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Comparison of Co-located and Distributed MIMO for Indoor Wireless Communication

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***Abstract*—This paper compares the communication performance for co-located and emerging distributed MIMO in a typical indoor scenario. The simulations, which are verified against experimental measurement data, show that distributed MIMO offers a significantly more uniform capacity for the users. The results also show that the same user capacity can be achieved with half the number of antennas in the distributed MIMO case.**

Keywords—Distributed, MIMO, 5G, 6G, propagation, capacity

I. INTRODUCTION

New wireless communication systems are needed to cope with the exponentially growing of data in current networks. Fifth generation mobile communication networks exploit massive MIMO and beamforming techniques as key ingredients to increase the spectral density and thus capacity compared to previous network generations. Base-stations equipped with co-located antenna arrays enable simultaneous spatial multiplexing between multiple users through beamforming techniques to increase the spectral efficiency. It has been shown that, the co-location of the antennas introduces strong correlation between the antenna-user channels, which diminish the benefit of adding antennas. Looking ahead towards next generation 6G systems, distributed MIMO (D-MIMO) and cell-free wireless communication has therefore emerged as a candidate to address these weaknesses to cope with the inevitable need for increased capacity [1], see Fig. 1. In D-MIMO, multiple access points (APs) are connected to a central unit (CU). It is critical that the APs are carefully synchronized and phase coherent to facilitate the desired beamforming capabilities.

The theoretical benefits of distributed-MIMO and cell-free MIMO over conventional co-located MIMO (C-MIMO) and small non-cooperative base stations have been investigated extensively in the literature. A comparison between many non-co-operative small-cells and cell-free massive MIMO is presented in [2]. The practical challenges involved in realization of distributed MIMO systems have resulted in relatively few works devoted to systematic experimental studies of the benefits of C-MIMO vs. D-MIMO. The authors of [3] have performed a study using a multi-port vector-network analyzer acting as channel sounder, and also compared results with propagation simulations. Recently, there have been several studies where radio-over-fiber techniques have employed to realize flexible D-MIMO experiments, both at sub-6 GHz [4]–[6] and mm-wave bands [7].

In this work, we extend the initial experimental studies presented in [5] by ray-tracing based RF propagation simulations. By validating the simulations against existing measurements, new simulation-based studies are performed to further investigate the potential and differences between co-located and distributed MIMO for next generation wireless communication systems.

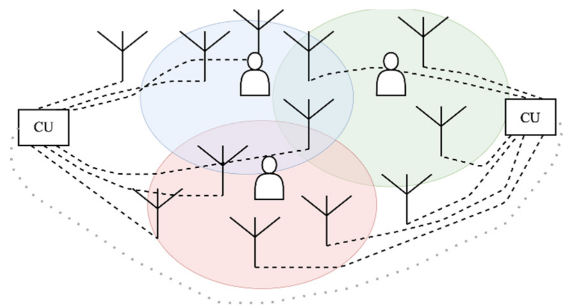


Fig. 1 Distributed MIMO antenna systems form the basis for realization of user centric cell-free massive MIMO communication systems [1]. Users are served by multiple carefully synchronized access points. The access points are served by central units (CUs).

II. EXPERIMENTAL SETUP

In this section we present the use case scenario where the subsequent studies will be performed. The experimental- and simulation setups are also introduced briefly.

A. Use case scenario

An in-door office environment has been used as a basis for the studies in this paper, see Fig. 2. The studies have been performed at an operating frequency of 2.35 GHz, considering 44 different user locations, as indicated in the figure.

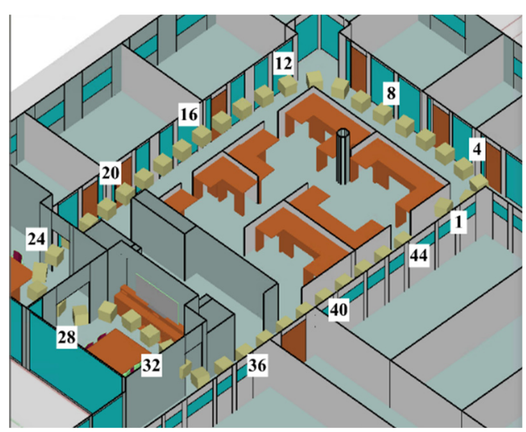
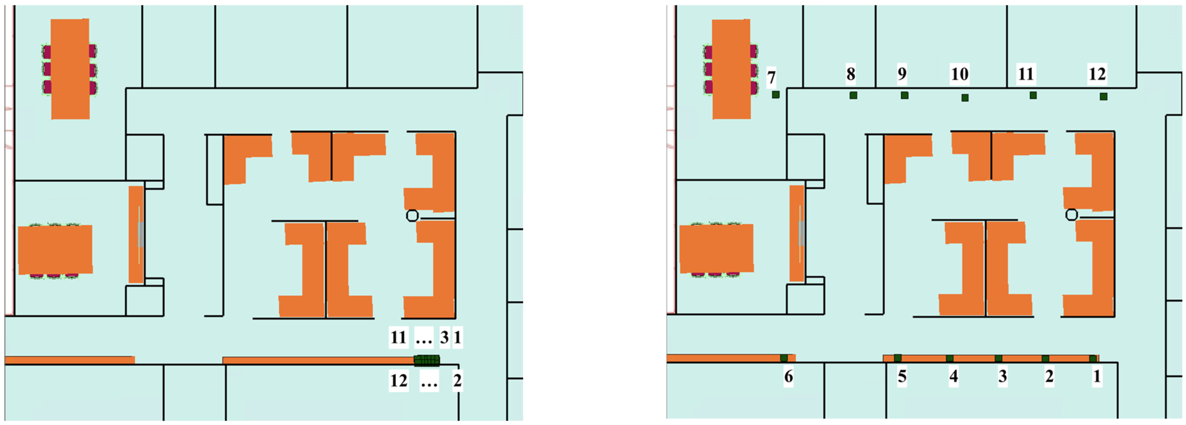


Fig. 2. In-door office enviroment used in this study. Performance will be predicted for 44 possible user positions, as indicated in the figure.



(a) Co-located MIMO (C-MIMO) antenna placement (b) Distributed MIMO (D-MIMO) antenna placement

Fig. 3. A MIMO transmitter system with 12 antennas placed in a) co-located and b) distributed MIMO configurations are considered in this study.

Two different antenna configurations have been considered in this environment, see Fig. 3. First, a co-located MIMO configuration is considered, where 12 antennas (APs) are placed at the same location. This configuration represents an active antenna installation representative of current 5G systems. Secondly, a distributed MIMO system is considered with APs placed around the periphery of the indoor office area.

B. *All-digital radio over fiber testbed*

MIMO channel and received power measurements have been performed at 44 positions in the environment above, using an automated and very flexible all-digital radio-over-fiber based testbed [5], see Fig. 4. The testbed facilitates flexible placement of to 12 access points, while maintaining excellent phase coherence. A detailed description of the testbed implementation is presented in [4]

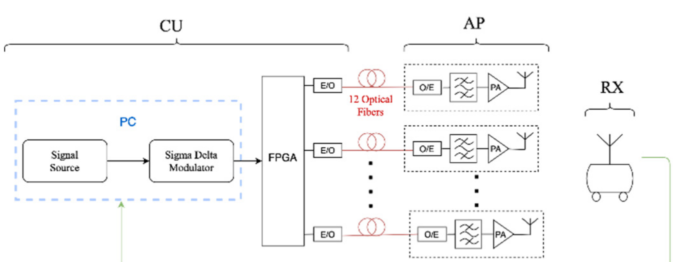


Fig. 4. All-digital radio-over-fiber testbed for D-MIMO measurements [5].

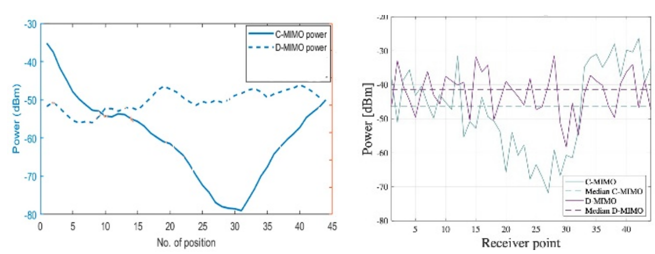
C. *Raytracing based RF propagation simulations*

The testbed measurements have been complemented with raytracing-based RF propagation simulations using the Remcom InSite software[1]. The simulations have been used to predict received power and channel matrixes between the 12 antennas and all 44 user locations. The simulations have considered default material parameters (loss, reflection coefficient, etc.) for the walls, ceiling, and floor in the environment. AP output powers and AP/receiver antennas have been selected to resemble the ones used in actual testbed measurements.

III. Results

A. *Experimental validation of simulation results*

The RF propagation simulations have been verified against measurements using the testbed described above. Fig. 5 compares the received power for co-located and distributed antenna placements. Although there is an offset of ca 10 dB in the absolute values, the results show a relatively good agreement. In particular, both results confirm the fact that the received power in D-MIMO is relatively independent of the user position. For C-MIMO, there is almost 40 dB difference between different user locations, with lowest power in the conference room (pos. 28-32). The good agreement gives confidence in using simulation based data for further studies.



(a) Measurements, from [5] (b) Simulations

Fig. 5. Comparison of received power at each of the 44 user positions, using a) testbed measurements and b) radio propagation simulations.

B. *Simulation based capacity studies*

The channel matrixes obtained from measurements and propagation simulations allow the MIMO sum capacity bound to be predicted [8]:

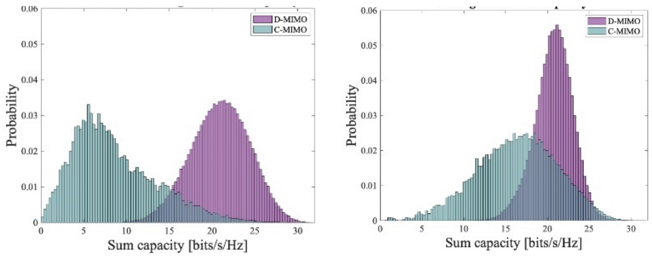
$$C_{\text{sum}} = \sum_{m=1}^{n_{\text{users}}} \log_2\left(1 + \sigma_m \frac{P_{\text{TX}}}{BN_0}\right) \text{ [bit/s/Hz]} \qquad (1)$$

where σ_m is the m'th singular value of the channel, P_{TX} is the transmit power (same from all APs), B is the bandwidth, and N_0 the noise power spectral density.

A scenario with four users randomly placed among the 44 locations is considered. The sum capacity is evaluated using (1)

[1] www.remcom.com

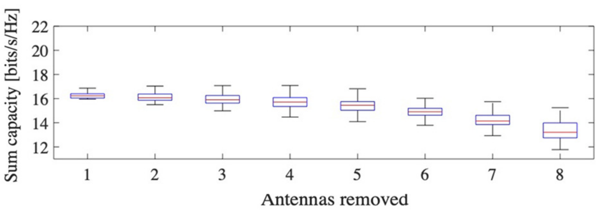
for each set of user positions, and depends on the specific user locations, and whether a C-MIMO or D-MIMO antenna configuration is considered, see Fig. 6. The results show that D-MIMO offers a more uniform and higher sum capacity than C-MIMO irrespective of the user locations. There is a good overall agreement in the behavior between measurements and simulations, although the simulations predict an overall higher capacity. This can be explained by uncertainties in material parameters and geometrical room definitions.



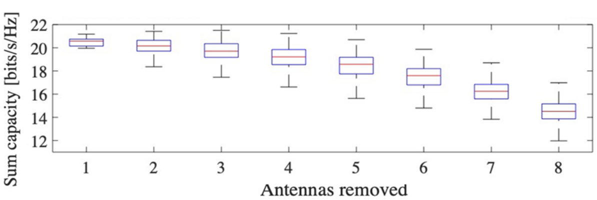
(a) Measurements, from [5] (b) Simulations

Fig. 6. Evaluation of MIMO sum capacity for four randomly placed users using a) testbed measurements and b) radio propagation simulations.

Significant energy savings can be realized if antennas can be removed without severely degrading the user capacity. The propagation simulations have therefore been used to investigate how the average system sum capacity for the same four-user setting as above is degraded if one or more of the 12 APs (antennas) are removed, see Fig. 7.



(a) Co-located MIMO system



(b) Distributed MIMO system

Fig. 7. Boxplots showing the spread of the average sum capacity if a random set of one to eight of the 12 APs (antennas) are removed from the a) co-located- and b) distributed MIMO systems, respectively.

The results in Fig. 7 show that the average sum capacity in C-MIMO remains at approximately 16 [bits/s/Hz] even if 5 of the 12 original antennas are removed. The performance for C-MIMO degrades relatively smooth as antennas are removed. The spread of the average capacity is relatively small, which indicates that it is not very critical which specific antennas that are removed. This result is expected as all antennas are co-located in the C-MIMO case. The D-MIMO capacity is significantly higher and remains higher than the fully equipped C-MIMO case even if 5 of the 12 antennas are removed. There is, however, a relatively larger spread of the capacity (taller boxes) depending on the choice of antennas removed. This is also expected in the distributed MIMO case, where each antenna tends to serve a certain area of the office environment well. In a real implementation, the spread can be reduced by intelligently choosing the active antennas depending on the user locations. Interestingly, with the same number of antennas as users (8 antennas removed in this case), co-located and distributed MIMO configurations show almost identical performance in terms of sum capacity.

IV. Conclusions

In this paper we have investigated the MIMO communication performance between a conventional co-located antenna configuration and a distributed antenna configuration in a typical indoor office deployment scenario. The capacity predictions made with a raytracing-based EM propagation software shows relatively good agreement with experimental data obtained with a flexible digital radio over fiber testbed. The results show that the D-MIMO system provides a significantly more uniform capacity, irrespective of the user placement. The results also show that almost 50% of the antennas can be disabled for reduction of energy consumption without a severe degradation of the sum capacity. Overall, the results give further support for D-MIMO as a strong candidate to improve capacity and quality of service in next generation wireless communication systems.

Acknowledgment

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