Reflectarray-based Intelligent Reflecting Surface to Improve mm-Wave 5G coverage in outdoor scenarios

Álvaro F. Vaquero(1), Eduardo Martinez-de-Rioja(2), Manuel Arrebola(1), Eduardo Carrasco(3), José A. Encinar(3), Safa Salman (4)and Maha Achour(4)

(1) Department of Electrical Engineering, Group of Signal Theory and Communications, Universidad de Oviedo, 33203, Gijón.
(2) Department of Signal Theory and Communications and Telematic Systems and Computing, Universidad Rey Juan Carlos, 28942 Fuenlabrada, Spain.
(3) Information Processing and Telecommunications Center, Universidad Politécnica de Madrid, 28040 Madrid, Spain.
(4) Metawave Corporation, Palo Alto, CA 94303, USA.

***Abstract*—This work presents the use of a reflectarray panel as an efficient and low-cost solution to improve millimeter-wave coverage in 5G scenarios. A dual-polarized shaped-beam is designed to radiate a flat-top beam to cover a blind zone without coverage. The design is carried out using a phase-only synthesis considering the beam specifications for the outdoor scenario. Then, a single-layer reflectarray element is used to perform a design at 27.7 GHz. This element provides an angularly-stable phase response at the operational frequency with an independent phase control in each linear polarization. The reflectarray panel shows a stable gain and a low both side-lobe level and cross-polarization within 1 GHz bandwidth.**

I. INTRODUCTION

The arrival of the Fifth Generation (5G) of mobile systems has sparked the use of millimeter-wave (mm-wave) spectrum to deliver high-speed wireless access in cellular networks. 5G mm-wave bands (mainly at 28, 39, and 60 GHz) aim to reach higher data rates, lower latency, and higher system capacities than the previous generation deployed at frequencies lower than 6 GHz (sub-6 GHz band). A major challenge of mm-wave communications is related to the signal propagation, which is more adverse than at the frequencies used within sub-6GHz communications. The propagation at mm-waves implies a significant increase of the path losses as well as larger penetration losses through obstacles, thus a higher sensitivity to physical barriers [1]. Throughout the last years, Intelligent Reflecting Surfaces (IRS) have been proposed to overcome both issues. An IRS is comprised of a planar arrangement of reflecting elements, which are designed to independently control the amplitude and/or phase of the reflected wave.

In this work, a reflectarray antenna is proposed as a low-cost alternative for passive IRS to improve wireless coverage for 5G mm-wave networks at 28 GHz. The IRS is presented to generate a shaped beam operating in dual polarization. The design is carried out using a phase-only synthesis aiming to concentrate the power received from the base station. The reflectarray is designed using a dipole-based element that provides independent control of both linear polarizations. The reflectarray shows a stable response within the band of 27.2 to 28.2 GHz, despite having high angles of incidence in the field provided by the base station.

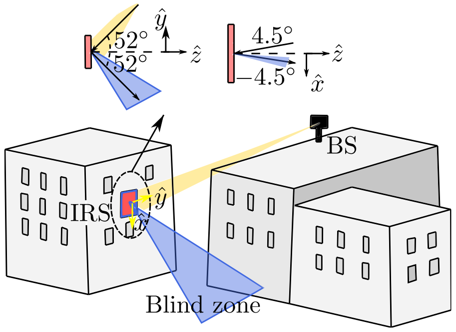


Figure 1. Sketch of an outdoor scenario with an IRS installed on the wall and illuminated from a FR2 5G base station (BS).

II. 5G MM-WAVE SCENARIO

The proposed reflectarray-based IRS is designed to be placed in an outdoor scenario to enhance the coverage within a blind zone, as the one shown in Fig. 1. The distance between the base station (BS) and the IRS is around 43.8 m with an angle of 52° and 4.5° in azimuth and elevation, respectively. The outgoing beam is reflected in the specular direction in azimuth and $-4.5°$ in elevation. Besides, the half-power beamwidth (HPBW) is 5.5° in azimuth and 1.5° in elevation. These specifications provide proper coverage within the blind zone. The IRS is comprised of 178×90 elements distributed in a regular grid of $5\,\text{mm} \times 4.1\,\text{mm}$, with an aperture size of $800\,\text{mm} \times 400\,\text{mm}$. The extremely large dimension between the BS and the IRS leads to an average value of the incidence angles of $\theta_i = 51.9°$ and $\varphi_i = 84.5°$, which implies a more complex design process.

III. IRS DESIGN AND VALIDATION

As a first approach, the phasing elements are designed to deflect the beam in a specific direction producing a pencil beam.

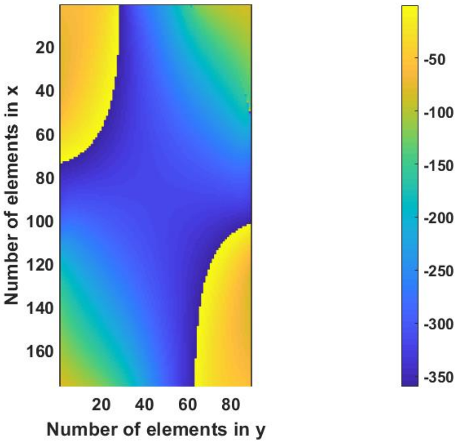


Figure 2. Phase distribution (in degrees) after the phase-only synthesis.

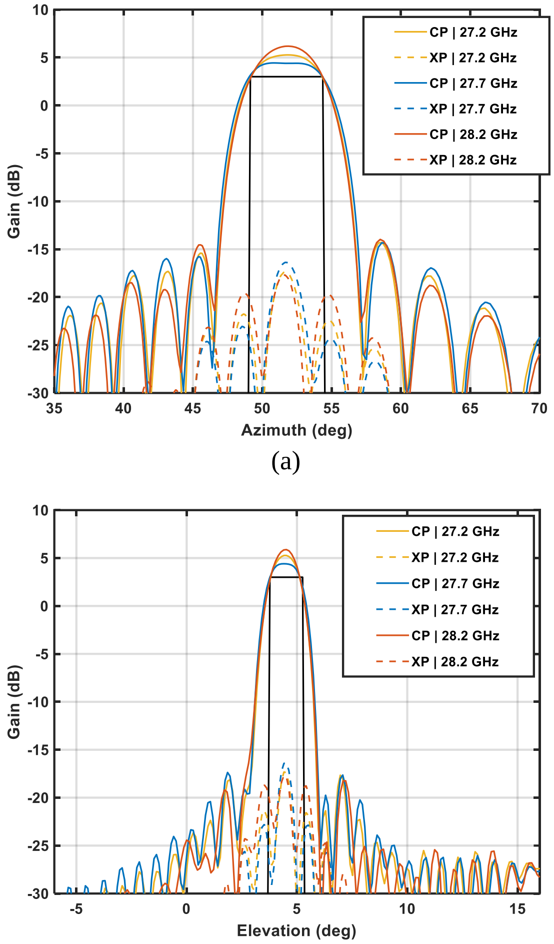
To collimate the beam in a direction (θ_a, φ_a), the phase-shift of the element can be computed as

$$\phi_{IRS}(x_m, y_n) = k_0(d_{BS} - (x_m \cos\varphi_a + y_n \sin\varphi_a) \sin\theta_a \tag{1}$$

where k_0 is the wave-number; d_{BS} is the distance from the BS to the (m, n)th element. In this case, (θ_a, φ_a) points to the center of the blind zone and the operational frequency is 27.7 GHz. Note that, the phase-shift of the IRS elements should be identical for both polarizations to ensure that the polarization of the reflected beam does not change.

The phase-shift obtained with (1) generates a beam with the highest gain in the desired direction. However, it presents a HPBW around 2° in azimuth and 0.7°, which is not wide enough to cover the blind zone. To enhance the beam performance a phase-only synthesis is carried out using the generalized Intersection Approach (IA) [2]. The synthesis aims to reach a flat-top beam with a maximum ripple limited to 3 dB. The HPBW is set to satisfy the coverage performance (5.5° in azimuth and 1.5° in elevation). After this process, the phasing element distribution of Fig. 2 is achieved, whose radiation pattern is shown in Fig. 3 (dotted line). Then, this phase distribution is used to carry out a design using an element based on dipoles [3].

The printed elements of the IRS are designed to provide the phase-shift distribution obtained with IA for each polarization. The design process is performed element-by-element adjusting the dipoles length to provide the required phase-shift in both polarizations. The radiation pattern of the resulting layout is analyzed by electromagnetic simulation, using an in-house code based on the Method of Moment (MoM) and local periodicity approach [3]. The azimuth and elevation cuts of the simulated radiation patterns in V and H polarizations are compared at 27.7 GHz, Fig. 3. As can be seen, the beam pointing (51° in azimuth and 18° in elevation) and the HPBW (5.5° in azimuth and 1.5° in elevation) are both compliant with the specifications. The cross-polar component is also analyzed, being 20 dB lower than the co-polar one within the region of the main lobe. Similar performances are found for both linear polarizations within a 1 GHz bandwidth.



(a)

(b)

Figure 3. Simulated radiation pattern in V-polarization at the central and extreme frequencies in (a) azimuth and (b) elevation, for the co-coplar (CP) and cross-copolar (XP) components.

ACKNOWLEDGMENT

The authors would like to thank Metawave Corporation for funding and leading the 5G KLONE Project. Also, the authors would like to thank the support received from the Spanish Ministry of Science and Innovation and the Spanish Research Agency within projects PID2020-114172RB-C21-2/AEI/10.13039/501100011033.

REFERENCES

[1] T.S. Rappaport, Y. Xing, G. R. MacCartney, A. F. Molisch, E. Mellios and J. Zhang, "Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks-With a Focus on Propagation Models," in *IEEE Transaction on Antennas and Propagation*, vol. 65, no. 12, pp. 6213-6230.

[2] D. R. Prado, J. A. López-Fernández, M. Arrebola, M. R. Pino and G. Goussetis, "General Framework for the Efficient Optimization of Reflectarray Antennas for Contoured Beam Space Applications," in *IEEE Access*, vol. 6, pp. 72295-72310, 2018..

[3] R. Florencio, R.R. Boix, E. Carrasco, J. A. Encinar, V. Losada, "Efficient numerical tool for the analysis and design of reflectarrays based on cells with three parallel dipoles," in *Microw. Opt. Technol. Lett.*, vol. 55, pp. 1212-1216, 2015.