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MU MIMO schemes assessment under realistic 3GPP 5G channel model

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Research context and motivation

- Over the past decade, the number of devices connected to the global network has skyrocketed, as have the number of services with increasing data requirements. To meet these new demands, the new standard for mobile networks, **5G**, identifies new advanced solutions to be adopted. One of the most promising is the transition from Multiple Input Multiple Output (MIMO) systems to **Massive MIMO** systems**.**
- Massive MIMO systems can be exploited to provide **Spatial Division Multiple Access (SDMA)**, sometimes referred as **Multi-User MIMO (MU MIMO)**, to serve multiple users in parallel. Very large **antenna arrays** are needed to successfully increase the number spatial channels, and they will become available through the new bands at higher frequencies (since shorter wavelengths require smaller antenna elements).
- However, the adoption of such range of frequencies, such as **millimeter Wave (mmWave)**, leads to new challenges for the signal propagation. Path attenuation, noise, interference, and atmospheric attenuation can hinder the communications.
- In order to analyze the performance of the network in such conditions, the use of new appropriate channel models must be considered because, unlike LTE, the assumption of 2D propagating waves is no longer valid: **3D channel models** are mandatory. 3GPP released its 3D stochastic channel model for 5G mmWave in the TR 38.901, for the range of frequencies 0.5–100 GHz.

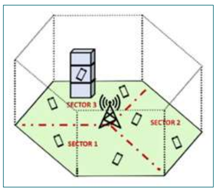

Fig.1 Simplified 5G cell site representation

Addressed research questions/problems

- For MU MIMO (Fig.2), proper precoding schemes at the transmitter side, and combining schemes at the receiver side, are exploited to orthogonalize the user channels. Different works studied and designed SDMA techniques, such as **Signal to Leakage Plus Noise Ratio (SLNR) precoding** and **Minimum Mean Square Error (MMSE) combining**, which are particularly interesting for their capabilities and limited complexity. However, no significant studies have been conducted on such techniques for 3D channel models (Fig.3), which better represent the new 5G mobile networks. New simulators are then required to analyze precoding and combining schemes in this scenarios.
- To efficiently exploit the richness of environments in which cellular networks are deployed, antenna arrays play a crucial role. Different shapes and arrangements of the elements are possible, which may lead to improvements in the overall system performance. Starting from the traditional **tri-sectorial cell**, in which each sector is equipped with a different **planar** (rectangular) **array**, it is interesting to analyze if their actual configuration can affect their capabilities to orthogonalize the user's channels and to increase the system spectral efficiency.
- A less common (and less studied) type of antenna array, i.e., the **cylindrical array**, can be investigated in order to determine if it may significantly improve the overall system performance. If so, a new way of conceiving the mobile network could arise, since the cylindrical array would not need the division of the cell into three different sectors.

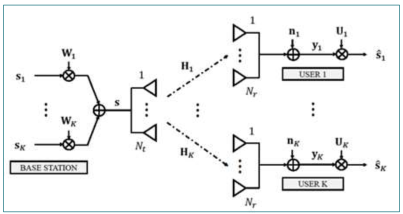

Fig.2 Schematic representation of MU MIMO scenario

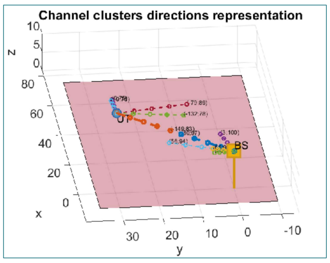

Fig.3 Representation of multipath signal clusters in a 3D channel model

Submitted and published works

- Riviello, D. G., Di Stasio, F., and Tuninato, R., "*Performance Analysis of Multi-User MIMO Schemes under Realistic 3GPP 3-D Channel Model for 5G mmWave Cellular Networks*", Electronics, Vol 11, no 3: 330, 2022.
- Riviello, D. G., Tuninato, R., and Garello, R., "Assessment of MU-MIMO schemes with cylindrical arrays under 3GPP 3D channel model for B5G networks", IEEE Consumer Communications & Networking Conference, Las Vegas, 2023.

Novel contributions

- Translation of the 3GPP TR 38.901 into an actual MATLAB simulator, providing a step-by-step tutorial (https://gitlab.com/daniel.riviello/3gpp-channelmodel-tr-38901).
- Performance analysis of MU MIMO with precoding and combining schemes for a Base Station equipped with large antenna arrays, in mmWave, to identify the best array configurations, the load of users that could be handled (Fig. 4), etc.
- Collected results showed the possible advantages of adopting cylindrical arrays in 5G cells when SDMA is adopted (Fig. 5).

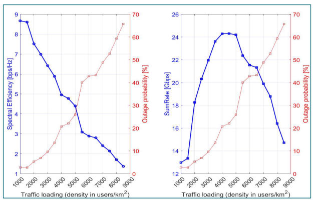

Fig.4 Performance for different users traffic density

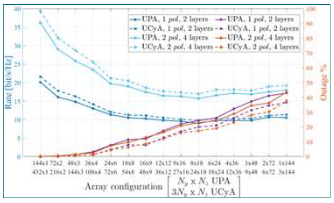

Fig.5 Uniform Planar (UPA) vs Cylindrical (UCyA) arrays

Adopted methodologies

- 3GPP Channel model (TR 38.901) study and implementation in MATLAB. Example of random positioning of the user on the cellular site in Fig.6 and channel generation in Fig.7.
- Precoding and combining techniques selection and implementation, to perform multi layer MU MIMO on the channel matrices generated by the channel model simulator.
- Validation of the entire simulator with simplified scenarios (e.g., single user in LOS).
- Definition, with the aid of TIM engineers, of realistic and interesting scenarios and parameters for the actual system simulation.
- Performance analysis and comparisons of the data (user rates and SINRs) acquired from the simulations.
- Ad-hoc functions to implement cylindrical arrays as an alternative to common planar arrays. Additional performance analysis for such antenna arrays and comparisons with planar antenna arrays.

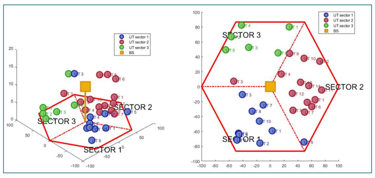

Fig.6 An example of simulator users' generation and assignment to the different sectors

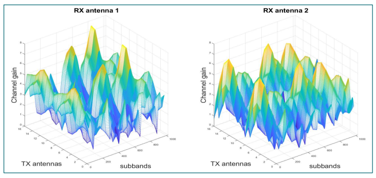

Fig.7 User channel response for different antennas

Future work

- Large antenna arrays permit to serve in parallel many users (in the order of the antenna elements). Anyway, **spatial correlation** among users can disrupt the connectivity or at least deteriorate the users rates. For this reason, proper **user scheduling and grouping** should be implemented to improve the performance and robustness of the network.
- At the moment the simulator allows only a single cell network but, since real mobile networks are composed by many cells, **Inter-Cell Interference** could arise. Simulators should be extended in order to consider more Base Stations.
- One of the most promising technologies to overcome the limits of mobile network is **cell-free networks** and **Intelligent Reconfigurable Surfaces (IRS)**. The analysis performed for the cellular networks could be widen to consider also this new solutions.

List of attended classes

- 01QFFRV – Tecniche innovative per l'ottimizzazione (25/02/2021, 4 credits)
- 01QRRRV – Advanced iterative techniques for digital receivers (11/07/2021, 4 credits)
- 01UMNRV – Advanced deep Learning (didattica di eccellenza) (14/06/2021, 6 credits)
- 02SFURV – Programmazione scientifica avanzata in Matlab (24/05/2021, 6 credits)
- 01QORRV – Writing Scientific Papers in English (17/02/2021, 3 credits)
- 01RRPRV – Lean startup e business for innovation management (18/04/2022, 4 credits)
- (Coursera) – Machine Learning; Andrew Ng, Stanford University (26/05/2021, 6 credits)
- (Coursera) – Applied Machine Learning in Python (03/03/2021, 6 credits)

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