Initial Measured OTA Throughput of 4G LTE Communication to Cars with Roof-Mounted Antennas in 2D Random-LOS

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***Abstract*—We present initial Over-The-Air (OTA) throughput measurements of an LTE device in a Volvo XC90 car with roof-mounted antennas. The measurements were performed in a semi-anechoic chamber and only in the horizontal plane. The throughput results are presented as a probability of detection (PoD) in 2D Random Line-Of-Sight (Random-LOS) with fixed polarization of the antenna at the base station side. Two car-mounted antennas were measured: a wideband two-port shark-fin type antenna in SISO and SIMO receive diversity-mode, and a narrowband monopole antenna. The PoD curves clearly show the expected performance improvements due to the antenna diversity. In addition, the Random-LOS measurements made it possible to discover potential for improvements of the tested antennas.**

***Index Terms*—vehicular, antenna, anechoic chamber, measurements, Random Line-Of-Sight, RLOS.**

I. Introduction

In the future there will be autonomous cars driving together with other traffic. Then, a secure and reliable wireless communication link to the cars will be needed, more than ever. The quality of the antennas must be tested together with the rest of the wireless system, including the car. Two approaches for automotive OTA tests are described in [1] and [2]. Cars will be used both in urban and rural environments, so we will need to have test environments corresponding to both of them.

In general, the OTA testing of wireless devices can be performed in both anechoic chambers (with absorbers on the walls) and reverberation chambers (with reflecting walls) [3]. The reverberation chamber emulates a Rich Isotropic Multipath (RIMP) environment [4], and is suitable for environments with a lot of scatterers, such as indoor and urban environments. The complementing pure Line-Of-Sight (LOS) environment corresponds to the well-known anechoic chamber that has been used for decades for testing the performance of antennas for fixed installations. A rural/highway environment is more similar to LOS than RIMP, and in particular for cars on the road, i.e., the automotive case, see Fig. 1. The difference compared to a traditional anechoic LOS environment is that the antenna under test (AUT) is not stationary for the automotive case. The car moves, so we need to consider that the Angle of Arrival (AoA) is random, and in the present case we will limit ourselves to randomness in the horizontal plane. This we will call a 2D Random Line-Of-Sight (Random-LOS) environment [5]-[6].

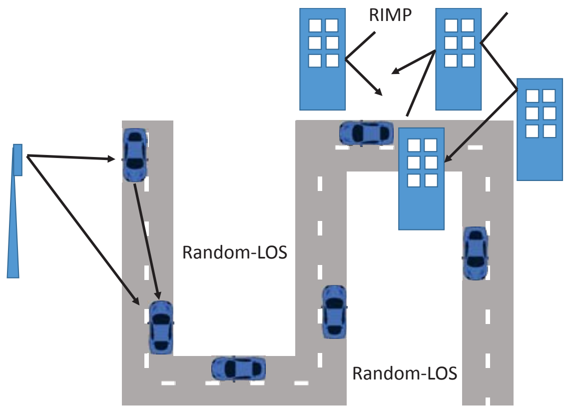


Fig. 1. Two edge environments for the autonomous cars. The RIMP and Random-LOS environments, which are present in urban and rural/highway environments respectively.

Indeed, autonomous cars will be deployed in propagation environments that resembles both RIMP and Random-LOS, see Fig 1. The ground reflections are neglected in this Random-LOS measurement setup, since they can be regarded as very small and random in a base station to car communication case. This is due to the inhomogeneous and uneven ground in terms of wavelengths at the 4G frequencies. For smooth regular grounds there exist simple models to include it, such as the two-ray model [7], but we do not consider it relevant at this stage of developing the Random-LOS test concept.

This paper presents the first experimental verification of the automotive Random-LOS OTA test scenario introduced in [1]-[2]. The setup is simplified making use of only one single wideband chamber antenna. Later it will be extended to an array of such chamber antennas in order to make a proper near- to far-field transformation of the test zone.

The main purpose at present is to test the Multiple Input Multiple Output (MIMO) concept in 2D Random-LOS. To assure small errors due to the short distance to the chamber antenna we locate the car in such a way that its roof antenna is located at a prolongation of the rotation axis of the turntable. We have performed tests with two different roof-mounted antennas. A wideband two-port "shark-fin" antenna is compared to a narrowband monopole antenna. Both antennas are vertically polarized, so we have limited the test setup to a fixed vertical polarization and one bitstream. We have performed LTE Single Input Single Output (SISO) measurements for both the antennas, and an additional LTE Single Input Multiple Output (SIMO) measurement for the shark-fin antenna. We also tried to generate two bitstreams by using a 2×2 MIMO setup by using both the vertically and horizontally polarized ports of the chamber antenna. This was only successful when using more than 10 dB higher power levels. This is natural, because we need to use orthogonal polarizations on both sides in order to get two bitstreams in a pure LOS environment with co-located antennas, see [8, Sec. 3.10].

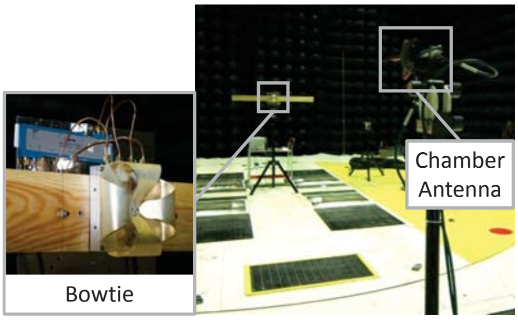
II. Method

The Random-LOS OTA testing environment was set up in a semi-anechoic chamber (SP Technical Research Institute of Sweden in Borås) with the dimensions $11\,\mathrm{m} \times 21\,\mathrm{m}$. The car was a new Volvo XC90 with a 2-port shark-fin antenna on the roof, see Fig. 2(b). The car had a panorama window in the roof in front of the antenna. The antenna elements were covered by a radome (also called antenna hood). The shark-fin antenna was connected to a Huawei LTE dongle (E398). The dongle was placed inside a shielded box in the car. A shielded box was used to make sure that the internal antennas of the dongle were inactive. The dongle was used together with an Apple MacBook Pro that was placed outside the shielded box, but still inside the car.

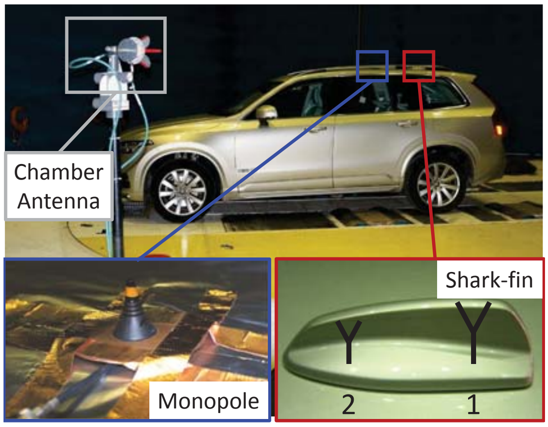
A communication tester (Rohde & Schwarz CMW500) was used for measuring the throughput. The instrument and the turntable control software was provided by Bluetest AB. The chamber/base station antenna used for the measurements was a Quadridge Horn antenna (ETS Lindgren Open Boundary Quadridge Horn, Model 3164-05), where only the vertical polarization was used. The chamber antenna was placed at the same height, 1.7 m, as the shark-fin antenna, with a distance 6.1 m between them.

The shark-fin antenna was compared to a narrowband monopole antenna, see Fig. 2(b). The panorama window in the roof of the car was covered by aluminium foil when the monopole was manually mounted on top of it and measured. Care was taken to place the car in such a way that both of the AUTs were positioned in the middle of the turntable, at the center of rotation.

The throughput for the SISO and SIMO cases were measured with the shark-fin antenna located on the car roof, when one bitstream was transmitted. The SIMO case corresponds to antenna diversity at the receiving side. Only SISO throughput measurements were performed for the monopole antenna. The measurements were performed at the LTE band 7, channel



(a)



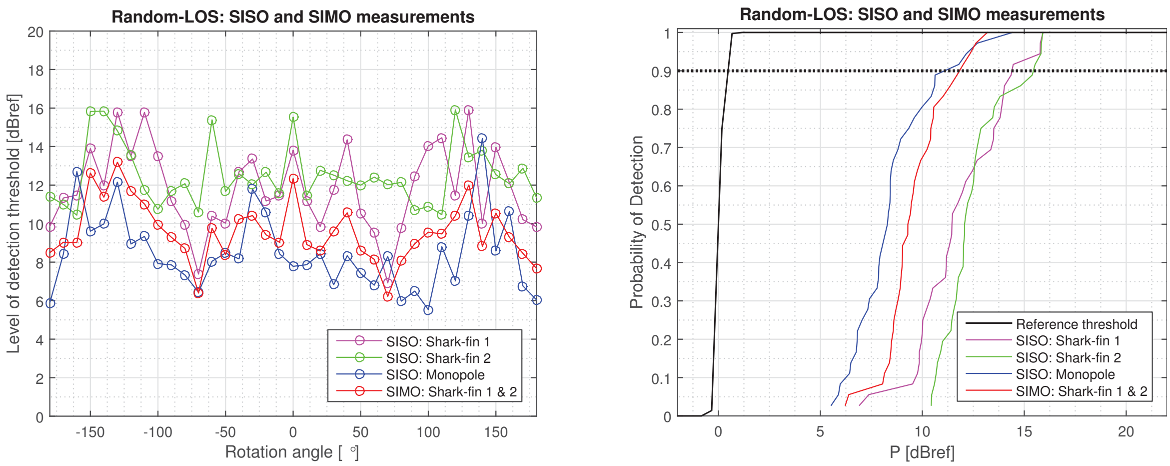
(b)

Fig. 2. Measurement setup. (a) Reference setup with a Bowtie antenna. (b) The Random-LOS measurement with the vehicle and the shark-fin antenna and the monopole. Only one antenna was used at the time.

3100 and downlink frequency 2.655 GHz. The chosen bandwidth was 5 MHz. A downlink and uplink modulation of 16-QAM and QPSK were used respectively. The number of subframes per sample was set to 400 and 25 resource blocks were used. The maximum throughput was 5.738 Mbps.

The car was rotated 360° in steps of 10° using the turntable. At each fixed angle step a whole throughput curve was measured. The whole throughput curve corresponds to measuring the throughput for a range of power values (with steps of 0.5 dBm), thereby allowing the relative throughput to decrease from 100 % to 0 % when the power decreases.

In order to obtain calibrated data in terms of received power, a reference measurement was performed. This was done by measuring the transmission when a bowtie antenna [9] was placed above the rotation axis of the turntable, instead of the car with its antenna, see Fig. 2(a). The bowtie antenna was used together with a 180°-hybrid (Krytar Double Arrow 180° Hybrid, Model 4010180), which was used as a balun. The gain of the bowtie antenna is 6.0 dBi at $f = 2.655$ GHz, and its return loss is 18 dB, corresponding to a mismatch factor of -0.07 dB. The insertion loss of the 180°-hybrid (i.e. the balun) is smaller than 2.9 dB. The same cables were used for the reference as for the car measurements. Therefore, the dB scale in the throughput curves obtained with the car antennas



(a) (b)

Fig. 3. (a) The level of detection threshold for the shark-fin and monopole antenna. (b) Shows the same data as in (a), but as a Probability of Detection. The 0°-position corresponds to that the front of the car is facing the chamber antenna. The results are presented in dBref, which is dB relative a reference threshold. The reference threshold comes from a measurement with the bowtie antenna at the 0°-position.

are relative to measurements in the same setup with an antenna with a realized gain of $6.0 - 2.9 - 0.07\,\mathrm{dB} = 3\,\mathrm{dB}$.

The reference was measured for the 0°-position. The 0°-position corresponds to that the bowtie antenna is pointing towards the chamber antenna. The 0°-position for the shark-fin measurements equals that the front of the car is facing the chamber antenna.

III. Results

The throughput can be modelled by the output of an ideal digital threshold receiver. For static propagation conditions the throughput will change very abruptly from 100 % to 0 % throughput [10] at a certain threshold. If the conditions change with time, the apparent level of this threshold (i.e., the threshold observed for a fixed transmitted power) will change with time as well. Therefore, the time-averaged throughput curve will deviate from the sharp threshold (vertical line) and becomes more “S-shaped”. Here we have chosen to describe the static throughput curves by an ideal detection threshold. The level of this static detection threshold is chosen to be at the 50 % value of the throughput in a setup with stationary AoA. The level of this static detection threshold, as a function of angle, is plotted in Fig. 3(a). The result is presented in dBref, which means dB relative to a reference antenna (as explained in Section II). The reference antenna in our case is the bowtie antenna at the 0°-position. The level of the detection threshold for the reference antenna was measured at -94.2 dBm.

From Fig. 3(a) we see that the SIMO shark-fin curve (receive diversity with one bitstream) is better than the two individual SISO curves. This is expected. It can also be seen that the SISO curve for the monopole is better than the shark-fin antenna at this specific frequency band. This is also expected, since the monopole antenna is much more narrowband, with a higher total radiation efficiency, than the shark-fin antenna.

Another way to present the information in Fig. 3(a) is to plot it as Probability of Detection (PoD) curves. The plotted PoD, in Fig. 3(b), is the same as the cumulative distribution function of the level of detection thresholds that are seen in Fig. 3(a). Normally the PoD from different curves are compared at the 90 % level. It is possible to see that the SIMO case is 2.6 dB better than the best SISO curve, and the monopole antenna is then 0.7 dB better than the SIMO curve.

The black curve in Fig. 3(b) shows the reference bowtie antenna, and its SISO threshold for the 0° position on the turntable. The same measurement settings have been used as for the shark-fin and monopole measurements. The difference between the reference and the car-antenna measurements can be explained by the realized gain of the reference antenna (see Section II) and the finite size of the roof of the car acting as a finite ground plane of the antenna. Therefore, realized gain of the antennas in the horizontal plane is 6 dB lower than that of vertically polarized antennas over infinite ground planes. This is a well known effect of edge diffraction due to finite ground planes.

IV. Conclusion

The Random-LOS environment can be seen as a rural environment. There will be one dominant path between the two communicating antennas (Line-Of-Sight), but the randomness of the AOA of the wave is also taken into account, in contrast to the traditional fixed antenna locations in LOS. It is desirable to test the antenna system in this type of environment, to see how well it performs in this extreme case. The antenna system needs to be able to handle the randomness in AoA.

With our simple Random-LOS measurement setup we are able to perform throughput measurements of antennas mounted on the car. We are able to see a clear difference between different antenna types and can clearly illustrate this in PoD curves. This is promising for the future and the further development of the Random-LOS measurement setup.

The measurement setup, presented in this paper, is an initial simplified setup that needs to be developed further. Further developments contain changes to the chamber antenna, which will be replaced with an array [11]. The array will make it possible to perform measurements, even when the AUT is not positioned at the center of rotation of the turntable. Then, a more suitable reference antenna is also needed. Ideally an omnidirectional antenna that can be rotated on the turntable.

ACKNOWLEDGMENT

The authors would like to thank SP Technical Research Institute of Sweden for providing the semi-anechoic chamber that was used for the measurements. We would also like to thank Markel Bertilsson at SP, who helped with the measurements. Special thanks to Mats Kristoffersen and Anton Skårbratt at Bluetest, who helped a lot with expertise and support with the measurement software. The project is partly supported by the Swedish Research Council VR, through an industrial PhD project.

REFERENCES

[1] P.-S. Kildal, A. A. Glazunov, J. Carlsson, and A. Majidzadeh, "Cost-effective measurement setups for testing wireless communication to vehicles in reverberation chambers and anechoic chambers," in *2014 Conference on Antenna Measurements Applications (CAMA)*, Nov. 2014, pp. 1–4.

[2] P.-S. Kildal, "Methods and apparatuses for testing wireless communications to vehicles," Jan. 2014, patent application number PCT/EP2014/054620. Applicant is Kildal Antenn AB.

[3] A. A. Glazunov, V.-M. Kolmonen, and T. Laitinen, "MIMO Over-The-Air Testing," in *LTE-Advanced and Next Generation Wireless Networks*, G. d. l. Roche, A. A. Glazunov, and B. Allen, Eds. John Wiley & Sons, Ltd, 2012, pp. 411–441.

[4] P.-S. Kildal, C. Orlenius, and J. Carlsson, "OTA Testing in Multipath of Antennas and Wireless Devices With MIMO and OFDM," *Proceedings of the IEEE*, vol. 100, no. 7, pp. 2145–2157, Jul. 2012.

[5] P.-S. Kildal and J. Carlsson, "New approach to OTA testing: RIMP and pure-LOS reference environments amp; a hypothesis," in *2013 7th European Conference on Antennas and Propagation (EuCAP)*, Apr. 2013, pp. 315–318.

[6] P.-S. Kildal, "Rethinking the Wireless Channel for OTA testing and Network Optimization by Including User Statistics: RIMP, pure-LOS, Throughput and Detection Probability," in *International Symposium on Antennas and propagation (ISAP 2013)*, Nanjing, China, Oct. 2013.

[7] J. Rustako, A.J., N. Amitay, G. Owens, and R. Roman, "Radio propagation at microwave frequencies for line-of-sight microcellular mobile and personal communications," *IEEE Transactions on Vehicular Technology*, vol. 40, no. 1, pp. 203–210, Feb. 1991.

[8] P.-S. Kildal, *Foundations of Antenna Engineering - A Unified Approach for Line-Of-Sight and Multipath*, 2015th ed. Kildal Antenn AB, May 2015, available at www.amazon.co.uk and www.kildal.se.

[9] H. Raza, A. Hussain, J. Yang, and P.-S. Kildal, "Wideband Compact 4-Port Dual Polarized Self-Grounded Bowtie Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 9, pp. 4468–4473, Sep. 2014.

[10] P.-S. Kildal, A. Hussain, X. Chen, C. Orlenius, A. Skarbratt, J. Asberg, T. Svensson, and T. Eriksson, "Threshold Receiver Model for Throughput of Wireless Devices With MIMO and Frequency Diversity Measured in Reverberation Chamber," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1201–1204, 2011.

[11] A. A. Glazunov, P.-S. Kildal, and M. S. Kildal, "Devising a Horizontal Chamber Array for Automotive OTA Tests in Random Line-Of-Sight." ISAP (This proceedings), 2015.