Generation and Analysis of Orbital Angular Momentum Modes for 6G Rectangular Arrays

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Abstract

Due to their infinite sets of orthogonal modes, vortex beams carrying orbital angular momentum (OAM) have drawn much interest in developing high-capacity wireless communication systems. However, the practical applications of these OAM modes are limited due to the stringent requirement of Uniform Circular Arrays (UCAs) for generating OAM beams using planar surfaces. An efficient method of generating Orbital Angular Momentum (OAM) beams for different modes has been proposed and investigated for Uniform Rectangular Arrays (URA). A 4×4 patch antenna array is selected for beam generation and analysis. Results are shown from MATLAB and Computer Simulation Technology (CST) and compared with the beams generated by UCA. Promising results have shown that traditionally deployed URAs can efficiently generate OAM beam modes.

Ⅰ. Introduction

Massive throughput per device, varied usage scenarios, exceptional spectrum efficiency, and previously unheard-of traffic quantities define fifth-generation (5G) networks and beyond [1]. Numerous critical technologies are put forth to handle the 1,000-fold increase in wireless traffic, including communication in the higher spectrum (mm-wave and visible light) [2], ultra-dense networks [3], sparse code multiple access massive MIMO [3], and orbital angular momentum (OAM) multiplexing [4]. Numerous studies have shown that the orbital angular momentum (OAM) can give the electromagnetic (EM) field rotational degrees of freedom, which is helpful for new multiplexing applications.

The generation of orbital angular momentum (OAM) requires a uniform phase shift $e^{il\varphi}$ between the circularly located antenna elements. Here, l is an integer, referred to as the topological charge and φ is the azimuthal angle. The uniform circular array (UCA) has been found to be a perfect candidate for the generation of OAM beams. However, a uniform rectangular array is a typical form of a conventional antenna array. It has a well-developed theory and implementation techniques for use in real-world scenarios. Consequently, this paper aims to generate the OAM vortex beams using traditional uniform rectangular arrays.

In [4], the authors used Hankel transform to convert the desired far-field pattern into a near-field pattern to get the closed-form excitation weights for URA to generate the OAM beam modes. Most of the authors worked on the generation of OAM beams using a uniform circular array [3-4].

Ⅱ. Methodology

A 4×4 microstrip patch antenna is used for analysis and results simulations as shown in fig. 1. The operating frequency of each element is $2.45Ghz$. The inter-element spacing between the antenna array element along the x-axis d_x and the y-axis d_y is 0.5λ, where λ is the ratio of speed of light in a vacuum to the operating frequency. The eight circular elements in array as shown by the dashed circle having a different inter-element distance, referred to as imperfect UCA is considered. All distances are measured in mm unit. Based on the XY positions of patch antenna elements as shown in fig. 1, the steering matrix $\mathbf{V}$ is evaluated for each element $v(n,\theta_m,\phi_j)$ given as

$$v\left(n,\theta_m,\phi_j\right) = e^{-j\frac{2\pi}{\lambda}[x_n(sin\theta_m cos\phi_n)+y_n(sin\theta_m sin\phi_j)+z_n(cos\theta_m)]} \quad (1)$$

where x_n, y_n and z_n is the location of the n^{th} element in the array, $\theta_m \in \{\theta_1,\theta_2,\dots\theta_M\}$ is the elevation steering angle and $\phi_m \in \{\phi_1,\phi_2,\dots\phi_M\}$ is the azimuth angle points respectively. M and J are the total number of elevation and azimuth angle points respectively.

The array pattern $\mathbf{AP}$ matrix is evaluated as element wise product of $\mathbf{V}$ and matrix $\mathbf{P}$ formed by concatenating individual element pattern vectors, $\mathbf{AP} = \mathbf{V}\odot\mathbf{P}$.

The field pattern E can be written as:

$$\mathbf{E}(\theta_m, \phi_j) = \mathbf{AP\ w} \qquad (2)$$

where $\mathbf{w}$ is the excitation of the antenna elements.

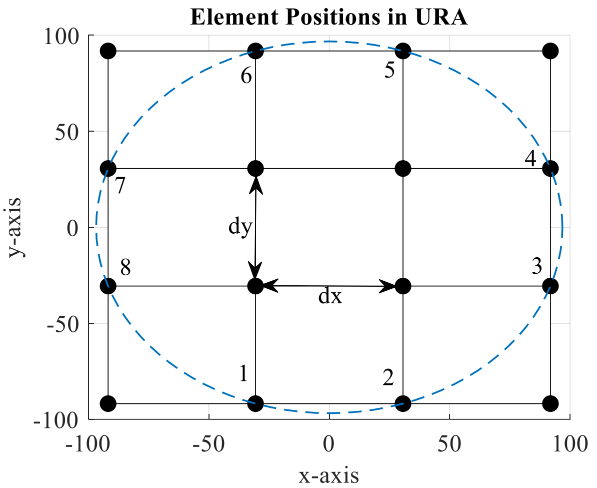

Figure 1: Positions of patch antenna elements in Imperfect UCA.

The distance between element 1 and 2 denoted by d_{12} is d_x, and the distance between element 2 and 3 denoted by d_{23} is found to be $\sqrt{2}d_x$ using the Pythagoras theorem as shown in equation 3.

$$d_{23} = \sqrt{{d_x}^2 + {d_y}^2} \qquad (3)$$

The phase of the excitation weights for mode M is found using the radia distance between the elements. The phase difference between elements 1 and 2 is calculated as shown in equation 4.

$$\gamma_{12} = M \times \frac{d_x}{4(d_x + \sqrt{2}d_x)} \times 360 \qquad (4)$$

Similarly, the phase difference between elements 2 and 3 will be calculated using equation 5.

$$\gamma_{23} = M \times \frac{\sqrt{2}d_x}{4(d_x + \sqrt{2}d_x)} \times 360 \qquad (5)$$

Using a similar strategy, one can find out all the phases of excitation weights. The phase and amplitude of excitation for OAM beam modes 1 and 2 are given in the following table.

Table 1: Excitation weights of Imperfect UCA for generation of OAM Mode 1 and 2

Element		1	2	3	4	5	6	7	8
Mode 1	Amplitude	0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.353
	Phase	0	37.2	90	127.2	180	217.2	270	307.2
Mode 2	Amplitude	0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.353
	Phase	0	74.5	180	254.5	360	217.2	434.5	614.4

Ⅲ. Results

The OAM vortex beam phase and intensity patterns of perfect UCA and imperfect UCA will be compared for different modes.

The perfect UCA having equal inter-element distance (0.5λ) and constant phase shift $(45°)$ between the adjacent elements is considered.

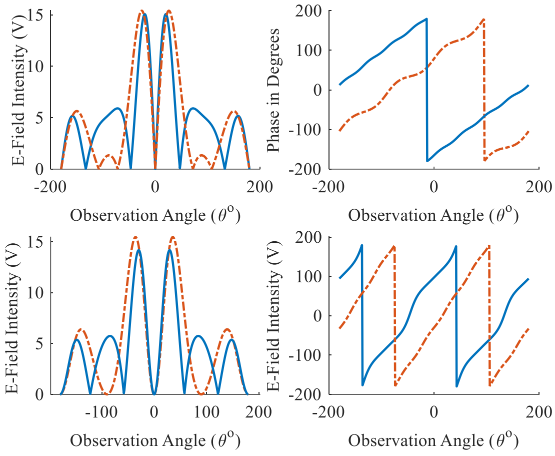

Figure 2: Intensity and phase patterns of OAM mode 1 and 2 for perfect and imperfect UCA.

In the fig. 2 solid line shows the patterns for perfect UCA and the dot-dashed pattern represents the imperfect UCA. One can observe that OAM modes can be generated perfectly using selected elements from the uniform rectangular array. A slight decrement in the intensity of perfect UCA is due to the radial distance. A wider beamwidth for an imperfect UCA is observed due to the large radius as compared to the perfect UCA.

IV. Conclusion

The orbital angular momentum vortex beam for different modes is generated perfectly using selected element from traditionally deployed uniform rectangular arrays.

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REFERENCES

[1] F. Mao, C. Ni, Z. Zhang, T. Li, C. Yang, and J. Zhang, "Massive OAM-MIMO transmission scheme for 5G networks and beyond," IET Communications, vol. 15, no. 7, pp. 973-979, 2021.

[2] W. Cheng, W. Zhang, H. Jing, S. Gao, and H. Zhang, "Orbital angular momentum for wireless communications," IEEE Wireless Communications, vol. 26, no. 1, pp. 100-107, 2018.

[3] M. Kamel, W. Hamouda, and A. Youssef, "Ultra-dense networks: A survey," IEEE Communications surveys & tutorials, vol. 18, no. 4, pp. 2522-2545, 2016.

[4] Y. Cho and W. Byun, "Analysis of a uniform rectangular array for generation of arbitrary orbital angular momentum (OAM) modes," Electronics Letters, vol. 55, no. 9, pp. 503-504, 2019.