Demo: Demonstration of Reconfigurable Metasurface for Wireless Communications

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***Abstract*—Various promising technologies for 5G wireless communication systems, such as massive multiple-input multiple-output (MIMO) have been deployed or are soon to be deployed around the globe. However, due to the high straight forwardness characteristic of ultra-high frequency range electromagnetic (EM) wave, the primary inevitable limitations are still existing. By adopting reconfigurable metasurface to ultra-high frequency range communication technologies, which are considered as a key technology for 5G communication network, we can overcome the tremendous amount of path loss and shaded communication areas. In this paper, we have developed a wireless communication system with 1-bit coding metasurface.**

Keywords—Wireless communications, coding metasurface, adaptive beam focusing

I. INTRODUCTION

28 GHz and other millimeter waveband communications which are introduced for 5G cellular communication, have advantages making good use of ultra-wideband spectrum instead of saturated microwave bandwidth [1]. Moreover, in the future, 6G communication technologies are expected to consider introducing higher terahertz wave bands. However, due to the high path loss, applications are very limited and commercialization has been delayed. The primary problems are inadequate for long distance communication and low transmission rates where line of sight is not maintained. Massive multi-input and multi-output (MIMO) system or hybrid beamforming is used as a way of compensating for path loss, but it still demands multiple RF-chain or phase-over deployments which the complexity and cost are greatly increased [2]. In this research project, we introduce metasurface technology to overcome the limitations of such millimeter waveband communications (Fig.1). Applying metasurface theory to communications enables beyond the existing limitations with very low cost. Metasurface can make large aperture which enables beamforming by controlling each unit cell as a simple control element, such as PCB pattern and PIN diode, and excludes the feed network. Furthermore, in the case of reflective metasurface, by converting the phase of incident electromagnetic (EM) waves of each cell, beamforming is capable to reflect EM waves in the desired direction. It means that by deploying metasurface reflectors near the shaded area, the problem of shading areas can be solved.

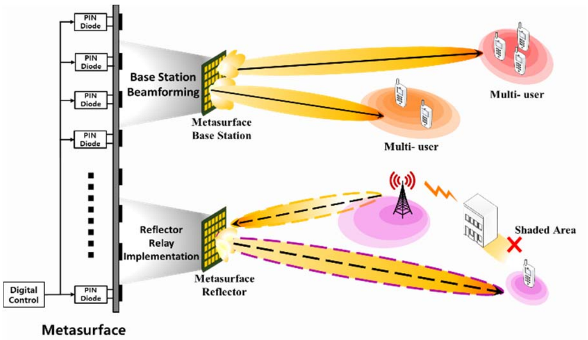

Fig. 1 Concept of wireless communication with 1-bit coding metasurface

II. SYSTEM MODEL

A. Reconfigurable Metasurface

We propose a 1-bit coding metasurface that enables dynamic beam focusing to the desired direction (Fig.2). Indeed, the proposed metasurface consists of 16 × 16 unit cells which are designed to operate at 5.8 GHz with two states (ON/OFF states) corresponding to a 0° or 180° phase shift of the reflected signal. The reflection phase of the unit cell has just two states: 0° or 180° corresponding to the coding "1" and coding "0", respectively.

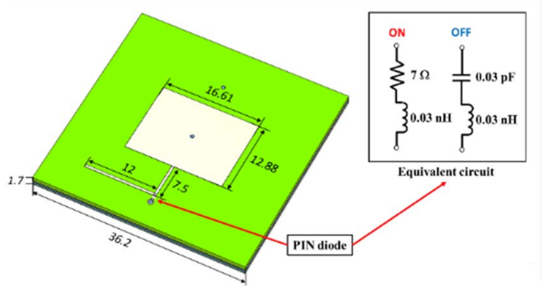

Fig. 2 Unit cell structure and dimension(mm)

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B. Adaptive Beam Steering Scheme

With the coding metasurface, we can focus the EM beam to a desired direction by conducting phase compensation and quantization. For adaptive beam focusing, we have to know the channel to obtain the optimal phase at the metasurface. To obtain the channel information, we used 256 independent ON/OFF patterns of the metasurface, which is based on the Hadamard matrix, as training pilots. After training, the optimal phase of each unit cell is obtained by taking the phase of the channel after being conjugated. However, only a limited phase shift can be provided with the coding unit cell. Then, it should be shifted to be in the range of $[0, 2\pi]$ before being quantized. Considering 1-bit coding unit cell, the shifted and quantized phase can be given as:

$$\phi_{mn}^{-} = \phi_{mn} - 2\pi\left[\frac{\phi_{mn}}{2\pi}\right], \qquad (1)$$

$$\phi_{mn}^{\wedge} = \begin{cases} \pi & \text{if } \pi/2 \leq \phi_{mn}^{-} \leq 3\pi/2 \\ 0 & \text{elsewhere} \end{cases} \qquad (2)$$

To demonstrate the focusing ability of the metasurface, we computed the ideal phase and quantized phase distribution of the 16×16 coding metasurface using the above phase compensation method and the corresponding beam pattern.

C. Communications Implementation

To transmit a signal to Tx antenna and verify the received signal, we used a USRP RIO and LabVIEW NXG, which are software-defined radio platform. The USRP RIO which covers the frequency from 10 MHz to 6 GHz, provides an integrated hardware and software solution for rapid prototyping high-performance wireless communication systems. Using LabVIEW NXG, we programmed the code to generate the signal, send the signal to a transmit antenna connected to USRP RIO, and analyze the received signal. Also, by analyzing the received signals, we can visually check the signal waveform and constellation.

III. EXPERIMENTAL RESULTS

In this demonstration, we transmit the OFDM signal, which is reflected and focused by the coding metasurface, to the receiver as shown in Fig.3. At the transmitter side, the feed horn is placed at 50 cm away and 30^0 with respect to the metasurface. Additionally, the receiving horn is located at a distance of 150 cm from the metasurface. Fig. 4 indicates the measured signal constellations with three different modulation schemes.

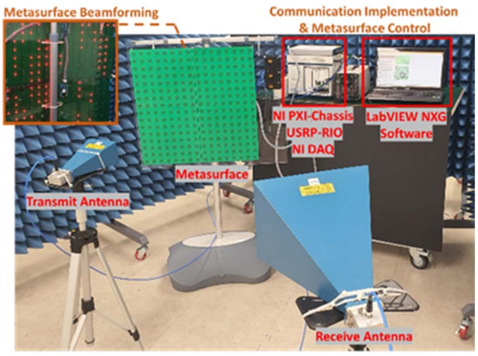

Fig. 3 Test environment

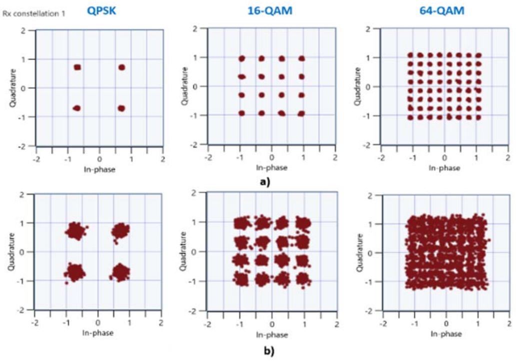

Fig. 4 Received signal constellations: a) at the focusing point; b) out of the focusing range

It is evident that with the help of the coding metasurface, better signal can be sent to the Rx.

For better understanding the effectiveness of the coding metasurface, we compare the received signal constellations when the coding metasurface is in active and inactive states in Fig. 5. It is clearly observed that in the case of inactive metasurface (Fig. 5b) the transmission error is higher compared to the active one (Fig. 5a).

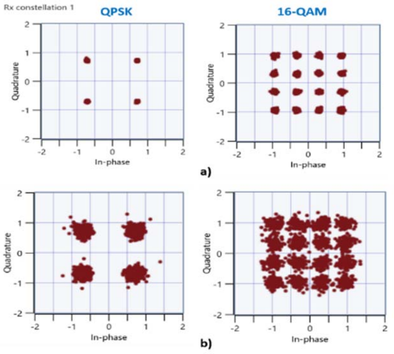

Fig. 5 Received signal constellations with the metasurface a) active; b) inactive

IV. CONCLUSION

In this paper, we proposed wireless communications based on 1-bit coding metasurface. We have built a prototype metasurface testbed for demonstrating the possibility of the communications between transmitter and receiver by using metasurface as a reflector. With 16×16 cells metasurface, we successfully reflected and focused OFDM signal to receive antenna. We expect that we can make good use of this research to a base station and reflector relay for mmWave communications.

ACKNOWLEDGMENT

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REFERENCES

[1] Wang, C. X., Haider, F., Gao, X., You, X. H., Yang, Y., Yuan, D., ... & Hepsaydir, E. (2014). Cellular architecture and key technologies for 5G wireless communication networks. *IEEE communications magazine*, *52*(2), 122-130.

[2] Gao, Z., Dai, L., Mi, D., Wang, Z., Imran, M. A., & Shakir, M. Z. (2015). MmWave massive-MIMO-based wireless backhaul for the 5G ultra-dense network. *IEEE Wireless Communications*, *22*(5), 13-21.