Optimization of the Antenna Mesh in an Indoor Distributed Massive MIMO System

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***Abstract*— Taking as reference channel data obtained by using a rigorous ray-tracing method for a concentrated multiple-input multiple-output system (C–mMIMO) in an indoor scenario, the objective of this work focuses on the optimization, among a mesh with potential locations, of the set antennas required in a distributed (D–mMIMO) system to meet the same channel requirements as those of the C–mMIMO one considered as reference. The optimization is carried out using a Dandelion optimizer, and the results presented at 26 GHz for the up-link show layouts with a reduction in the number of receiver antennas that depends on the number of users in the pico–cell.**

I. Introduction

Massive multiple-input multiple-output (mMIMO) technologies have become enabling technologies in the development of the services envisioned for present 5G and future 6G mobile communications systems [1]. In mMIMO channels with Q user terminals (UTs) and M antenna elements at the base station (BS), with M>>Q, the capacity increases as M increases. However, one of the drawbacks deals with the difficulty to group such a large array in a certain BS location. As an alternative to concentrated mMIMO (C–mMIMO), the idea of distributing a large number of antennas over a wide area, in such a way that the M-antennas array surrounds the Q UTs has led to the idea of distributed mMIMO (D–mMIMO) systems and has aroused the interest of researchers [2].

The authors have already shown in [3] using ray-tracing and focusing on the up-link (UL) that the distributed mMIMO channel clearly outperforms the concentrated one in terms of capacity under the same array size (M) at the BS. This work changes the focus presented in [3] and tries to analyse: 1) how many antennas and which, among a potential set spread over a mesh, are required to keep active in the distributed system to match the performance of the M-antennas C–mMIMO array, and 2) the influence of the number of active UTs on the number of antennas required in D–mMIMO to match the channel metrics of the C–mMIMO system. The antenna selection task is carried out using a binary version of a swarm intelligence bioinspired optimization algorithm, the Dandelion Optimizer (DO) [4], considering a cost function to be minimized that takes into account the differences in the cumulative distribution function (CDF) of both the spectral efficiency and the equality between the spectral efficiency of the users (fairness), as well as the number of active antennas required in the D–mMIMO system to equal the performance of the C–mMIMO one considered as reference and overall goal.

II. Antenna Selection using DO

Let us concentrate on the UL of a mMIMO indoor cell with Q active UTs and M elements at the BS antenna array, considering that orthogonal frequency-division multiplexing (OFDM) with N_f sub-carriers and that the channel matrix of order M×Q can be obtained from ray-tracing simulations [5]. Regardless of the mMIMO system, either concentrated or distributed, under different assumptions the individual and sum spectral efficiencies (*SE*) of the q-th user on the k-th sub-carrier can be calculated using (1) and (2), respectively; where *SINR* represents the signal to interference plus noise ratio [5].

$$SE_q[k] = \log_2\left(1 + SINR_q[k]\right) , \tag{1}$$

$$SE[k] = \sum_{q=1}^{Q} SE_q[k] . \tag{2}$$

Finally, a metric to quantify the fairness of the channel to share out the *SE*, the so called Jain`s fairness index (*JFI*) is also considered as given in (3), where $E\{\cdot\}$ is the mathematical expectation.

$$JFI = E\left\{\frac{\left(\sum_{q=1}^{Q} SE_q[k]\right)^2}{Q\sum_{q=1}^{Q} SE_q^2[k]}\right\} . \tag{3}$$

Considering a D-mMIMO system to be deployed with a certain mesh for the BS antenna locations, the role of the DO involves finding out the optimal set of active antennas (within that mesh topology) necessary to meet certain requirements in terms of channel achievable *SE* and *JFI*, making it necessary to promote solutions involving the lowest number of active antennas, contributing to the reduction of both complexity and power consumption of the network.

Concerning the optimizer, a DO that simulates the flight of dandelion seeds relying on wind, has been considered [4]. To link the DO and the problem at hand, let us consider a set of S seeds where each seed's position is a M-dimensional vector $\mathbf{X}_s=(x_1,\ldots, x_M)$, and every element in $\mathbf{X}_s$ take values 1 or 0 indicating that an antenna of the D-mMIMO must be 'on' or 'off', respectively. Iteratively, the position of a population of S seeds, randomly initialized, changes and explores the solution space considering three stages (rising, descending and landing) and the weather conditions, represented by several parameters and conditions, driving the search to a global optimal solution. At each iteration, the accuracy corresponding to each seed`s position, $\mathbf{X}_s$, is weighed using a fitness function. Taking as reference the CDF of *SE* and *JFI* computed for C–mMIMO (used as reference) and D–mMIMO systems (under $\mathbf{X}_s$ proposed layout), the fitness function proposed to be minimized and used to weigh up the error and the accuracy of each seed is given by:

$$F_s = 0.002 \left|\sum_{k=1}^{N_f}\left(SE_C[k] - SE_{D,s}[k]\right)\right| + \left|\sum_{k=1}^{N_f}\left(JFI_C[k] - JFI_{D,s}[k]\right)\right| + \sum_{m=1}^{M} x_m . \quad (4)$$

III. Results

The methodology proposed has been tested in the indoor environment presented in Fig. 1 [3], including details of the locations of the UTs, taken in groups of 5, 10, 15 and 20 UTs, i.e. UT_5, UT_{10}, UT_{15} and UT_{20}, to analyze the influence of the number of active UTs in the results. Details of both C– and D–mMIMO array locations are also included. The C–mMIMO array is a vertical square array consisting of 10×10 dipoles 0.536 λ uniformly spaced at 26 GHz; whereas the D–mMIMO mesh consists of 100 potential locations uniformly distributed in the building.

For the four UTs sets, the averaged convergence results of 10 independent runs of the DO-based method is shown in Fig. 2. Larger final residual errors for small UTs-sets are related to the higher number of antennas to keep active in D-mMIMO, influenced by the third summand in (4). However, this fact does not influence the accuracy of the results, as presented in Fig. 3, in which the D–mMIMO perfectly fits the CDFs of the C–mMIMO *SE* considered as reference. Basically, as the number of UTs increases, the macrodiversity and the decorrelation experienced by the channel matrix columns reduces the size of the mesh (the number of active antennas required), as shown in Fig. 4 for the UT10 case and summarized in Table I.

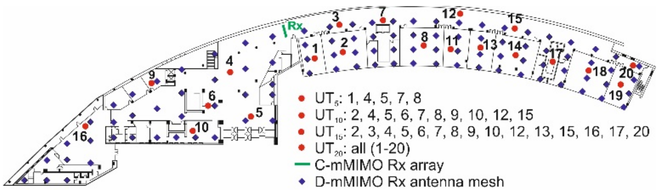

Figure 1. Top-view of the building floor considered, 183×50 m in size.

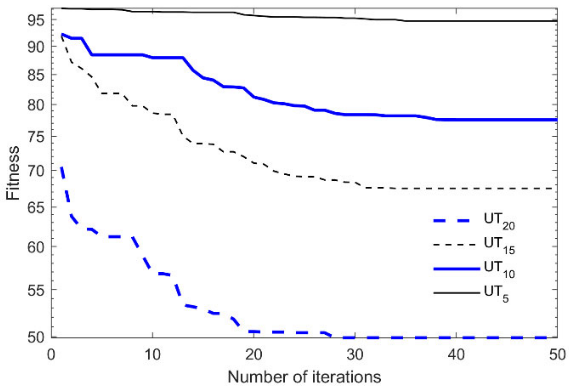

Figure 2. Fitness evolution when averaging 10 simulations for each case.

TABLE I. DO Results: Fitness and Size of The Mesh.

	UT_5	UT_{10}	UT_{15}	UT_{20}
F (average)	94.8	78.2	69.6	50.5
Antena mesh (min)	90	73	58	46

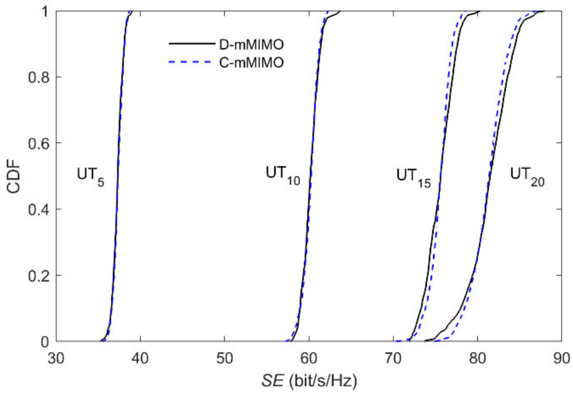

Figure 3. CDF of the sum *SE* for the UT-sets considered.

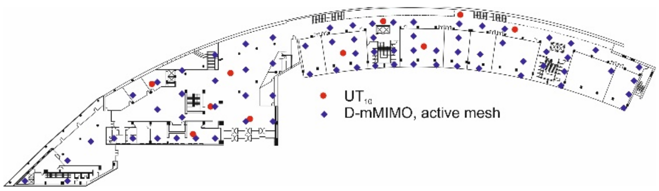

Figure 4. Optimized D-mMIMO mesh topology for UT_{10} (73 antennas).

IV. Conclusion

A methodology to optimize the mesh topology in a distributed mMIMO system taking as reference metrics such as the channel *SE* and fairness of a concentrated mMIMO system, has been presented. The channel raw data for both C– and D–mMIMO have been obtained at the 5G n258 band (26 GHz) using a ray-tracing tool, and a metaheuristic DO has been applied to find the set of antennas in the D–mMIMO mesh that best match the C–mMIMO channel performance. Results demonstrate the usefulness of the approach, showing that the size of the optimized D–mMIMO array is reduced as the number of active UTs in the cell increases.

Acknowledgment

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