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## SCOPE

The task set was to consider two front-/rear-antenna configurations with different radiation patterns and mounting positions and to identify the one that offers the prospectively highest transmission reliability in selected traffic scenarios. Additionally, an omnidirectional roof-mounted antenna was taken into account for reference.

The customer provided antenna patterns for the simulation that had been measured in an EMV-laboratory on the actual antennae mounted to the car in the intended locations. Configuration 1 exhibited an approximately omnidirectional coverage pattern with a maximum gain of about 3dBi front sided / 6 dBi back sided at angles of about 45° off the

lane in either direction. This configuration only achieved a negative gain of -8 dBi and -5 dBi straight in, respectively opposite, the direction of travel. The customer assumed that lateral coverage could e.g. provide an advantage at crossroads.

Configuration 2 provided a relatively strong directional pattern aligned with the lane with approx. 9 dBi gain towards both front and rear. Both antenna configurations were to be mounted behind the front bumper and in the boot lid. The rear antenna of configuration 1 was mounted slightly higher elevated than the rear antenna employed for configuration 2.

The ideal omnidirectional reference antenna should be modelled as a roof-antenna at height 1.3 m for comparison.

# Car-to-X Communication

## Flexible Integration of Antenna Systems

The best place to mount an antenna to achieve maximum range for car-to-X communication is on a vehicle's roof top. But where to place the antenna, if the vehicle completely lacks a roof? Faced with the challenge to find an antenna position for convertible cars, a renowned German car maker turned to Qosmotec for support. Qosmotec's channel emulator QPER allows engineers to evaluate the road capability of wireless communication systems in the lab. Thus, basic issues can be resolved even before prototyping, which may significantly reduce the need for drive tests saving valuable time and resources. The following article describes the set-up, execution and results of the above-mentioned project.

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As a figure of merit for the comparative valuation, the range beyond which the connection suffers a packet loss rate exceeding 10 % was to be considered. The customer suggested six reference traffic scenarios defined in a white paper of the Car-to-car Communication Consortium [1]:

- rural LOS (Line of sight): two communicating vehicles in direct line of sight follow each other on a straight road in an open area
- urban approaching LOS: two communicating vehicles approach each other from opposite directions on a straight road in an urban area with roadside buildings
- urban following NLOS: two communicating vehicles following each other in an urban area with a third vehicle blocking the line of sight (also termed Obstructed line of sight by some publications)

- urban crossing NLOS: two vehicles encounter each other at rectangular crossroads with buildings blocking the line of sight
- highway LOS: two communicating vehicles follow each other on a multi-lane highway with road signs, bridges, hills and other vehicles
- highway NLOS: analogous to Highway LOS but with a truck blocking the line of sight between the communicating vehicles.

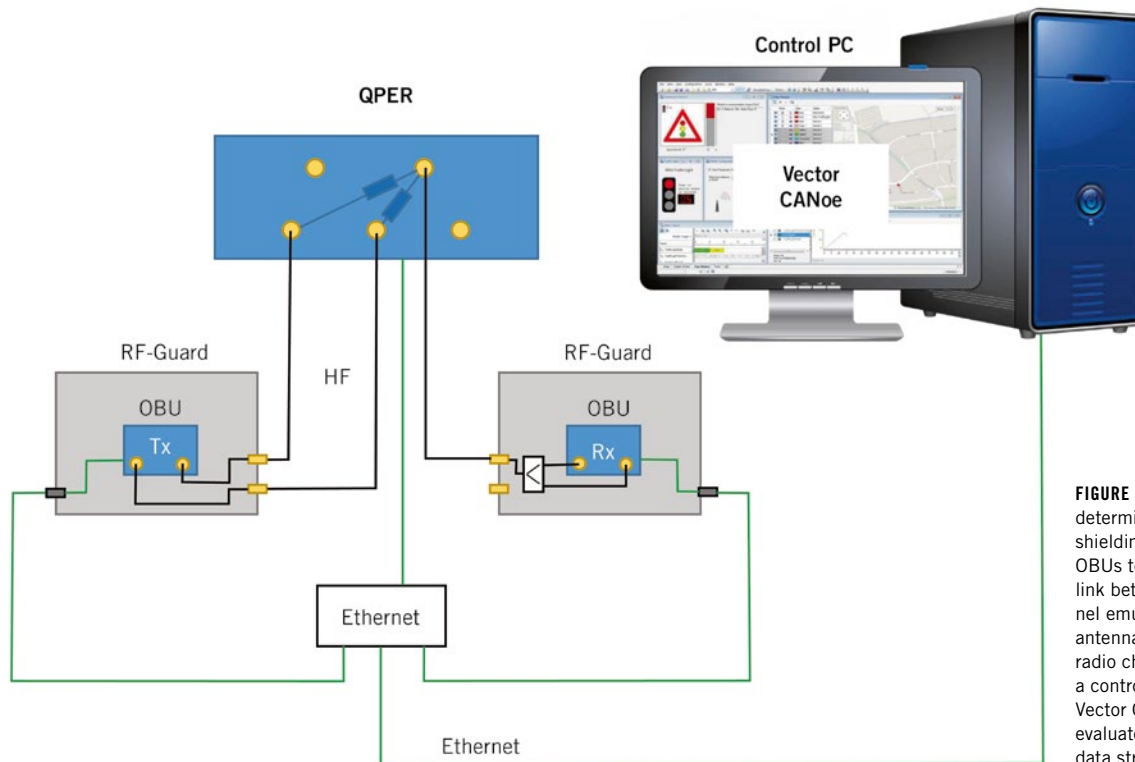
Qosmotec proposed an additional Rural Crossing LOS scenario with two vehicles approaching each other at rectangular crossroads in an open area with permanent line of sight contact.

### CHANNEL EMULATION

For generic modelling of the scenarios described above, the following channel models were investigated and integrated into Qosmotec's channel emulation platform:

- two-way propagation with ground reflection [2]: This model combines free-space attenuation, where the signal level drops off with the square of the distance (path loss exponent -2), with a 4<sup>th</sup> power distance law (path loss exponent -4) beyond a certain breakpoint-distance (typically a couple of hundred meters) that is determined by the antennae heights on sender and receiver side and the wavelength of the employed radio signal. This common RF-channel-model can be applied





**FIGURE 1** Measurement setup to determine the packet loss rate: shielding boxes enclose the OBUs to block a direct radio channel link between them; the channel emulator QPER models antenna coverage pattern and radio channel characteristics; a control PC running the tool Vector CANoe generates and evaluates the measured packet data stream (© Qosmotec)

to the Rural-scenarios, with a fast signal fading process (Rice-Fading) added optionally.

- shadow-fading model by Abbas et. al. [3]: This model also assumes a change of the path loss exponent beyond a breakpoint-distance, depending on antennae heights and wavelength. It additionally considers shadowing of the signal source by buildings (Shadow Fading). It models shadow fading with a normal distribution of the signal level measured in dB around its mean level. The path loss exponents for short and long distances, as well as the parameters of shadow fading, were established in an empirical study by the authors for different environments (Highway, Urban), with both direct LOS and obstructed LOS. This model suits all Urban- and Highway-scenarios, except for Urban Crossing NLOS.
- NLOS-Model for Crossroads by Mangel et. al. [4]: The third model, being based on empirical studies as well, considers exactly and exclusively the situation of urban crossroads in the midst of buildings blocking the line of sight between vehicles except within the intersection area. A virtual signal source in the middle of the intersection replaces the transmitting vehicle.

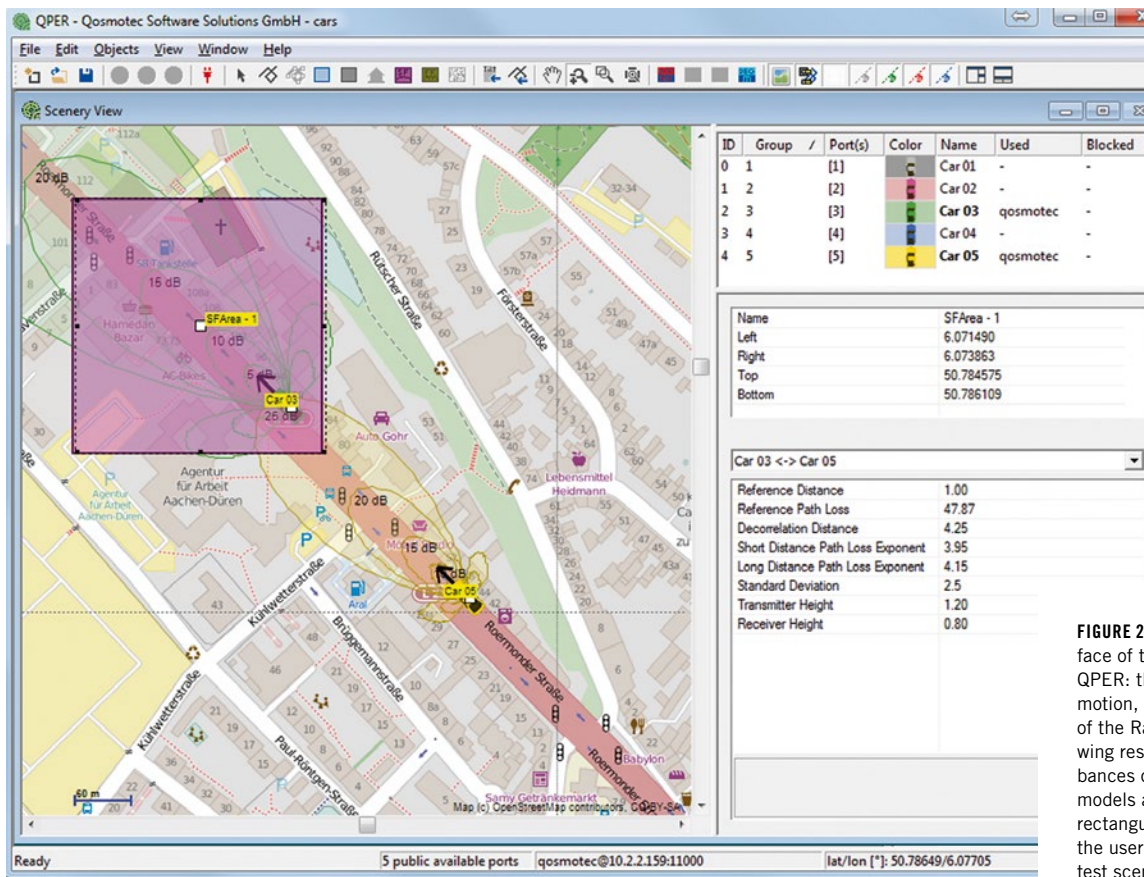
The signal strength of the transmitter, the distance to middle of the intersection, antennae heights and road widths determine the signal level sensed by the receiver. To take into account the antenna pattern, not considered in the original study, the antenna gain of the transmitting vehicle in direction of the reflecting and diffracting building edges of the intersection was determined and added to the signal level. In accordance with the authors of the model, the signal was overlaid with a fast fading process with a standard deviation of 4.1 dB in amplitude.

#### EXECUTION OF THE MEASUREMENTS

The measurement setup to investigate the packet loss rate, **FIGURE 1**, consisted of two Cohda Wireless MK4a On-Board Units (OBUs) for car-to-X communication. Both OBUs were isolated from each other in Qosmotec RF-Guard shielding boxes and connected to the channel emulator QPER via coaxial cables, which manipulated the signals according to the models described above. The channel emulator comprises a RF-attenuator-matrix which links all RF connectors of the box with

one another. The attenuators are controlled programmatically, so a user can e.g. simulate that two OBUs connected to the emulator hardware first approaching each other with rising signal level until they pass one another and start moving away from each other again with the signal level dropping consequently. The programmatic control makes it possible to also emulate fast fading processes or antenna gains according to particular antenna coverage patterns.

QPER's software provides a GUI which displays a simulated landscape (Scenery) that can be underlaid with a map for better orientation. Users can place Radio Devices into the Scenery and move them around. The channel emulator determines the attenuation to be applied in the hardware from the distance, antenna characteristics, and the employed channel model. Each Radio Device is associated with one of the physical RF connectors of the channel emulator, and each pair of Radio Devices corresponds to an associated signal path through an RF attenuator inside the hardware. The user may draw routes in the Scenery which determine the trajectories of the Radio Devices. Shadowing, Fading or different channel models can be added to the scenery in form of Areas, which are

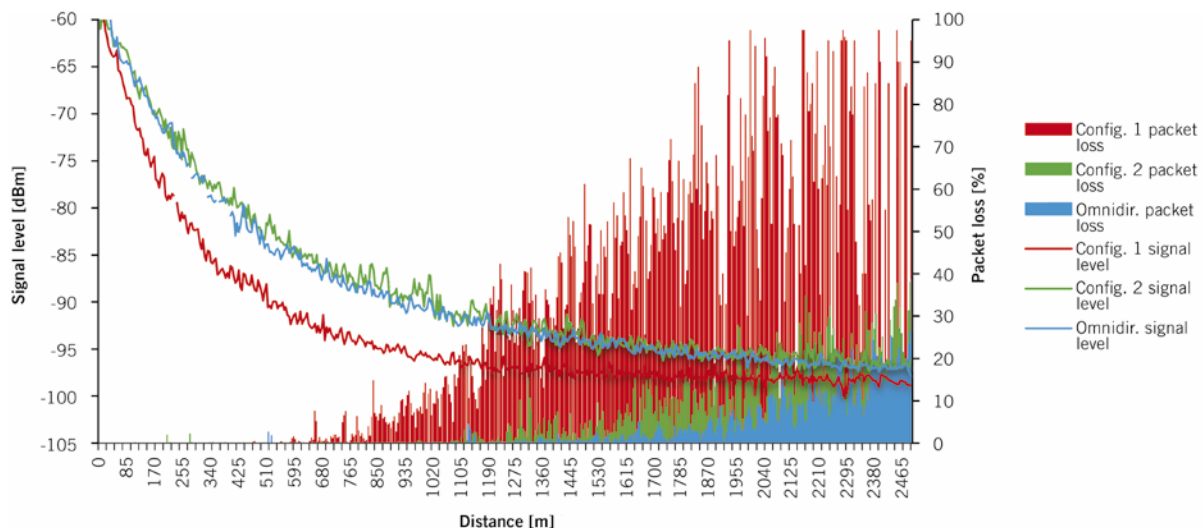


**FIGURE 2** Graphical user interface of the channel emulator QPER: the user can determine motion, velocity and direction of the Radio Devices by drawing respective trails; disturbances or different channel models are introduced inside rectangular areas; this way, the user can design realistic test scenarios (© Qosmotec)

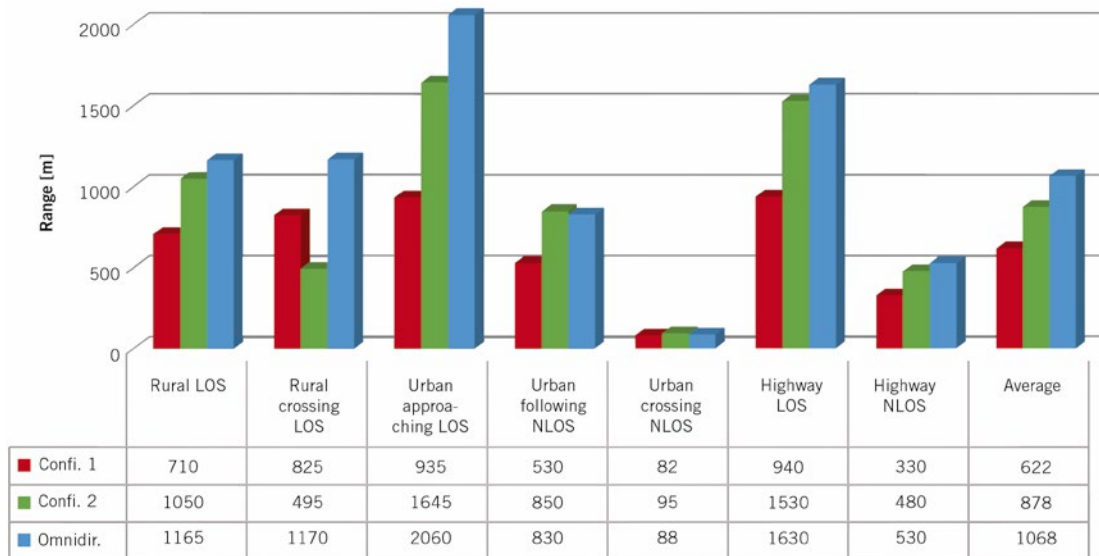
crossed by the routes of the Radio Devices. For example, **FIGURE 2**, shows a violet-coloured Slow Fading Area the parameters of which are shown in the box bottom-right. To simulate the purported traffic scenarios, engineers just

need to draw routes in the scenery for the involved vehicles, assign speed, length and directions to them and overlay an area with the desired channel model. To generate packets and measure packet loss rate, Qosmotec has implemen-

ted the corresponding routines for Vector Informatik's CANoe Software, which was being run on a control PC. The OBUs were connected to the control PC via Ethernet. 400 packets per second with a length of 106 to 140 bits and successive



**FIGURE 3** Packet loss rate and signal level over distance for the traffic scenario Urban Approaching LOS: The directional coverage pattern of configuration 2 (green) provides an adequate substitute for an omnidirectional roof-mounted antenna (© Qosmotec)



**FIGURE 4** Comparison of the ranges for 10 % packet loss rate over all the considered traffic scenarios: The directionally acting antenna configuration 2 exhibits reliably superior ranges than the more omnidirectionally radiating configuration 1; the single lower performance for the Rural Crossing LOS scenario is still more than sufficient (© Qosmotec)

packet numbers were exchanged between the OBUs and the control PC, where the packet loss rate was established based on the missing packet numbers.

QPER permanently transmitted the simulated vehicle position to the CANoe measurement routines to establish the dependency between packet loss rate and distance. In order to obtain results for front and rear antennae, traffic-scenarios with following vehicles where modelled in a way, that one vehicle was overtaking the other. The overtaking vehicle with the front-/rear antenna configuration under investigation assigned to it assumed the role of the sender, while the receiving vehicle was simulated with an omnidirectional antenna at a height of 1.3 m. The simulations were repeated ten times average out the random shadow- and rice-fading variations.

## RESULTS

As a sample specimen for the obtained results, **FIGURE 3**, reveals signal level (line graph) and packet loss rate (bar chart) for the Urban Approaching LOS scenario, where both vehicles pass each other at 50 km/h, driving in opposite directions. The red graphs refer to configuration 1 (approximately omnidirectional coverage). The green graphs refer to configuration 2 (strong directional characteristic). The blue graphs refer to the theoretically perfect omnidirectional reference antenna mounted on the roof top.

The graphs indicate that configuration 2 exhibits nearly the same range as the reference antenna, while configuration 1 fares significantly worse. Configuration 2 achieves a very good range, because the vehicles approach each other head on and therefore, the directivity offers a huge advantage. Still, the reference antenna achieves a slightly larger range, because of its higher mounting position. This causes a longer breakpoint-distance compared to the other configurations, below which an absolutely lower path loss exponent takes effect. This results in a smaller loss for close-up ranges that more than compensates the smaller antenna gain. This could be verified by simulations with higher mounted configurations 1 and 2.

What about the other scenarios?

**FIGURE 4** gives an overview of the achieved ranges for 10 % packet loss rate over all simulated scenarios. Obviously, the omnidirectional antenna mounted on the roof top would be the preferred option. As this antenna cannot be mounted in convertibles, configuration 2 offers a reasonable alternative. Configuration 1 is superior in only one case: the additionally considered Rural Crossing LOS scenario with a permanent line of sight. However, the range of nearly 500 m for configuration 2 is more than sufficient for this particular

scenario and therefore is no criterion for exclusion, regarding its superior performance in all the other scenarios. The assumption that configuration 1 might be superior in Urban Crossing NLOS was refuted, however.

## CONCLUSION

The simulation with Qosmotec's car-to-X platform provided a clear-cut recommendation, which antenna configuration should be deployed. The superior range of a directional antenna compensates the lower mounting position, and in most traffic situations it is advantageous to align the signal with the direction of driving. In addition to this qualitative statement, quantitative figures on the ranges of the antenna configurations could be obtained as well. Thus, the customer could avoid time consuming drive tests.

## REFERENCES

- [1] Car-2-Car Communications Consortium, Task Force Antennae & Wireless Performance. Whitepaper Version 1.2, Kapitel 4.2.1 Scenarios
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- [4] Mangel, T.; Klemp, O.; Hartenstein, H.: 5.9 GHz inter-vehicle communication at intersections: a validated non-line-of-sight path-loss and fading model. EURASIP Journal on Wireless Communications and Networking 2011, 2011:182, <http://bit.ly/1JcP2RN>



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