moving in opposite direction, approaching each other, the roof and left-side mirror antennas can experience shadowing due to the roof or body of the transmitter and receiver cars itself, even when there is line-of-sight in between the cars, whereas the bumper antenna does not suffer from this problem. However, the bumper or windshield antennas do not provide good coverage to vehicles in the backward direction, which may affect collision warning times severely. Therefore it is better to have a pair of antennas placed at different positions than to have a single roof or bumper mounted antenna. The use of these antenna positions requires, however, long cables which introduce an additional attenuation unless some countermeasures are taken.

TABLE I

90^{th} PERCENTILE OF RMS-DELAY AND RMS-DOPPLER SPREAD FOR THE RB×RB LINKS (2×2 MIMO)

Scenario	$\tau_{rms}(ns)$				$\nu_{rms}(Hz)$			
	R-R	R-B	B-R	B-B	R-R	R-B	B-R	B-B
Highway	10.0	10.8	-	7.8	30	31	-	15.5
Urban-Convoy	35	21.8	55.4	62.6	67	23.6	364	287
Urban-Opposite	21.9	28	32.2	15.2	42.2	107	59.3	26.5
Rural-Convoy	103	21.6	4.1	96	24.1	28.6	-	19.4
Rural-Opposite	12.2	8.5	9.8	10.7	196	26.2	79.7	127

REFERENCES

[1] J. R. J. K Fujimoto, "Mobile antenna systems handbook," *Artech House, Boston*, 1994.

[2] G. Acosta-Marum and M. Ingram, "Six time- and frequency- selective empirical channel models for vehicular wireless LANs," *IEEE Veh. Technol. Mag.*, vol. 2, no. 4, pp. 4–11, 2007.

[3] S. Kaul, K. Ramachandran, P. Shankar, S. Oh, M. Gruteser, I. Seskar, and T. Nadeem, "Effect of antenna placement and diversity on vehicular network communications," in *4th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, SECON '07*, Jun. 2007, pp. 112 –121.

[4] I. Sen and D. W. Matolak, "Vehicle-vehicle channel models for the 5 GHz band," *IEEE Trans. Intell. Transp. Syst.*, vol. 9, no. 2, pp. 235–245, Jun. 2008.

[5] A. Paier, J. Karedal, N. Czink, C. Dumard, T. Zemen, F. Tufvesson, A. F. Molisch, and C. F. Mecklenbräuker, "Characterization of vehicle-to-vehicle radio channels from measurements at 5.2 GHz," *Wireless Personal Commun.*, vol. 50, pp. 19–29, 2009.

[6] O. Renaudin, V. M. Kolmonen, P. Vainikainen, and C. Oestges, "Non-stationary narrowband MIMO inter-vehicle channel characterization in the 5 GHz band," *IEEE Trans. Veh. Technol.*, vol. 59, no. 4, pp. 2007–2015, May 2010.

[7] A. Thiel, O. Klemp, A. Paier, L. Bernadó, J. Karedal, and A. Kwoczek, "In-situ vehicular antenna integration and design aspects for vehicle-to-vehicle communications," in *EUCAP*, Apr. 2010.

[8] T. Mangel, M. Michl, O. Klemp, and H. Hartenstein, "Real-world measurements of non-line-of-sight reception quality for 5.9 GHz IEEE 802.11p at intersections," *Communication Technologies for Vehicles, Springer Berlin Heidelberg*, vol. 6596, pp. 189–202, 2011.

[9] M. Schack, D. Kornek, E. Slottke, and T. Kürner, "Analysis of channel parameters for different antenna configurations in vehicular environments," in *IEEE 72nd Vehicular Technology Conference (VTC 2010-Fall)*, Sept. 2010, pp. 1 –5.

[10] L. Reichardt, T. Fugen, and T. Zwick, "Influence of antennas placement on car to car communications channel," in *3rd European Conference on Antennas and Propagation, EuCAP 2009*, March 2009, pp. 630 –634.

[11] R. Thoma, D. Hampicke, A. Richter, G. Sommerkorn, A. Schneider, U. Trautwein, and W. Wirnitzer, "Identification of time-variant directional mobile radio channels," *Instrumentation and Measurement, IEEE Transactions on*, vol. 49, no. 2, pp. 357 –364, apr 2000.

[12] T. Abbas, F. Tufvesson, and J. Karedal, "Measurement based Shadow Fading Model for Vehicle-to-Vehicle Network Simulations," *ArXiv e-prints*, Mar. 2012.

[13] O. Klemp, "Performance considerations for automotive antenna equipment in vehicle-to-vehicle communications," in *URSI International Symposium on Electromagnetic Theory (EMTS)*, Aug. 2010, pp. 934 –937.

[14] R. Vaughan and J. B. Andersen, *Channels, Propagation and Antennas for Mobile Communications (IEE Electromagnetic Waves Series, 50)*. Institution of Engineering and Technology, Feb. 2003.

[15] J. Karedal, F. Tufvesson, N. Czink, A. Paier, C. Dumard, T. Zemen, C. Mecklenbräuker, and A. F. Molisch, "A geometry-based stochastic MIMO model for vehicle-to-vehicle communications," *IEEE Transactions on Wireless Communications*, vol. 8, no. 7, pp. 3646–3657, 2009.