Dual-Antenna System Composed of Patch Array and Planar Yagi-Uda Array

Qiang Chen*, Shi-Wei Qu†, Jianfeng Li*, Lin Wang*, Qiaowei Yuan‡, and Kunio Sawaya*
*Tohoku University, Japan
†University of Electronic Science and Technology of China, China
‡Sendai National College of Technology, Japan

Abstract—**A dual-antenna system (DAS) is developed as a reflector to improve the propagation channel of wireless communications in a a non-line-of-sight (NLOS) environment. The DAS includes a folded-patch antenna array, a power transmission network, and a plannar Yagi-Uda antenna. A 4-element array of the dual-antenna is evaluated by numerical analysis and experiment to demonstrate the performance and effectiveness of the DAS array in improvement of the receiving signal noise ratio (SNR) and channel capacity in the MIMO communications under the NLOS environment.**

I. Introduction

It is a serious problem that radio wave from base stations of cellular mobile communications is blocked by high and large buildings in urban areas, especially in narrow streets, resulting in a very weak signal level and very poor communication quality. These areas are typically called blind spots. Many efforts have been made to eliminate the blind spots which may dramatically degrade the efficiency of data transmission between mobile users and base stations because of degrade of the receiving SNR. For a multi-input multi-output (MIMO) system, the channel capability may be greatly decreased due to the block of multipath.

Generally, the approach of using RF boosters is effective to eliminate these blind spots, but the cost is very high because electric devices with active conponents and power supplies are required. Moreover, installation of the heavy boosters is also a critical issue because quake-resistance regulations should be taken into account in areas with frequent earthquakes, especially in Japan. Therefore, a passive device with little weight and manufacting cost is generally desired from the practical and technological points of view.

A reflectarray which can reflect an incident wave to a specified direction is an effective tool to solve the problem of blind spots. The reflectarray has its advantages, such as surface mountable with low mass and volume, easily deployable, low manufacturing cost, scannable beam, and integratable with a solar array, etc [1]-[4]. It is considered to embed the reflectarray into the vertical building walls or to integrate them into firmly settled advertisement boards on the top of buildings. In this case, the reflectarray should scatter the normal incident wave from base stations on the top of buidings to the direction down to the street. Therefore, a very large scattering angle, almost 90° degrees, is expected. However, theoretically, it is very difficult to design a reflectarray with a very large scattering angle if the reflectarray has a planar structure.

In this research, a dual-antenna system (DAS) is developed to be used as a reflector instead of the reflectarray. The DAS is a passive device includes a folded-patch antenna array, a power transmission network, and a plannar Yagi-Uda antenna. The DAS has a broad scattering angle, and is caperble of polarization transition, and these features are required in solving the blind spots problem in urban area. A 4-element array of the dual-antenna is evaluated by numerical analysis and experiment to demonstrate the performance and effectiveness of the DAS array for improving the receiving SNR and channel capacity in MIMO communications under a non-line-of-sight (NLOS) environment.

II. Dual antenna system

Fig. 1 shows the geometry of the proposed DAS. The DAS is composed of a 4-element folded-patch antenna (FPA), the power divider/combiner, and a planar Yagi-Uda antenna. The FPA is built on the top side of the substrate, and its microstrip-line-based feeding network is etched on the bottom side, connected to the input port of the Yagi-Uda antenna. The electromagnetic waves incident from $+z$ direction is received by the FPA and then delivered to the Yagi-Uda antenna through the power divider/combiner and a microstrip transmission line for re-radiation. Feeding probes A, B, C, and D of the four patch elements are connected to four output ports of the power divider through four via holes on the ground plane. The total dimensions of one DAS unit are $110\times440\times20.8$ mm^3, in width, length and thickness, respectively. Practically, one can place this kind of unit as many as required along x direction or increase the number of patch elements on one unit in order to improve the gain. It should be noted that one of the critical techniques to improve the gain of DAS is the polarization transition in yz plane, i.e. from the θ-polarized incident waves to the ϕ-polarized re-radiated waves. Because of the thin substrate, a large aperture for re-radiation cannot be obtained if the re-radiated wave is still θ-polarized. Therefore, the polarization transition is necessary to increase the gain of the re-radiation beam.

The employed Yagi-Uda antenna is located in xy plane as shown in Fig. 2, and it has a driven element, two directors and a large corrugated ground plane as a reflector. The Yagi-Uda antenna is fed by a parallel stripline through a transition from a microstrip line. The ground plane is corrugated periodically to suppress the side lobes in H plane and consequently to improve antenna gain [7]. Its double-layered structure is designed on a substrate with a relative permittivity of 3.3 and thickness of 0.8 mm, currently available in our laboratory. The element in the FPA is identical to the designed geometry in [8] because of its compact size. There is a tradeoff between compact size and high gain, and if large antenna gain is in priority, other antennas with planar patches will be competent, i.e. patch antenna in [9].

The main advantage of this design over ordinary reflectarray [3] as a passive RF booster is its flexible beam control capability. The DAS proposed here is also different from the DAS given by [6] because the present design uses a planar Yagi-Uda antenna instead of the open waveguide for easy fabrication.

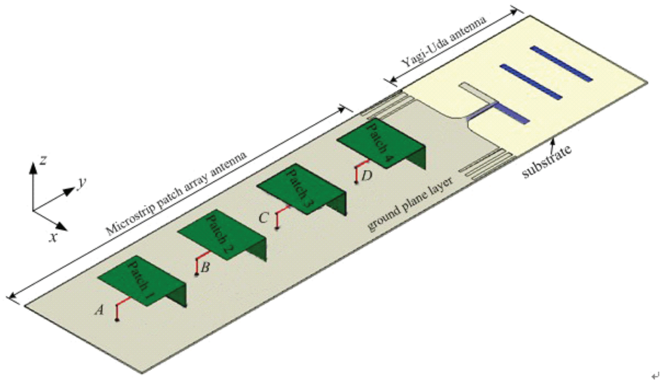

Fig. 1. Geometries of the proposed DAS composed of an FPA and a planar Yagi-Uda antenna.

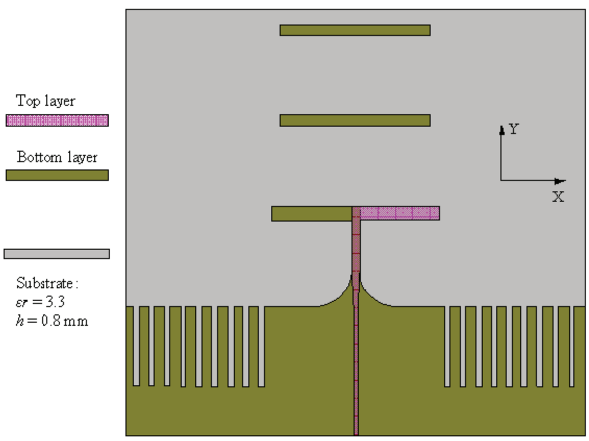

Fig. 2. Geometry of the planar Yagi-Uda antenna with corrugated ground plane.

The DAS is supposed to be used in an environment shown in Fig. 3. An equivalent bi-static radar cross section (BRCS) [5] is deduced to present a theoretical explanation to the operating principles of the DAS, as given in (1):

$$\sigma_{eq} = \frac{\lambda^2}{4\pi} G_1 G_2 \quad (1)$$

where G_1 and G_2 are the gains of two antennas in the proposed dual-antenna system. It is found that the performance of the DAS is dependent on the BRCS. In oder to increase the BRCS, the DAS array should be used. We have designed and fabricated a 4-unit DAS shown in Fig. 4. The performance of the 4-unit DAS is evaluated in the following.

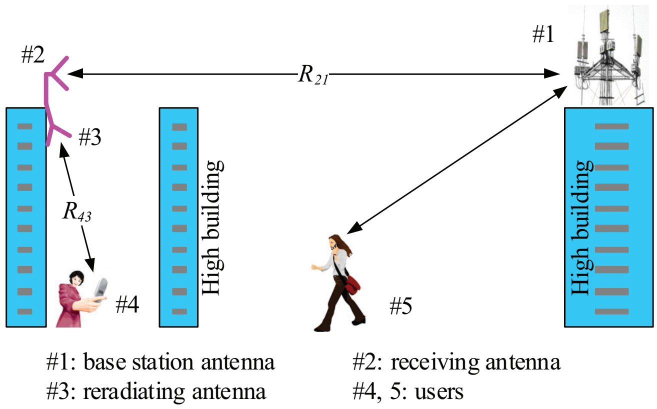

Fig. 3. Wireless communications in urban area.

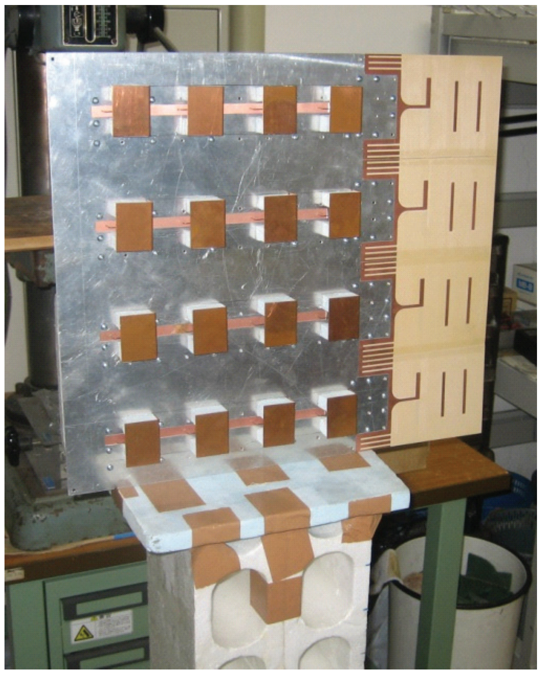

Fig. 4. A 4-unit DAS.

III. Numerical and Experimental Evaluation of DAS

The simulated equivalent BRCS of one unit of the proposed DAS in yz plane is shown in Fig. 5, compared to the BRCS of a metal plate with the same size, when plane waves are incident from $+z$ direction. The metal plate presents a symmetrical BRCS pattern and the value in θ = 90° is tending to zero, determined by how thin the metal plate is. For the proposed DAS, the forward scattering is over 10 dB smaller than the metal plate, indicating that the aperture efficiency of the FPA is quite good, but the scattering along $+y$ direction are over 10 dB larger as $75° \leq \theta \leq 105°$ ($\Phi = 90°$) with a maximum value of -8.1 dBsm, benefiting from the re-radiation of the planar Yagi-Uda antenna. Moreover, the scattering in the lower-right half plane is similar to that of the metal plate. Thus, the DAS can change the direction of incident to almost orthogonal direction while the traditional reflectarray or other planar structures cannot. Compared to the structure without corrugated ground plane, the maximum BRCS is improved by 1 dB along $+y$ direction. In order to increase the equivalent BRCS, a array was developed which consists of 4 units of the DAS side by side along x axis. A 14.5 dB improvement is obtained compared with that of the one unit, slightly larger than the theoretical value of 14 dB.

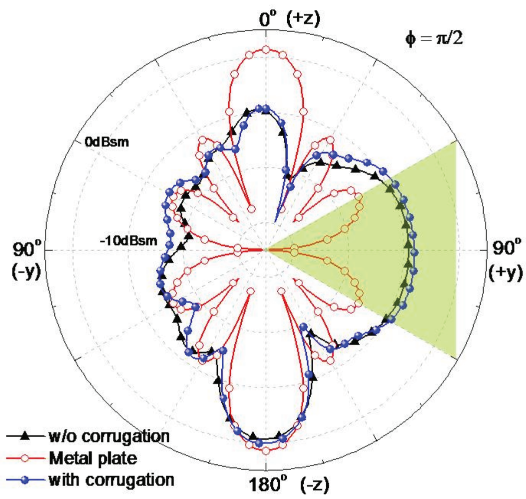

Fig. 5. Simulated BRCS of the one-unit DAS.

The application of DAS in MIMO communication system was measured to investigate if the DAS affects the propagation channel and improve quality of the communications in a NLOS environment. The measurement was carried out in an indoor area shown in Fig. 6. Two half-wavelength thin-wire dipole antennas are used for both the transmitting and receiving antennas to construct a 2×2 MIMO system. The transmitting antennas were horizontally mounted to transmit horizontal polarization wave, while the receiving antennas were vertically mounted to receive the vertical polarization wave. The array spacing of the transmitting antenna array is one wavelength, and that of the receiving antenna array is a half wavelength . The operation frequency is 2 GHz. The receiving antenna array was moved in a area of 0.5 m×0.5 m to measure the received power for each antenna at 441 points. The H-Matrix withe complex matrix elements for the

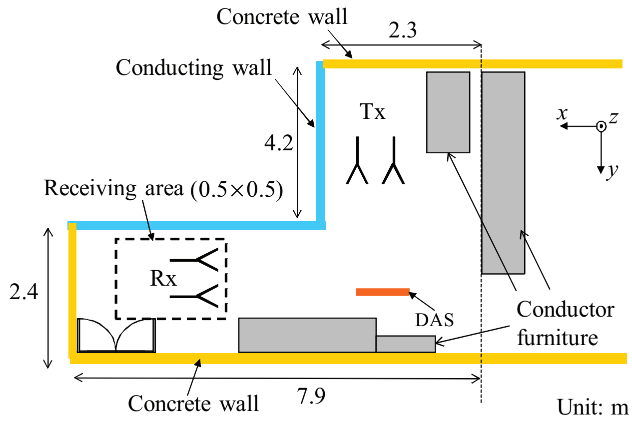

Fig. 6. MIMO measurement system.

2×2 MIMO antennas were measured by using a 2-port vector spectrum analyzer [10]. The output powerlever of the signal generators to feed the transmitting antenna array is -20 dBm for each antenna. The cumulative distribution function (CDF) of the received power is shown in Fig. 7. At CDF=0.1, about 3-5 dB improvement was obtained for the receiving power because of existence of the 4-unit DAS. When the received noise lever is supposed to be -120 dBm/Hz, the MIMO channel capacity can be calculated and the results are shown in Fig. 8. It is found that channel capacity is increased by 1.2 bps/Hz by using a 4-unit DAS as reflector in the propagation channel.

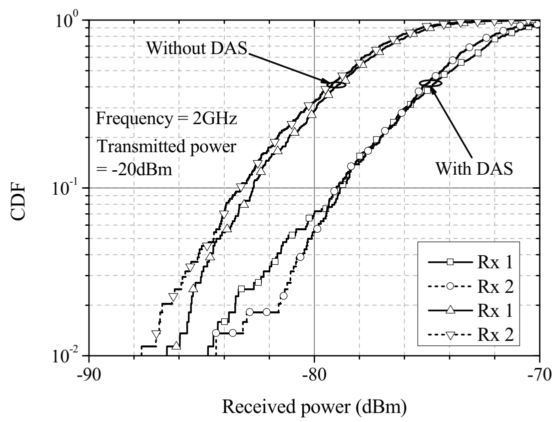

Fig. 7. CDF of the received power with and without 4-unit DAS.

IV. Conclusions

A new dual-antenna system (DAS) has been proposed and developed, which is composed of a folded-patch antenna array, a power transmission network, and a plannar Yagi-Uda antenna. A 4-element array of the DAS has been evaluated by numerical analysis and experiment to demonstrate the performance and effectiveness of the DAS array for improving the receiving SNR and channel capacity under a NLOS

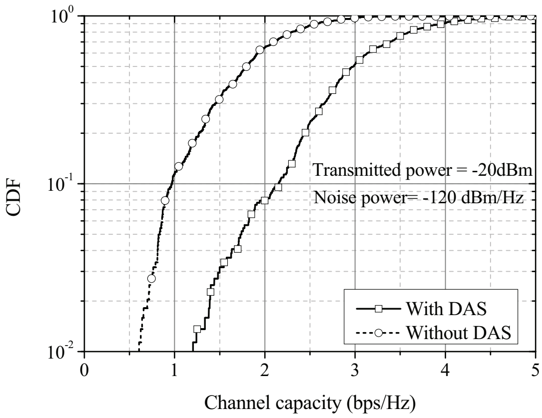

Fig. 8. CDF of the channel capacity with and without 4-unit DAS.

environment. It has been found that about 3-5 dB improvement was obtained for the receiving power and the channel capacity is increased by 1.2 bps/Hz due to the 4-unit DAS.

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