MIMO in far field with reconfigurable intelligent surfaces

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This work addresses MIMO communications when the multipath propagation between the transmitting and receiving arrays is mediated by a “Reconfigurable Intelligent Surfaces (RIS)”, i.e. a surface containing many antenna-like devices, able to change the phase of the reflected or transmitted waves. While MIMO may work under the condition of suitable multipath propagation on both sides of the RIS, a small size of the latter may limit the number of degrees of freedom of the Tx → Rx channel down to 1D, hence reduce the capacity (known as the “keyhole” effect [1]), while in the near field MIMO communications are possible [2]. This phenomenon is here investigated through a simple model of the antenna system, of the far field multipath propagation and of the RIS. The results highlight the interplay between channel matrix correlations and effective SNR at the receiver, depending on major features of the propagation scenarios, as regards the MIMO channel capacity.

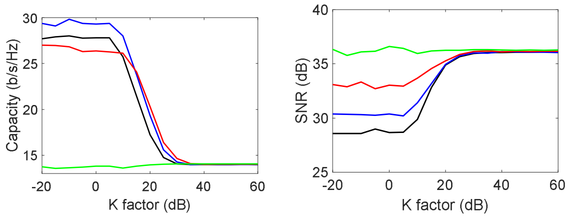

Figure 1. Capacity (left) and SNR (right) dependence on K factor (from black to green: fully horizontal to fully vertical RIS arrays) ;

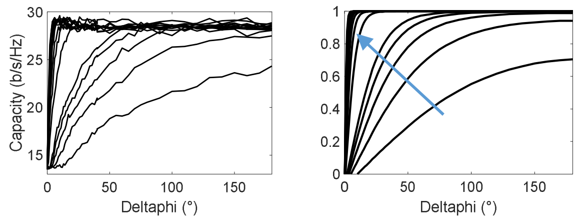

Figure 2. simulated and empirically modeled capacity variation vs. the azimuth spread, for a 33x1 horizontal RIS array of increasing size (sense of the arrow)

We consider a propagation model with a fixed number M_t and N_r paths of outgoing (from Tx) and incoming (to Rx) and paths. Furthermore. Since the goal is to address the impact of multipath propagation in its essential features,

- Outgoing/incoming azimuth/elevation angles of the wavevectors at RIS level are uniformly distributed
- Multipath amplitudes are Rice distributed on both sides of the RIS
- All path phases amplitudes are independent and uniformly distributed over 2π radians
- A power normalization is applied to the complex amplitudes A_{tm} and B_{rn} of paths, for Tx and Rx sides

$$\sum_m |A_{tm}|^2 = \sum_n |B_{rn}|^2 = 1 \tag{1}$$

Furthermore the antenna element signals of both Tx and Rx arrays are assumed to be statistically completely independent and the RIS scattering elements completely uncoupled.
In Fig. 1 is shown, as an example the ergodic capacity vs. the Rice K factor for a 4x4 MIMO case (both horizontal Tx/Rx arrays) with 33x1, 11x3, 3x11 and 1x33 RIS configuration (N_h x N_v horizontal x vertical elements) cases. We see the step down degradation of the optimized capacity and the correlated step up variation of the SNR.
In Figure 2 we see for a Rayleigh channel how the capacity evolves vs. the azimuth spread, for a set of 33x1 horizontal RIS array of total width ranging from 0.64 λ to 61 λ (left), in comparison with an empirical model (right).
These results highlight the necessity to have sufficiently wide RIS arrays for MIMO communication schemes, especially when the angular spread is low. More details will be presented during AT-RASC 2024.

References

[1] D. Chizhik, G.J. Foschini and R.A. Valenzuela, "Capacities of multi-element transmit and receive antennas: correlations and keyholes", *Elect. Lett.* **36**, 1099 (2000)
[2] A. Sibille, “MIMO links mediated by Reconfigurable Intelligent Surfaces”, *EuCAP, Virtual Conference*, 22-26 March 2021