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Diversity Mechanisms and MIMO Throughput Performance of a Compact Six-Port Dielectric Resonator Antenna Array

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ABSTRACT: This paper demonstrates multiple-input-multiple-output (MIMO) throughput performance of a six-port dielectric resonator antenna (DRA) array for Wireless-LAN applications in a measured indoor office environment when a six-port dual-polarized patch array is used at the transmitter. The throughput was obtained using an IEEE802.11n/Draft 5.00 simulator for measured channels with different antenna and propagation setups. The throughput performance of the patch-DRA array set-up is found to be similar to that of a set-up with six-port monopole arrays at the receive and transmit ends in the non-line-of sight (NLOS) environment. The compact design of the DRA array causes lower port efficiencies relative to those of the monopole array, notwithstanding the compact DRA array is shown in this paper to effectively utilize angle, polarization and spatial diversity mechanisms to achieve comparable throughput performance.

INTRODUCTION

The demand for higher data rates in wireless communications is the driving force behind the adoption of multiple-input-multiple-output (MIMO) technology in current and upcoming wireless systems. However, the hyped potential of MIMO to provide a data rate that is directly proportional to the number of the antennas is conditioned on the state of the overall communication channel. In order for multiple antennas to offer the required degrees of freedom in a propagation environment and enhance performance, they need to provide sufficiently distinct spatial samples. Commonly, this is achieved by ensuring that the antennas are adequately spaced. Unfortunately, this approach is in conflict with the restrictive volume allocated for the antennas in today's terminals such as mobile phones, PC-cards and laptops. Likewise, compact designs are of interest for indoor (picocell) base stations and wireless access points. Thus, future multiple antenna solutions should effectively extract available degrees of freedom to alleviate the negative performance impacts of miniaturization.

The use of dielectric resonators has proved to be a promising approach for miniaturizing both single-port and multi-port antenna elements [1-5]. The innovative dielectric resonator antenna (DRA) solution for Wireless-LAN (WLAN) applications in [3] employs two modes of a dielectric cube in combination with an embedded monopole antenna to offer compact design. More importantly, the multi-port DRA also serves as an example of designing for low branch correlation through polarization and angle diversity, instead of spatial diversity. In [4], spatial diversity is further appended to the design in order to double the numbers of antenna ports to 6. Moreover, the work in [4-5] evaluates the effectiveness of the design in exploiting available degrees of freedom and the resulting effect on measured MIMO capacity in typical WLAN application scenarios.

This paper provides further insights into how the design of a compact six-port DRA array in [4] exploits different diversity mechanisms. Moreover, this paper presents and analyzes the MIMO throughput performance of the DRA array in a typical office environment using the DRA array at the receive (RX) terminal and an elevated dual-polarized patch array as the transmit (TX) array at the access point. As a comparison, MIMO throughput performance was evaluated for a RX and TX antenna array set-up of six-port monopole arrays exploiting only spatial domain in the same environment. The 6×6 MIMO channels are measured in line-of-sight (LOS) and non-line-of-sight (NLOS) office scenarios and used for throughput evaluation in a simulated WLAN system model, based on IEEE 802.11n draft 5.00 standard.

TX AND RX ANTENNA ARRAYS

All the arrays used in this study are tuned for 2.65 GHz, instead of 2.45 GHz, to avoid interference from existing WLAN systems during the measurement campaign, while maintaining similar propagation characteristics.

Compact six-port DRA array: The six-port DRA array comprises two three-port DRA elements placed as mirror images of each other around the center line of the longer side of a ground plane with size 100×80 mm². Detailed geometry of the array is provided in [4]. Each element comprises a rectangular dielectric resonator and a monopole

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antenna inserted in the middle of the dielectric block. The monopole antenna gives rise to one polarization while two more polarizations are excited in the dielectric block by means of two patch elements. The patch elements excite two fundamental transverse electric (TE-) modes which radiate like magnetic dipoles. The monopole radiation is orthogonal to the radiation modes of the dielectric resonator and does not couple to them due to its clever placement. The antenna efficiencies of the six ports of the DRA array are in range 65%.

Six-port dual-polarized patch array: The patch array in this study comprises six consecutive patch elements (three vertically and three horizontally polarized) within one horizontal row of a 4×8 uniform planar patch array [4]. All other ports were terminated with 50Ω . The array utilizes polarization diversity as well as spatial diversity, since adjacent elements are spaced by half a wavelength. The array elements in the measurement set-up were vertically oriented, in order to direct the radiation towards the RX end. The antenna efficiencies of the array elements are approximately 83%.

Six-port monopole arrays: Each monopole antenna array comprises six quarter-wavelength monopole antennas on a ground plane of size $460 \times 345 \text{ mm}^2$. The six antennas are spaced in a 2×3 formation with the adjacent antennas separated by one wavelength apart from one another, assuring good spatial diversity. The antenna efficiencies of the array elements are approximately 82%. The monopoles are linearly polarized. In this study, the RX and TX monopole arrays were orientated to extract and excite vertical polarization, respectively.

EVALUATION METHODS

To evaluate the diversity mechanisms, the radiation characteristics of the six-port DRA array and a reference six-port monopole array, were measured in an anechoic chamber using the Satimo Stargate 64 system [6].

In order to evaluate the 6×6 MIMO throughput performance of the antenna arrays set-ups, a system model of IEEE 802.11n draft 5.00 standard was created in Matlab [7]. The model comprises sets of encoding, modulation and MIMO schemes as specified in [8] and several receiver types (only MMSE receivers are considered in this paper). For each six-port array set-up and propagation scenario, all 76 specified combinations of the encoding, modulation and MIMO schemes were run for a range of SNRs and the best performing MIMO throughput at any given SNR was chosen. In this paper, throughput is defined as the error-free data rate that the system supports within the WLAN system bandwidth of 20 MHz. Further details on the system model can be found in [7].

The interactions of the antenna arrays with the propagation scenarios were incorporated into the simulator in form of 6×6 MIMO channel matrices. These were obtained through MIMO channel measurement with the RUSK LUND wideband channel sounder in an indoor environment in a typical furnished office [4]. The RX array in the channel measurements was placed at the height of an office table, whereas the TX array was elevated to the level of a wall mounted access point. Two propagation scenarios were measured: a LOS scenario, with a direct LOS path between the TX and RX arrays, both placed inside a large office, and a NLOS scenario, where the RX array is located inside the office and has no direct LOS path with the TX array, which is located in the corridor outside the office. The channel matrices were normalized to a common reference, in order to take into consideration differences in antenna gains. A detailed description of the measurement campaign can be found in [4].

DIVERSITY MECHANISMS AND MIMO THROUGHPUT PERFORMANCE

Fig. 1 shows the measured radiation and polarization behavior of the DRA array. Due to space constraint, only the three ports of one DRA element are represented. Since there is mirror symmetry in the six-port DRA array, the radiation and polarization performances of the three ports on the second DRA element are mirror reflections of the presented ones. The excited TE-modes in the dielectric resonator in Fig. 1 (a)-(b) have similar radiation pattern behavior in the elevation, with the main gain concentrated at $\theta = 25^\circ$. In the azimuth, however, the main gain is at $\phi = 160^\circ$ and $\phi = -160^\circ$, respectively. As a result, the excitation of the two modes enables angle diversity. Moreover, a more dominant diversity mechanism is observed in the polarization states of the two ports. The circles representing left and right hand circular polarizations (blue and red) in Fig. 1 (a)-(b) show that for each point in the radiation pattern the two modes excite orthogonal polarizations. Thus, polarization diversity is evident. Meanwhile, the monopole radiation pattern gives good coverage in elevation in the upper hemisphere, with the peak gain at around $\theta = 50^\circ$. In the azimuth, the monopole has a broad range of high gain and a peak gain at $\phi = \pm 180^\circ$. Since the solid angle of the monopole's peak gain is distinct from those of the TE-modes, the monopole pattern further reinforces the angle diversity in the setup. Additionally, the polarization states excited by the monopole are largely orthogonal to those of the TE-modes, which reinforce the DRA element's polarization diversity. Therefore, angle and polarization diversity is achieved across the three ports of one DRA element. The second DRA element, which is placed at half-wavelength spacing, extracts spatial diversity relative to the ports of the first DRA element. Moreover, the orientation of the two elements is intended to induce angle and polarization diversity between the ports in both DRA elements.

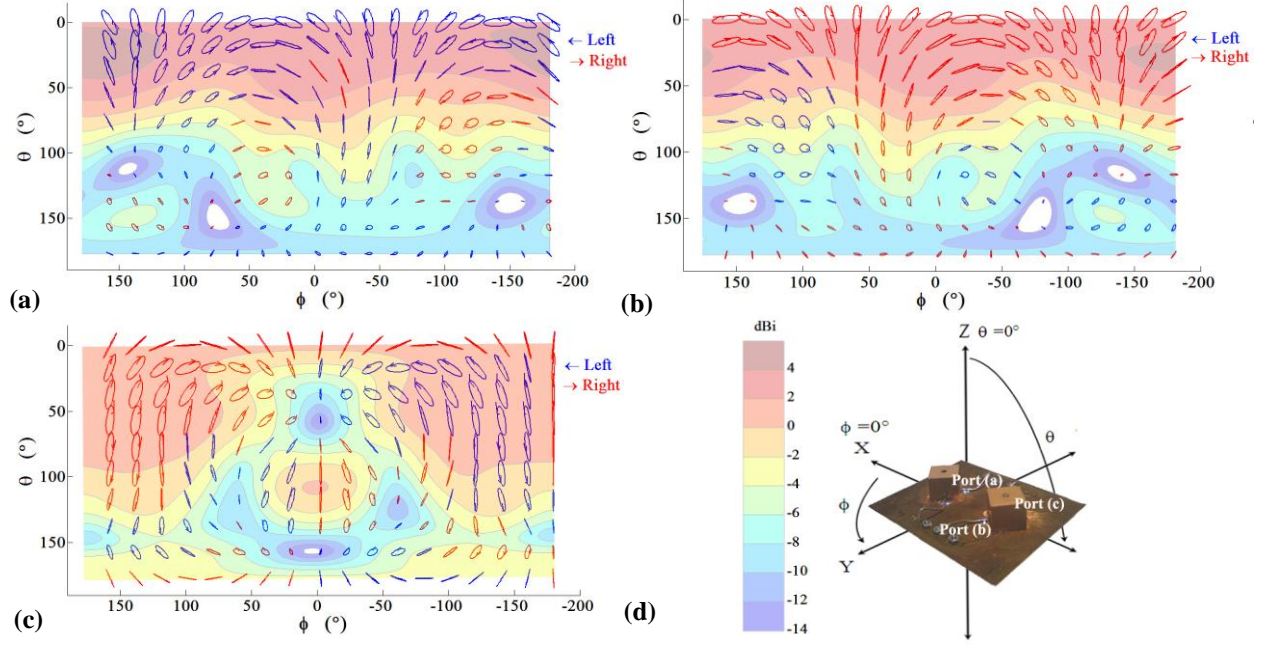


Fig. 1 2D presentation of 3D realized gain and polarization states (Left arrow = left hand circular polarization (LHCP), Right arrow = right hand circular polarization (RHCP)) at 2.65 GHz for the three ports in one DRA element of the six-port array; (a)-(b) patch ports and (c) monopole port (d) the gain scale and orientation of the DRA array in the coordinate system used in the radiation pattern measurements

In contrast, the measured radiation and polarization behavior of one of the elements of the six-port monopole array is shown in Fig. 2. The remaining elements share a similar performance, since there is low coupling between the adjacent elements (due to the large separations) and all antenna elements having the same minimum distance to the ground plane edges. The peak gain of the monopole is at $\theta = 60^\circ$ and is nearly omnidirectional in azimuth. It can be seen in Fig. 2 that only the vertical polarization is excited. Consequently, the array design does not enable either angle or polarization diversity. However, due to the spatial separation of the elements, spatial diversity is obtained.

Fig. 3 shows the throughput performance of the patch-DRA and monopole-monopole array set-ups for the LOS and NLOS cases. For the LOS environment and the patch-DRA array set-up, due to the dominant LOS path and small TX-RX separation, the angular spread and the polarization mixing in the strong propagation paths are both limited. This means that the scarcely altered transmitted dual polarizations are collected by the diverse DRA array ports. However, spatial and angle diversity are not fully exploited. For the monopole-monopole array set-up, the transmitted vertical polarization is effectively collected at the vertically polarized RX, and spatial diversity is utilized to an extent (especially since the *elevated* TX monopole array elements have no LOS path with the desk-level RX monopole array elements, which results in weaker dominant paths). It is, however, the better efficiencies of the monopole array ports than the DRA array ports at the RX that allow the collection of the more energy from the propagation paths. Consequently, the monopole-monopole array set-up performs slightly better than patch-DRA up to approximately 35 dB SNR (see Fig. 3). At higher SNRs, the monopole-monopole set-up more significantly outperforms the patch-DRA set up. This is however due to the lack of suitable encoding, modulation and MIMO schemes in the IEEE802.11n draft 5.00 standard for this specific set-up in the higher SNR range. This conjecture has been confirmed by an evaluation of capacity performance at high SNRs [7], since capacity does not depend on transmission schemes.

In NLOS, the multipath propagation induces significant cross polarization mixing and a broad angular spread at TX and RX ends. The multipath rich environment causes slightly improved performance in the NLOS compared to LOS for SNRs of up to 32 dB for both monopole-monopole and patch-DRA array set-ups. Moreover, in NLOS, the throughput performances of the two set-ups are practically the same. The propagation environment allows the DRA array at the RX to collect energy by exploiting all the diversity mechanisms. Despite the lower port efficiencies of the DRA array caused by miniaturization, the set-up facilitates as good throughput performance as the reference monopole-monopole array set-up where antenna port efficiencies are higher but only spatial diversity is exploited. The ability of the compact DRA array to exploit available degrees of freedom in both the LOS and NLOS indicates robustness in the array design.

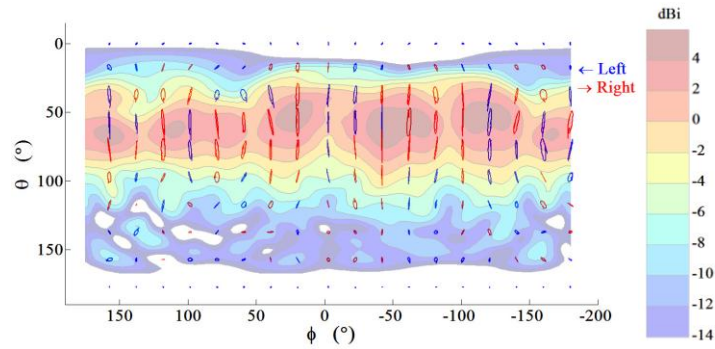


Fig. 2 2D presentation of 3D realized gain and polarization states at 2.65 GHz for one of the ports in one six-port monopole array

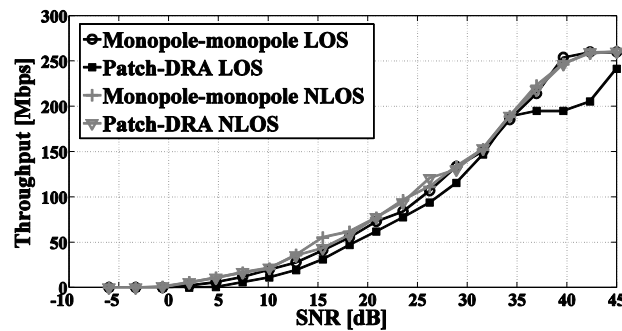


Fig. 3 Throughput performance of the patch-DRA and the monopole-monopole array set-ups for LOS and NLOS scenarios

CONCLUSIONS

In this contribution, throughput evaluations were performed for six port antenna arrays using measured channels in an IEEE802.11n/D 5.00 simulator. The results show that despite the negative impact of miniaturization on the efficiencies of the antenna elements in an array, the proposed compact six-port DRA array design can assure performance robustness by simultaneously enabling the diversity mechanisms of angle, polarization and spatial diversity. In NLOS, this ability enables a TX-RX set-up of patch-DRA arrays to provide similar throughput performance to that of a reference set-up of efficient monopole-monopole arrays that only utilizes spatial diversity. In LOS, the throughput of the patch-DRA array set-up is slightly lower than that of the reference set-up, due to lower DRA port efficiencies.

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