Experimental Study on MIMO Performance Using Passive Repeater

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Abstract: A passive repeater (PR), which comprises one 4-element folded-patch antenna (FPA) array, one planar Yagi-Uda array, and one power combiner, was fabricated to evaluate its performance in a multipath Multiple-Input Multiple-Output (MIMO) communication system experimentally. The received power and the MIMO channel capacity were extensively measured to illustrate the effectiveness of a 4-unit PR for improving the quality of communication channel in the MIMO environment. It was found that the medians of the received power of Rx1 and Rx2 are improved by about 14 dB, compared with those in other experiments without using the PR. When the received noise level is supposed to be -120 dBm/Hz, the median of the MIMO channel capacity can be increased by 6 bps/Hz as well.

key words: passive repeater, MIMO system, communication blindness

1. Introduction

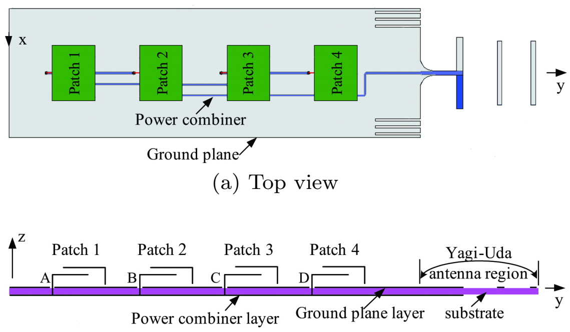
It is a severe problem that radio wave from base stations of cellular mobile systems is blocked by high and dense buildings in urban areas, especially in narrow streets, resulting in very weak signal level received by mobile terminals and poor communication quality. Many efforts have been made in order to eliminate the blind areas that will dramatically degrade the efficiency of data transmission between mobile users and base stations due to poor receiving signal noise ratio (SNR). Generally, if one of channels in a MIMO system is blocked, the total channel capacity may be reduced significantly. In cases where a direct microwave link cannot be established between two points (i.e., None-Line-of-Sight [NLOS] situations), it is possible to reconstruct the path by using a repeater. The primary function of such repeaters is to amplify and then relay the received EM signals so as to overcome or alleviate the blocking effects of various obstacles (e.g., buildings or mountains). Among them, passive repeaters (PR) are attractive candidates to be used in MIMO system due to their lower cost of manufacturing, operation, and maintainence compared with traditional active repeaters [1], [2].

Recently, Li *et al.* designed a broadband reflectarray antenna as a PR to remove the blind areas [3]. However, the aperture efficiency of the reflectarray is greatly degraded when a very large scattering angle is desired because of physical limitations of the reflectarray. In [4], although a dual-antenna system (DAS) composed of a patch antenna array and an open-ended waveguide was proposed to realize a large scattering angle, there still exist disadvantages such as bulky size, high cost, and low equivalent bi-static radar cross section (BRCS), etc. In [5], a quasi-planar DAS was proposed to solve these problems, but the authors only provided numerical analyses. However, it is also important to demonstrate the effectiveness and reliability of the proposed DAS when used in practical applications.

In this report, a quasi-planar PR, which consists of one 4-element FPA array, one planar Yagi-Uda array, and one power combiner, is designed and fabricated. Experiments in a multi-path environment are then carried out to demonstrate the improvements of channel quality when the PR is incorporated into MIMO systems.

In what follows, the basic configuration of the fabricated PR is presented in Section II. The detailed measurement setup in a MIMO environment is described in Section III. Experimental results are shown in Section IV, and the improvements of the communication quality due to the usage of the proposed PR are discussed as well. Finally, some concluding remarks are given in Section V.

2. Configuration of the PR



(a) Top view

(b) Side view

Figure 1: Configuration of one-unit PR.

Fig. 1 shows the configuration of one unit of the proposed PR. It comprises one 4-element FPA array, one planar Yagi-Uda array, and one power combiner. The element of the FPA array residing on the top substrate is chosen as the same as Set 1 in [6] due to its compact size. As is well known, there is a tradeoff between antenna's size and gain. Thus, if high gain is of primary concern in applications, other planar antenna types with slightly larger sizes can also be chosen to meet the requirement, such as the broadband patch antennas proposed in [7]. The adopted Yagi-Uda antenna has one driven element, two directors, and the ground plane acts as the reflector. The ground plane is corrugated periodically to suppress the side lobes in H plane, and the antenna gain can be enhanced effectively [8]. The power combiner is designed on the bottom substrate, connected to the driving port of the planar Yagi-Uda array. Feeding probes A, B, C, and D for the patch elements are connected to four input ports of the power combiner through the via holes through the ground plane. When the incident wave impinges the FPA array, the received EM signal is delivered to the Yagi-Uda antenna through a power combiner for

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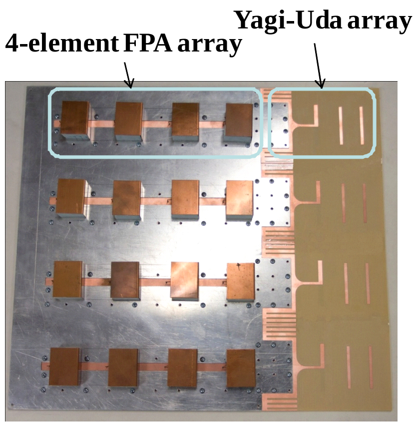
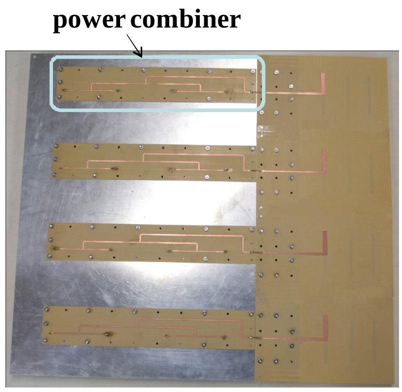
reradiating the signal with vertical polarization [5]. A 4-unit PR prototype is fabricated as shown in Fig. 2. In the design, the substrate with a thickness of 0.8 mm and relative permittivity 3.3 is utilized.



(a) Top layer



(b) Bottom layer

Figure 2: Photographs of the fabricated 4-unit PR.

3. MIMO measurement

A 2 × 2 MIMO system is constructed to demonstrate the effectiveness of the 4-unit PR for improving the quality of communication channel. The experiment is implemented in the second floor of a building with the concrete structure as shown in Fig. 3. It is seen that we have constructed a NLOS environment similar to the blind areas in urban cities as shown in [3], [5]. Two $\lambda/2$ dipole antenna arrays with 1.2λ array spacing are used as the transmitting antenna, and the transmitting signal is a continuous wave (CW) operating at 2 GHz. Agilent 89600S vector signal analyzer with two RF input channels are used to receive the signals from two $\lambda/2$ dipole antenna arrays with $\lambda/2$ array spacing. The location of transmitting antennas is fixed, while the receiving antenna is moved gradually by a step of 2.5 cm in a 50 cm × 50 cm square area. Therefore, measurement is repeated 21 × 21 times. Distance between the center of the 4-unit PR and that of receiving area, d_1, is 12.25 m. d_2, the distance between the center of the 4-unit PR and the transmitting antenna, is chosen to be 3.4 m. Ceiling height measured from floor is 2.42

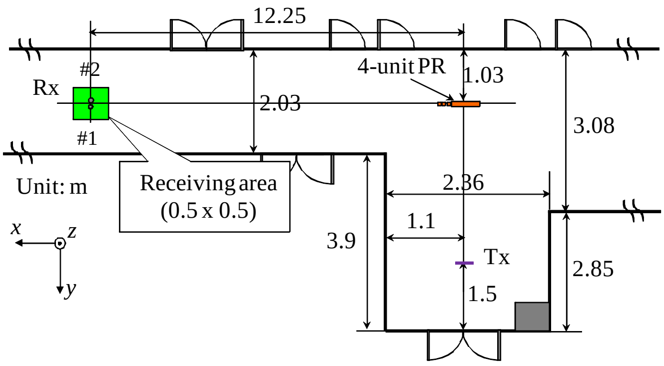


Figure 3: MIMO measurement environment.

m, while receiving antennas, the center of transmitting antennas, and the 4-unit PR are placed above the floor by the same height (1.21m). The transmitting antennas are fixed to radiate horizontally polarized signals, whereas the polarization directions of the receiving antennas vary from the vertical direction ($\theta = 0^o$) to the horizontal direction ($\theta = 90^o$) in the xoz plane as shown in Fig. 4 in order to investigate the effectiveness of the 4-unit PR for the practical applications.

4. Experimental results

441 experimental results are obtained for various polarization directions and they are further expressed in the form of cumulative distribution function (CDF).

Fig. 5 shows the CDF of the received power with/without the 4-unit PR for $\theta = 45^o$. The results of Rx1 and Rx2 are denoted by solid line and short dash line, respectively. It can be seen that when the 4-unit PR is used, the medians of the received power of Rx1 and Rx2 are improved by about 14 dB, compared with the results without using the PR. We also find that the gradients of the fading of the channels are a few different with and without the 4-unit PR. The reason is that the use of the 4-unit PR could produce more pronounced multi-path effects than that of the system lack of the 4-unit PR, due to the field distribution variation in an indoor environment. In other words, the introduction of the proposed PR can generate more uncorrelated signals and brings benefit for the communication system.

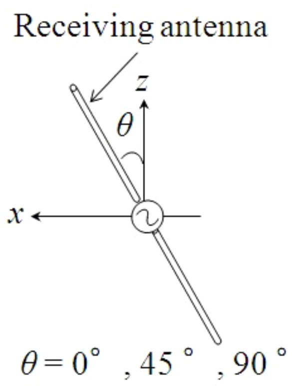


Figure 4: The polarization directions of the receiving antennas.

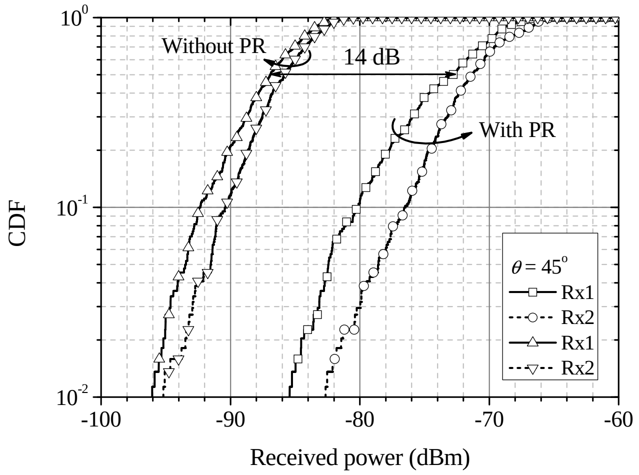


Figure 5: The CDF of the received power with/without 4-unit PR for $\theta = 45^o$ (received noise level=-120 dBm/Hz).

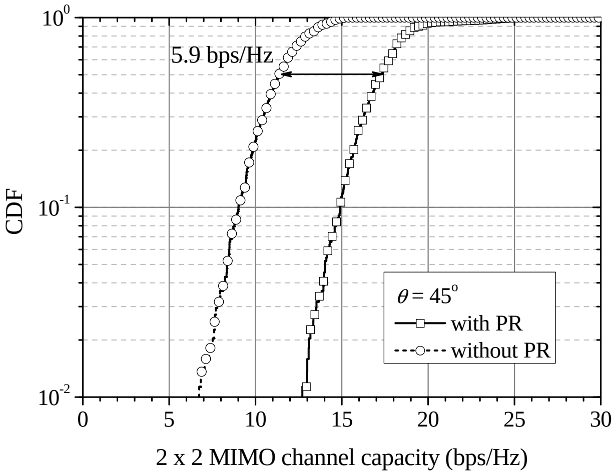


Figure 7: The CDF of the 2 × 2 MIMO channel capacity with/without 4-unit PR for $\theta = 45^o$ (received noise level=-110 dBm/Hz).

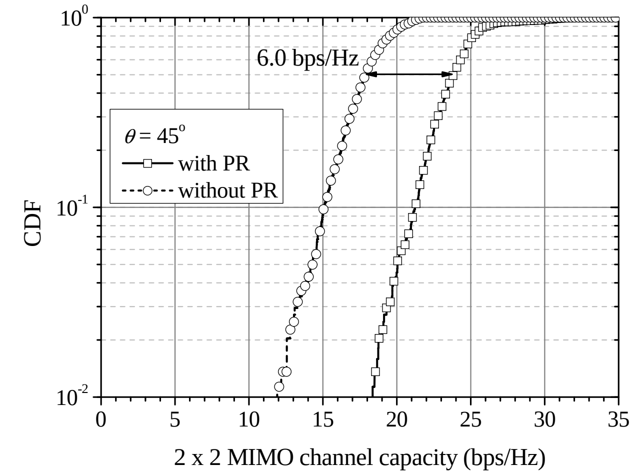


Figure 6: The CDF of the 2 × 2 MIMO channel capacity with/without 4-unit PR for $\theta = 45^o$ (received noise level=-120 dBm/Hz).

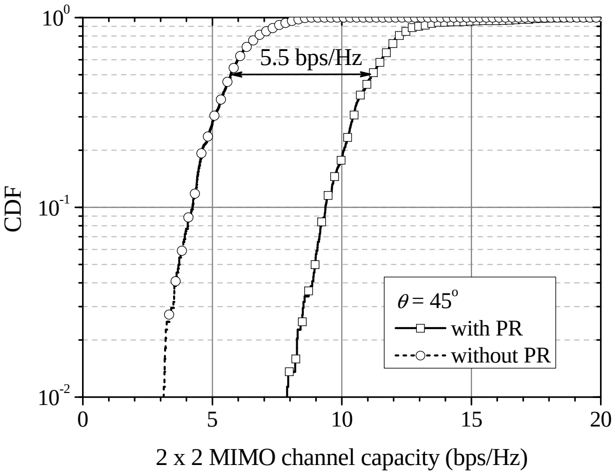


Figure 8: The CDF of the 2 × 2 MIMO channel capacity with/without 4-unit PR for $\theta = 45^o$ (received noise level=-100 dBm/Hz).

The channel capacity is also calculated for evaluating MIMO performance. Fig. 6 - Fig. 9 show the CDF of the 2 × 2 MIMO channel capacity with/without the 4-unit PR for $\theta = 45^o$ (received noise level=-90 dBm/Hz - -120 dBm/Hz with 10 dBm/Hz step). It can be found that when the received noise level is supposed to be -120 dBm/Hz, the median of the MIMO channel capacity with the 4-unit PR is increased by 6 bps/Hz comparing with that of lack of the 4-unit PR. Moreover, the gain of the MIMO channel capacity will decrease with increasing the received noise level.

Similar conclusions for other polarization directions can also be drawn. In the case of $\theta = 90^o$, the gain of the received power and the MIMO channel capacity is smaller than that of other cases because of the cross polarization problem. Furthermore, it is found that the gain of the MIMO channel capacity is decreasing nonlinearly with the reduced received power. The above experimental results demonstrate the effectiveness of the 4-unit PR for improving the channel quality in MIMO communications.

5. Conclusions

The 4-unit PR is fabricated to investigate experimentally the MIMO performance in multipath environments. Based on experimental results as obtained above, it is found that the received power and the MIMO channel capacity are improved clearly by using the 4-unit PR, which demonstrates the validity of the 4-unit PR for the practical applications to MIMO system. Furthermore, the gain of the MIMO channel capacity will decrease with increasing the received noise level. At CDF = 0.5 ($\theta = 45^o$), about 14 dB improvement is obtained for the received power due to the existence of the

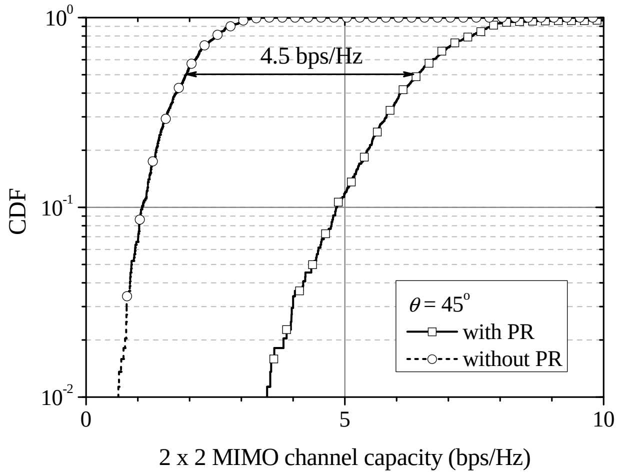


Figure 9: The CDF of the 2 × 2 MIMO channel capacity with/without 4-unit PR for $\theta = 45^o$ (received noise level=-90 dBm/Hz).

4-unit PR. When the received noise level is supposed to be -120 dBm/Hz, the median gain of the MIMO channel capacity is increased by 6 bps/Hz as well.

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