Comparison of 2-bitstream Polarization-MIMO Performance of 2 and 4-port Bowtie Antennas for LTE in Random-LOS

Sadegh Mansouri Moghaddam[1], Andres Alayon Glazunov[1], Jian Yang[1], Mattias Gustafsson[2], Per-Simon Kildal[1]
[1]Department of Signal and Systems, Chalmers University of Technology
[2]Huawei Technologies Sweden AB
Gothenburg, Sweden

***Abstract*—We evaluate the performance of a dual-polarized wideband antenna in terms of polarization-MIMO in Random-LOS for two different modes of operation: 2 and 4-port excited mode. The 2-port mode was obtained by differential excitation of two opposite ports of the 4-port design by using two baluns. The Zero-Forcing receiver throughput is evaluated based on the Probability of Detection of two bitstreams when orthogonal polarizations provide the MIMO subchannels. Assuming a uniform distribution for the Angle of Arrivals and orthogonally polarized waves incident on the antennas, the overall PoD over coverage cones of 30°, 60° and 90° are presented. The 2-bitstream multiplexing MIMO efficiency defined at the 95% Probability of Detection is evaluated for the two modes of operation at different frequencies and for different coverage cones. The 2-bitstream coverage pattern of the antenna for the two modes are plotted over the range of Angles-of-Arrival (AoA), by choosing fixed polarization (horizontal and vertical) for the incoming waves. The coverage pattern is significantly degraded for the 2-port mode, in particular in the middle of the band.**

Keywords—MIMO ; Random-LOS; probabilty of detection; Digital threshold receiver

I. INTRODUCTION

Multiple-input and multiple-output (MIMO) technology make use of multiport antennas to increase channel capacity and improve the reliability of the communication system [1]. In this paper, a polarization-MIMO antenna is studied. Using orthogonal polarizations to transmit two bitstreams through MIMO subchannels can lead to more compact antenna designs. This is especially important for wideband micro-BTS (Base Transceiver Station) applications. The Over-The-Air (OTA) performance of multiport MIMO antennas operating in multipath channels are accurately characterized in reverberation chambers by their total embedded efficiencies, diversity gains and maximum available channel capacity [2-3]. On the other hand, there might be a significant line of sight (LOS) component between the micro-BTS and the user due closeness. This LOS contribution will also increase as the frequency goes up such as for 5G systems. Therefore, it is important to introduce characterization methods valid for LOS propagation conditions. This LOS component will arrive from a random direction due to the random location of the user. The orientation of the user terminal will be also random leading to a random orientation of the polarization of the LOS wave impinging at the micro-BTS. Therefore, it is appropriate to introduce a Random-LOS test scenario [4-5] as a complement to the Rich Isotropic MultiPath (RIMP) emulated in a reverberation chamber [3].

The Random-LOS characterization of MIMO-diversity and MIMO-multiplexing has been introduced in [6] and [7]. In this paper, we use the self-grounded 4-port bowtie antenna [8-9] in two different modes of operation. We set out to compare its performance in the 4-port mode and in the 2-port mode for 4 × 2 MIMO and 2 × 2 MIMO systems, respectively. The 2-port mode is obtained from the 4-port mode when opposite ports are differentially excited. The comparison is done in terms of Probability of Detection (PoD), 2-bitstream MIMO multiplexing efficiency and throughput coverage patterns.

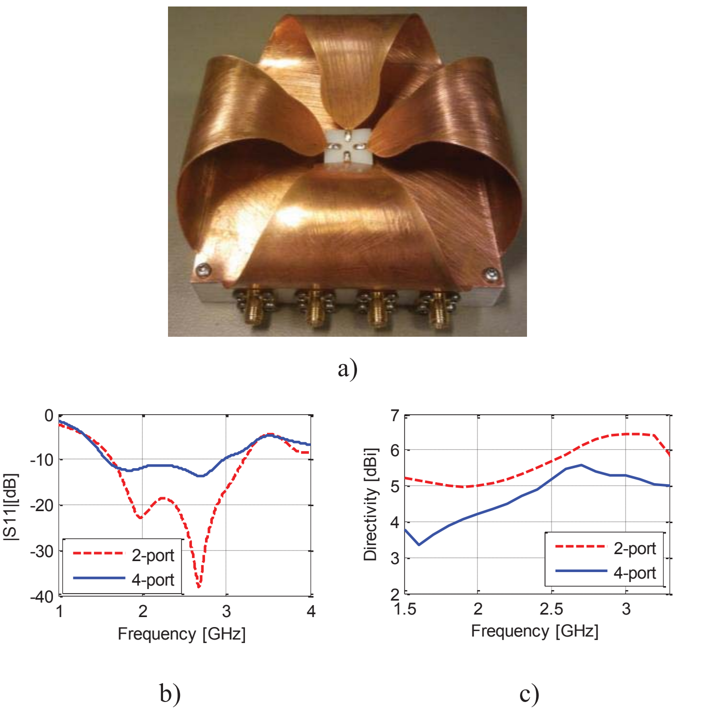

Fig. 1: a) Self-grounded bow-tie antenna, b) reflection coefficient, i.e., S11 and c) directivity of each port for the 2 and 4-port operational modes

This work has been supported by two projects from Sweden´s innovation agency VINNOVA, one within the VINN Excellence Center Chase at Chalmers and another via the program Innovative ICT 2013, and by internal support from Chalmers.

Simulations are performed with the ViRM-lab (Visual Random Multipath environment Laboratory) simulation tool [10], which is MATLAB® based.

The 2-bitstream PoD curves are computed based on the threshold receiver model assuming the Zero Forcing (ZF) receiver algorithm [11]. The MIMO multiplexing efficiency at 95% level of the PoD curve is presented for different frequencies in the band of interest. The 2-bitstream MIMO throughput coverage patterns of the antenna are presented too. The reference level for the coverage patterns are the PoD coverage of a wall-mounted isotropic antenna that is polarization-aligned with the incident wave. The MIMO multiplexing efficiency relative to the isotropic polarization-aligned case is referred to as the MIMO efficiency in dBi at 95% PoD.

II. The Self-Grounded Bowtie Antenna

The dual-polarized self-grounded bowtie antenna is a low profile directional antenna which can be used as a 4-port antenna with 4-ports individually excited, or as a 2-port antenna with opposite ports differentially excited using two baluns [8], [9]. A photograph of the antenna is shown in Fig.1. The general structure is generated by bending 4 triangular-shaped petals that are attached to the ground plane, over virtual cylinders. The simulated reflection coefficient and the directivity of the 2 and 4-port mode are shown in Fig.1, both for the 2- and 4-port cases. As we can see, the reflection coefficient is below -10dB over the bandwidth 1.6-3.2 GHz and 1.5GHz-3GHz for 2 and 4-port modes, respectively. The directivity varies from 5dB to 6.5dB for 2-port and 3.5-5.5 for 4-port mode in the band of interest.

III. MIMO 2-Bitstream Performance

A. *Threshold receiver model and simulations*

According to the threshold receiver model [11], the average relative throughput can be expressed by

$$T_{put}(P_{av}/P_{th})/T_{put,\max} = PoD(P_{av}/P_{th}) = 1 - CDF(P_{th}/P_{av}) \quad (1)$$

where $T_{put,\max}$ is the maximum throughput, P_{th} is the threshold power level of the receiver. PoD is the Probability of Detection of the data bitstream and CDF is the cumulative distribution Function of the output power of the receiver. As can be seen, the relative throughput can be interpreted as a probability of detection.

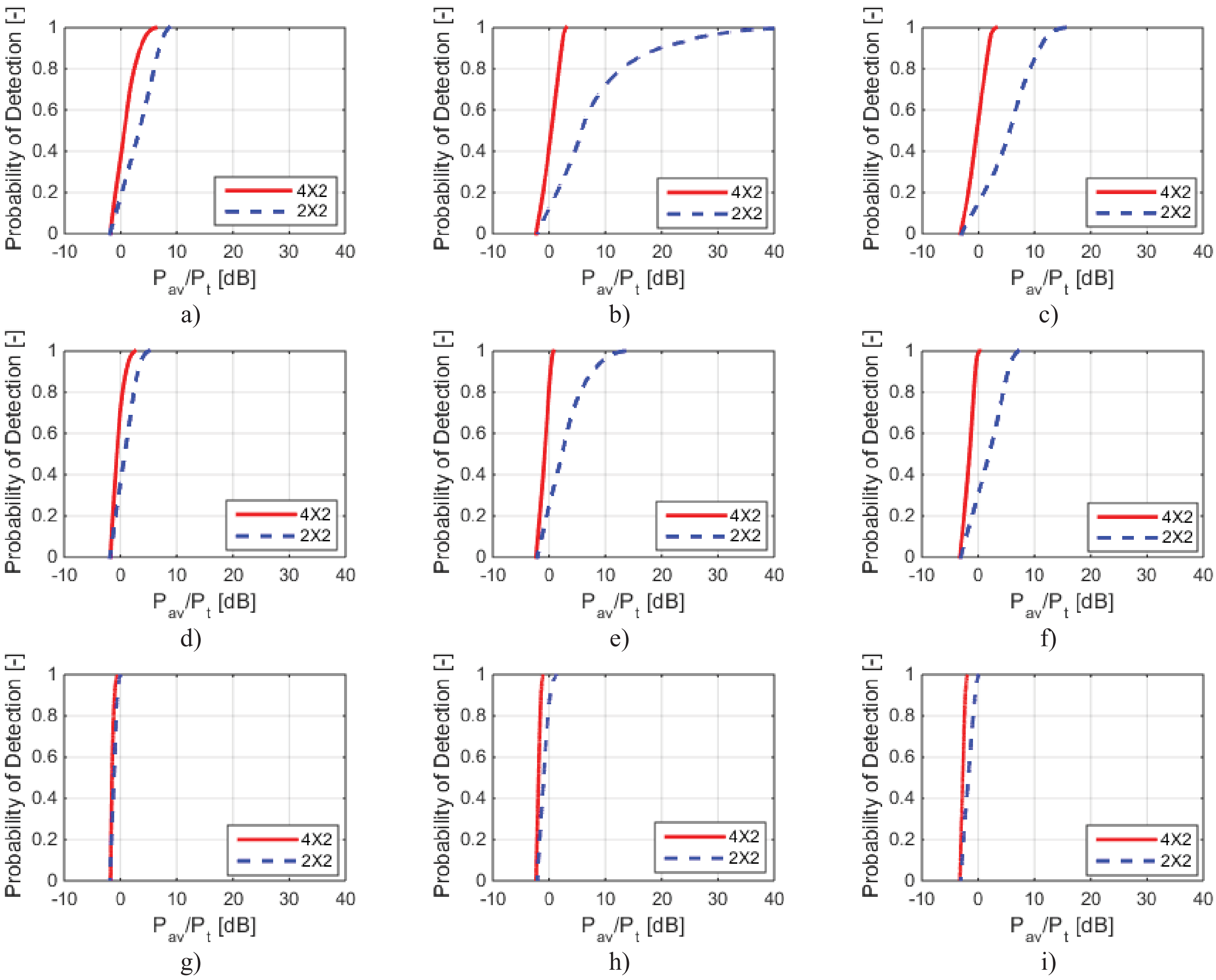

Fig. 2: Probability of Detection (PoD) of two bitsreams at frequencies 1.7GHz (left column), 2.2GHz (center column) and 2.7GHz (right column) over coverage cones with apex angles equal to 90º (top row), 60º (center row) and 30º (bottom row) for two different modes of operation.

We further assume that there is no information available on the transmit side. Therefore equal power distribution at the transmitter ports are considered and zero forcing (ZF) algorithm is used to extract the information from received signal at the antenna ports. In polarization-MIMO in Random-LOS, it is not possible to use more than two bitstreams (for co-located antennas), which corresponds to two orthogonal polarizations through the environment. It is worthwhile to note that ideal orthogonally polarized antennas on both sides of the LOS link can resolve two bitstreams without being polarization-aligned [12, Sec. 3-10]. A ray-based simulation tool named ViRM-lab is used to evaluate the performance of the antenna [10]. Uniform distributions for the Angles-of-Arrivals (AoA) and the polarization of two orthogonal incoming waves are assumed. The corresponding PoD curves for the two considered modes of operation of the bowtie are plotted in Fig. 2. The power level corresponding to PoD=0% is the maximum received power obtained from the ZF algorithm. For example, for the 2x2 MIMO system, this value equals the negative of the realized gain - 3dB. This arises from the fact that the Bowtie antenna patterns are orthogonal in the main beam and the transmit power is equally divided between the two bitstreams. Also the dBt reference is a polarization-matched single-port antenna which has an isotropic far-field function over the desired angular coverage. The latter is here assumed to be the full unit sphere.

B. *MIMO efficiency in dBi*

The 2-bitstream MIMO multiplexing efficiency is defined here as the difference between output power (in dB) of the ZF receiver at the 95% PoD level and the threshold power level of a single bitstream when using an isotropic polarization-aligned antenna. Fig. 3 shows the multiplexing efficiency obtained for the 2-port and 4-port modes, for different coverage pattern cones at different frequencies.

As can be seen, the MIMO multiplexing efficiency of the 2-port mode shows a considerable drop, i.e., more than 25dB at 2.2 GHz. Compare this to the much smaller variation of the MIMO multiplexing efficiency for the 4-port excited bowtie at the same frequency. This degradation in the center becomes less severe when the coverage apex angle decreases. It is worthwhile to note that the performance degradation would not have been as severe if a more directive antenna was used as reference. This cannot be seen from the graph, because we use the isotropic polarization-aligned antenna as a reference. On the other hand, if the reference had been an antenna with uniform coverage within the conical coverage region, we would have seen degradation in MIMO multiplexing efficiency for small angles too.

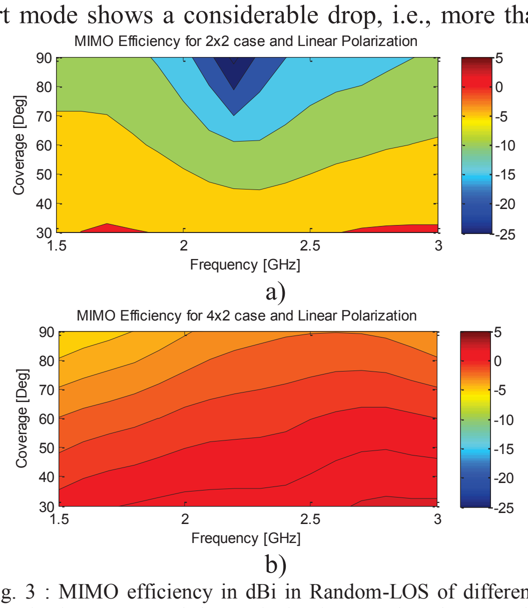

Fig. 3 : MIMO efficiency in dBi in Random-LOS of different conical coverage in degrees around the vertical axis normal to the ground plane of the antenna, versus frequencies for a) 2×2 and b) 4×2 case considering two orthogonal linear polarizations of the incoming waves.

C. *MIMO throughput coverage pattern*

The MIMO throughput coverage patterns are obtained as follows. For each AoA, we consider two incoming waves with fixed orthogonal linear polarizations (horizontal and vertical). Then, we evaluate the 4×2 or 2×2 MIMO channel matrices when these waves are received at four or two ports (differentially excited) of the bowtie antenna, respectively. Thereafter we use the ZF-algorithm to estimate the corresponding received power of each bitstream. The simulation is repeated for a uniform distribution of AoA within the hemisphere.

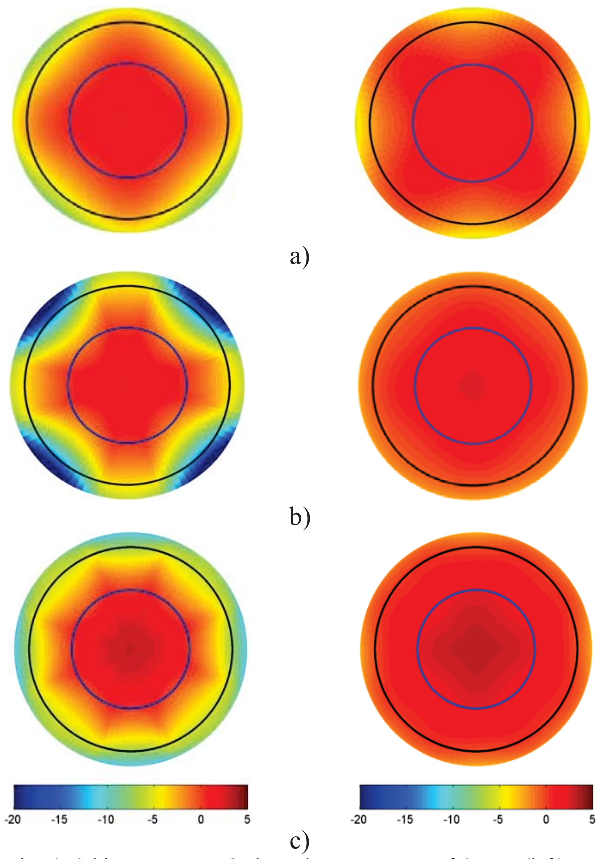

Fig. 4: 2-bitstream MIMO throughput coverage of 2-port (left) and 4-port (right) bow-tie antenna corresponding to two orthogonal linearly polarized incoming waves at various frequencies a) 1.7GHz b) 2.2GHz and c) 2.7GHz. The blue circles and the black circles correspond to the 60º and the 30º coverage cones, respectively.

The 2-bitstream MIMO throughput coverage of the individually excited 4-port mode and the differentially excited

2-port mode of the bowtie antenna are shown in Fig. 4. The black and blue circles indicate coverage cones of 60° and 30° polar angles, respectively. We see that for the 4-port bowtie antenna, the MIMO coverage is almost flat over the whole coverage hemispehere. Despite this, when the antenna is fed as a 2-port antenna, there are deep nulls in the coverage pattern at the middle of the frequency band at the edges of the coverage. Since these deficiencies of detections are mostly in the edge of the coverage, they will not be seen as a frequency variation in the MIMO multiplexing efficiency performance when the angular coverage decreases, as illustrated in Fig. 3 above. However, the whole curve will have bad efficiency compared to having two orthogonal ports with sector radiation patterns filling the desired coverage cones. To see this we would need to produce new coverage graphs using such 60° and 30° sector beams as references.

The reason for the appearance of nulls in the MIMO throughput coverage pattern of the differentially excited 2-port bowtie antenna can be mainly attributed to two factors: first, loss of orthogonality of the radiation patterns of the antenna ports for large AoAs, and second, less spatial (at certain directions) coverage of the radiation pattern of the antenna ports. For future work, we aim to verify the simulation results, i.e., the performance of the antenna will be evaluated in a Random-LOS measurement set-up that is currently being developed for automotive OTA tests [13], [14]. In addition, thanks to the identified performance degradation, the antenna design will be improved to exhibit better MIMO multiplexing performance at mid frequencies too.

IV. Conclusion

The performance of a self-grounded bowtie antenna in polarization-MIMO Random-LOS has been evaluated for 2- and 4-port operation modes of the antenna. A performance degradation of the differentially excited 2-port bowtie antenna was discovered in the middle of the band, thanks to the application of a new characterization method based on Probability of Detection curves. A degradation of about 25dBi in terms of MIMO multiplexing efficiency at the 95% PoD level was observed in the middle of the frequency band, which stands in contrast to the consistently good performance over the whole bandwidth of the individually excited 4-port bowtie antenna. The MIMO throughput coverage patterns have been instrumental in identifying the position of the degradation in certain spatial directions. It has been suggested that the performance degradation is the combined result of orthogonality loss and low directive gain values in the radiation pattern of the antenna at some parts of the desired coverage sector.

References

[1] D. Gesbert, M. Shafi, D.-S. Shiu, P. Smith and A. Naguib, “From theory to practice: An overview of MIMO space-time coded wireless systems,” IEEE J. Sel. Areas Commun. ,2003,21, (3), pp.281-302.

[2] P.-S. Kildal and K. Rosengren, “Correlation and capacity of MIMO systems and mutual coupling, radiation efficiency and diversity gain of their antennas: Simulations and measurements in reverberation chamber”, IEEE Communications Magazine, vol. 42, no. 12, pp. 102-112, Dec. 2004.

[3] P- S. Kildal, C. Orlenius, and J. Carlsson, ``OTA testing in multipath of antennas and wireless devices with MIMO and OFDM," *Proc. IEEE*, vol. 100, no. 7, pp. 2145_2157, Jul. 2012.

[4] 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.

[5] 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 ISAP 2013, Nanjing, China, Oct. 2013.

[6] P. -S. Kildal, U. Carlberg, and J. Carlsson, ``Definition of antenna diversity gain in user-distributed 3D-random line-of-sight," *J. Electromagn. Eng. Sci.*, vol. 13, no. 2, pp. 86_92, Jun. 2013.

[7] P.-S. Kildal, X. Chen, M. Gustafsson, Z. Shen, "MIMO Characterization on System Level of 5G Micro Base Stations Subject to Randomness in LOS", IEEE Access, Vol. 22, pp. 1062-1075, Sept. 18, 2014.

[8] H. Raza, A. Hussain, J. Yang, and P.-S. Kildal, ``Wideband compact 4-port dual polarized self-grounded bowtie antenna," *IEEE Trans. Antennas Propag.*, vol. 62, no. 9, pp. 4468_4473, Sep. 2014.

[9] S. Mansouri, J. Kvarnstrand, A.A. Glazunov, J. Yang and P.-S. Kildal, “Double Broadband Balun Structure Using CRLH TL for Differential Excitation of Dual-polarized Selfgrounded Bow-tie Antenna”, *Progress in Electromagnetic Research Symposium (PIERS),* Prague, July 2015

[10] U. Carlberg, J. Carlsson, A. Hussain, and P.-S. Kildal, ``Ray based multipath simulation tool for studying convergence and estimating ergodic capacity and diversity gain for antennas with given far-_eld functions," in *Proc. 20th Int. Conf. Appl. Electromagn. Commun. (ICECom)*, Dubrovnik, Kroatia, Sep. 2010, pp. 1_4.

[11] 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.

[12] P.-S. Kildal, *Foundations of Antenna Engineering: A unified Approach for Line-Of-Sight and Multipath*, Kildal Antenn AB, 2015, available at www.amazon.com and www.kildal.se.

[13] M. S. Kildal, J. Kvarnstrand, J. Carlsson, A. A. Glazunov, A. Majidzadeh and P.-S. Kildal, ” Initial Measured OTA Throughput of 4G LTE Communication to Cars with Roof-Mounted Antennas in 2D Random-LOS”, *ISAP* 2015(This proceedings), Hobart, Nov. 2015.

[14] 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 2015* (This proceedings), Hobart, Nov. 2015.