Shaping Smart Radio Environment through Reconfigurable Flexible Antennas for Beyond 6G

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Abstract

In the last decade, rapid wireless technology advancements have driven a surge in mobile data demand and connected devices. With 6G deployment offering high-quality, low-latency services, research has focused on meeting these demands. Recently, reconfigurable surfaces emerging as a promising solution for smart radio environments through their capabilities of manipulating electromagnetic waves. Thus, it leads to a paradigm shift from conventional antennas to flexible reconfigurable antennas where it can dynamically adjust its topology according to user location. This paper proposed a short survey related to emerging reconfigurable flexible antennas which appears as the strong candidate to enhance spectral efficiency. In addition, this paper focusses on the study of spectral efficiency enhancement for fluid antenna, movable antenna, pinching antenna, and pixel-based antenna.

I. Introduction

Considering standardization and commercialization in 5^{th} generation (5G) of wireless communications, now researchers, engineers, and executives from the academia industry have turned their attention to new candidate technology for the upcoming 6G communication. With the rising concept of reconfigurable intelligent surfaces (RIS) that can adapt based on incoming electromagnetic waves (EM), leads to a concept called smart radio environment [1]. On the other hand, a concept of smart radio environment enables low-cost deployment of wireless equipment which can adapt or dynamically adjust for different user purposes [2]. Hence, it causes a paradigm shift of designing antennas, from static topology to dynamic topology.

Several reconfigurable-based array antennas have been proposed to enhance spectral efficiency by dynamically adjusting surface, inter-antenna distance, or intentionally turned-off some of the elements. This paper proposes a short survey related to the existing structures of reconfigurable flexible antennas. This study discusses the benefits and practical perspective of appearances of flexible and reconfigurable antennas.

II. Fluid Antenna System (FAS)

Fluid antenna system proposed in [3], where the main purpose is to enhance signal diversity through port numbers (depicted in Figure 1). Consider N presets location with linear distribution, the displacement of k-th port is expressed as follows:

$$\Delta d_{k,1} = \left(\frac{k-1}{N-1}\right) W\lambda, \quad \text{for } k = 1, 2, \ldots, N \tag{1}$$

where W is the total length. Furthermore, the classical channel model is expressed as:

$$\begin{cases} g_1 = \sigma x_0 + j\sigma y_0 \\ g_k = \sigma\left(\sqrt{1-\mu_k^2}x_k + \mu_k x_0\right) + j\sigma\left(\sqrt{1-\mu_k^2}y_k + \mu_k y_0\right) \\ \quad \text{for } k = 2, \ldots, N, \end{cases} \tag{2}$$

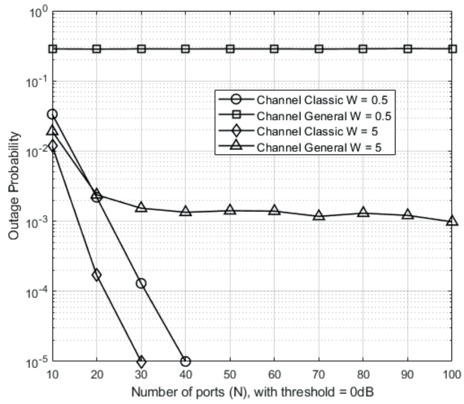

Figure 1. Performance evaluation of FAS-based transmission with various channel configurations.

, where it contains spatial correlations. Hence, the SNR is written as:

$$\Gamma = \sigma^2 \frac{\mathrm{E}[|\mathrm{x}|^2]}{\sigma_\eta^2} \tag{3}$$

In comparison, the generalized channel model for phase differences of arriving path is written as:

$$\begin{aligned} \phi_{g_k g_\ell}(\Delta d_{k,\ell}) &= \frac{\sigma^2}{2} J_0\left(2\pi \frac{\Delta d_{k,\ell}}{\lambda}\right) \\ &= \frac{\sigma^2}{2} J_0\left(\frac{2\pi(k-\ell)}{N-1} W\right). \end{aligned} \tag{4}$$

III. Pinching Antenna System (PAS)

Pinching antenna system proposed in [4], where a small dielectric particle is placed on the waveguide to smartly adjust EM wave for a certain user. In comparison with conventional antennas, a pinching mechanism ('Pin') reduces the total distance from BS. This is because in conventional transmission, the distance is calculated from BS to users. In pinching antenna system, the distance from BS and user can be extended by a waveguide and utilize pinching mechanism to direct EM-wave to user. The data-rate is expressed as follows:

$$R_{\rm sum}^{\rm Pin} = \frac{1}{M}\sum_{m=1}^{M}\mathcal{E}_{\psi_m}\left\{\log_2\left(1+\frac{\eta P_m}{|\psi_m^{\rm Pin}-\psi_m|^2\sigma^2}\right)\right\} \quad (5)$$

IV. Movable Antenna System (MAS)

Movable antenna system proposed in [5] and [6], where the BS can dynamically move the antennas based on user distribution. In general, the capacity of movable antenna system is written as:

$$C(\mathbf{q},\mathbf{u}) = \log_2\det\left(\mathbf{I}_{NB}+\frac{1}{\sigma^2}\sum_{k=1}^{K} p\mathbf{h}_k(\mathbf{q},\mathbf{u})\mathbf{h}_k(\mathbf{q},\mathbf{u})^H\right) \quad (6)$$

where it consist of the position and orientation of the antennas itself.

V. Conclusion

This study observes 3 different reconfigurable antenna systems which had a potential to be implemented in 6G and beyond. FAS enhances outage probability through port diversity, PAS enhances spectral efficiency by covering more users on the same frequency band, while MAS enhances data-rates by adjusting an array. In the perspective of deployment cost, PAS has the cheapest, since it takes simple pinching mechanics on waveguide. However, there are several limitations among these 3 reconfigurable flexible antennas, especially on use case scenario and backward compatibility. This is because primary base stations work with conventional UPA for MIMO-based transmission. Hence, it is meaningful to investigate the interference model between flexible antennas and conventional MIMO – with a proper strategy to eliminates it.

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