Reconfigurable Antenna Arrays for Integrated Space and Terrestrial Networks

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Abstract – **Integrated space and terrestrial networks are expected to be a key technology beyond 5G communication systems. One main challenge posed for their antennas is the deteriorated array performance caused by elements' various orientations mounted to the conformal platform. To overcome this challenge, a reconfigurable antenna element that can switch between four linear polarizations is reported and applied in the conformal array. An efficient array synthesis algorithm is utilized to attain high-gain, low-sidelobe, and low-cross-polarization characteristics. A linear conformal array is presented to verify effectiveness of the developed algorithm.**

Keywords — **6G antennas, multi-linear polarizations, reconfigurable conformal antenna, space communication.**

I. INTRODUCTION

5G mobile and wireless systems are expected to have coverage requirements similar to earlier generations of terrestrial networks. In contrast, space-communication networks provide vast coverage for people and vehicles at sea and in the air, as well as in remote and rural areas. They are complementary to terrestrial networks. Clearly, future information networks must seamlessly integrate space networks with terrestrial networks to achieve significant advances beyond 5G. This integrated wireless ecosystem may become one of the most ambitious targets of 6G systems [1]. It is currently envisaged that 6G wireless systems will support truly global wireless communications, anywhere and anytime. An integrated space and terrestrial network (ISTN) is expected to be at the core of beyond 5G communication systems. As a consequence, the development of the technologies to achieve a high-capacity, yet low-cost ISTN is of significant importance to all of the emerging 6G wireless communication systems.

Currently, there are a number of commercial and government space-borne and airborne platforms that support various applications in communications and sensing. These include geostationary Earth orbit (GEO), medium Earth orbit (MEO), and low Earth orbit (LEO) satellites. As their names indicate, they operate at different altitudes relative to the Earth's center. Various airborne platforms also operate at different altitudes such as high altitude platforms (HAPs), airplanes, and unmanned aerial vehicles (UAVs, otherwise known as drones). It is anticipated that any eventual 6G and beyond mobile wireless communications networks will thus consist of three network layers, namely, the space network layer, the airborne network layer and the terrestrial network layer.

Airborne networks have a number of unique characteristics. First, most of their nodes would have multiple links to achieve network reliability, high capacity and low latency. Second, most of them will be mobile. Therefore, both their network links and topologies will vary with time, some faster than others. Third, the distances between any two adjacent nodes will vary significantly, from hundreds of meters to tens of kilometres. Fourth, the power supplied to any node would be limited. Consequently, as in the case for terrestrial networks, the energy efficiency of each node not only impacts the operation costs, but also the commercial viability of the entire network. Fifth, it is highly desirable for antennas on most airborne platforms to be conformal in order to meet their aerodynamic requirements and to maintain their mechanical integrity.

All of the noted, desirable ISTN features pose a number of significant and interesting challenges for future 6G antennas and antenna arrays. The antennas, for example, must be compact, conformal, and high gain. They must be reliable, light weight, and low cost. The corresponding arrays must have a high aperture efficiency and maintain a high quality communication link. One main challenge amongst all of them is arguably the deteriorated array performance caused by various orientations of array elements mounted to the conformal platform. One possible solution is to employ multi-linear polarization reconfigurable (MLPR) antenna element to alter and select its polarization states. A subsequent conformal array is then capable of achieving high gain with low sidelobe and cross-polarization (x-pol.) levels when the polarization state of each MLPR element is appropriately selected.

II. ANTENNA ELEMENT

Conventional linearly-polarized conformal antenna arrays are supposed to have low aperture efficiency and increased x-pol. levels. This arises from the changeable co-polarized component radiated by each element mounted on the conformal platform. It is thus highly desirable to have the polarization of the antenna elements reconfigurable.

Several techniques have been reported to facilitate reconfigurable multi-linear polarizations with broadside-beam patterns. Those include a centre-fed slotted patch antenna [2], a Balun-fed multi-dipole antenna [3], and a circular patch antenna with a switchable feed network [4]. One finds that those reported antenna elements are not suitable for conformal arrays, because of either large element dimensions [2], i.e., more than one wavelength, or exposed feeding/biasing networks printed on the element's bottom surface [3], [4].

A MLPR antenna that is reported in our previous work [5] can switch among four linear polarization states, i.e., along ϕ = 0°, 45°, 90°, and 135°. Its overlapped operating bandwidth is ranging from 2.30 to 2.55 GHz. The measured realized gain values are varied between 5.3 to 5.9 dBi. Antenna's dimension is around 0.57λ ×0.57λ×0.07λ at 2.45 GHz. Note that this antenna's compact configuration makes it attractive for conformal applications. Moreover, a solid ground plane that is printed at the antenna's bottom surface provides a metallic covering and eases antenna's integration. Nevertheless, this element must be modified in order for deployment in conformal arrays. First, antenna's radiating patch is optimized to prevent radiation deterioration arising from the curved conformal platform. Furthermore, an approach that can facilitate integration of electronic switching devices, i.e., PIN diodes, in conformal arrays will be reported.

III. RECONFIGURABLE CONFORMAL ANTENNA ARRAY

Fig. 1 shows an illustration of reconfigurable and conventional conformal antenna arrays. If one elects to employ conventional element that has a fixed linear polarization state, the radiated co-polarized component of each element is varied in a far-field observation point. As a consequence, the overall gain of the entire array will be reduced, and the sidelobe and x-pol. levels are increased. Thus, one needs to utilize the aforementioned MLPR antenna and select proper polarization state for each element in order to realize the maximum gain as well as low x-pol. levels for the conformal array, as noted in Fig. 1. Effective array synthesis algorithms are thus needed to facilitate the selection of each element's polarization states.

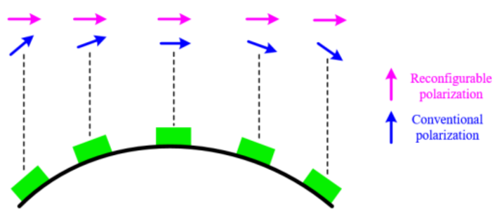

Fig. 1. Illustration of reconfigurable and conventional conformal antenna arrays.

A dynamic differential evolution algorithm was developed in [6] that co-optimizes the element rotation and excitation phase for a linear array. Sidelobe values and x-pol. levels were simultaneously controlled to reach the desired values for the shaped power patterns. This joint rotation/phase optimization was extended in [7] to synthesize planar arrays. Moreover, active element pattern and mutual coupling were included for providing a more generalized synthesis process. One example that has an 11×11 array with rotated cavity-backed patch antenna element respectively obtained the sidelobe and x-pol. values of −10.32 dB and −10.18 dB.

Note that element rotation technique used in the previously reported algorithms is equivalent to select the desired polarization states for each element. However, those algorithms are not directly applicable to conformal arrays. Several challenging issues are posed for synthesizing conformal arrays that use the MLPR elements. First, given the multiple polarization states for each element, the total number of the variable parameters in the array synthesis is increased extensively. This requires the synthesis algorithms to be efficient and capable of dealing with a very large number of variables. Furthermore, the conformal platform makes element's radiation features and mutual coupling more complex. An efficient and effective algorithm will be reported to overcome these challenges. As an illustration, a subsequent linear conformal array with the MLPR element will be investigated to demonstrate effectiveness of the developed algorithm.

IV. CONCLUSION

Beyond 5G mobile and wireless communications systems are expected to have an aerial layer of mobile nodes. The connectivity of these nodes require reconfigurable conformal antennas to achieve maximum aperture and energy efficiencies. In this paper, we discuss the requirements of these antennas, present our research on reconfigurable antenna elements and arrays for the intended applications.

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