Beamforming Control of Reconfigurable Intelligent Surfaces
可重構智慧面板之波束控制

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Abstract

Reconfigurable Intelligent Surfaces (RIS) plays an important role in 6G communication system. An RIS can manipulate the propagation of wireless signals by dynamically adjusting the phase shifts of the reflected signals. RIS can enhance signal strength, reduce interference, and enable precise beamforming, leading to more efficient and reliable wireless communications in comparison to existing systems.

The purpose of this project is to study the passive beam control for RIS-aided communications. Also, MATLAB-based implementations were developed for channel estimation using compressed sensing and for optimizing the RIS phase configurations and BS beamforming vectors through alternating optimization techniques.

Method

1.Cascaded Channel Estimation

- **Row-Structured Sparsity**: The channel from the RIS to the BS remains common for all users. Consequently, the non-zero elements of $\{\tilde{H}_k\}_{k=1}^{K}$ lie on the same rows for all users.
- **Partially Column-Structured Sparsity**: Different users may share some scattering paths between the RIS and the users, resulting in partially common paths with shared angles at the RIS. As a result, $\{\tilde{H}_k\}_{k=1}^{K}$ exhibits partially common column structures.

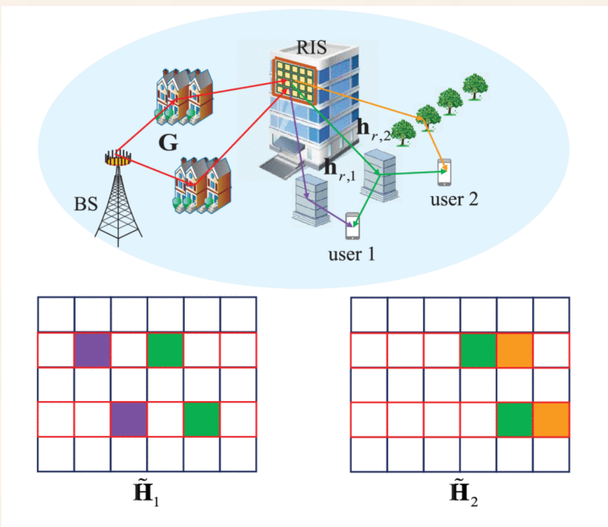


Fig. 1. Double-structured sparsity of the angular cascaded channels

Algorithm: DS-OMP Based Cascaded Channel Estimation

- Estimate the completely common row support.
- Estimate the partially common column supports.
- Estimate the individual column supports for each user k.
- Using the derived support sets, perform least squares (LS) channel estimation to obtain the angular cascaded channel for k=1,…,K.
- Derive the cascaded channel for k=1,…,K based on the estimated .

2.Alternating Optimization: Minimizing Transmit Power by Adjusting RIS Phase

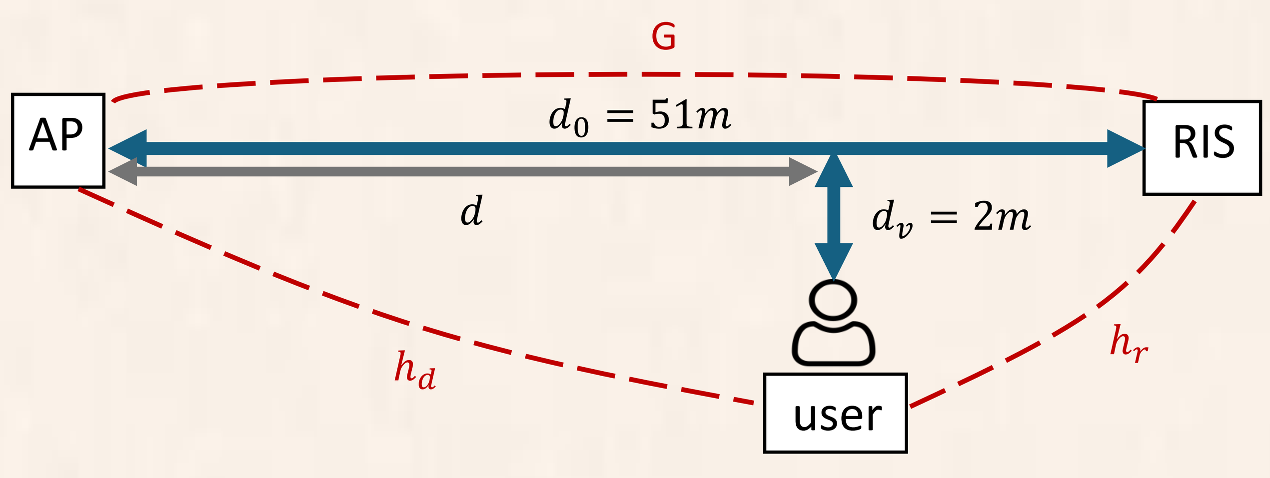


Fig. 2. simulation setup of the single-user case

To solve the optimization problem, we make use of triangular inequality:

$$\left|(h_r^H\Theta G + h_d^H)\overline{w}\right| = \left|h_r^H\Theta G + h_d^H\overline{w}\right| \le \left|h_r^H\Theta G\overline{w}\right| + \left|h_d^H\overline{w}\right|$$

Equality holds when the phases of the reflected and direct signals are aligned, i.e.

$$\arg(h_r^H\Theta G\overline{w}) = \arg\left(h_d^H\overline{w}\right) \triangleq \varphi_0.$$

Thus, the optimal phase shift for the RIS elements is given by:

$$\theta_n^* = \varphi_0 - arg\left(h_{n,r}^H g_n^H\overline{w}\right) = \varphi_0 - arg\left(h_{n,r}^H\right) - arg\left(g_n^H\overline{w}\right)$$

This ensures that the reflected and direct channel signals are coherent when they reach the receiver, enhancing the overall received power.

Next, compute the beamforming vector and transmit power using the Maximum Ratio Transmission (MRT) approach.

Repeat the process above until convergence is achieved.

Results

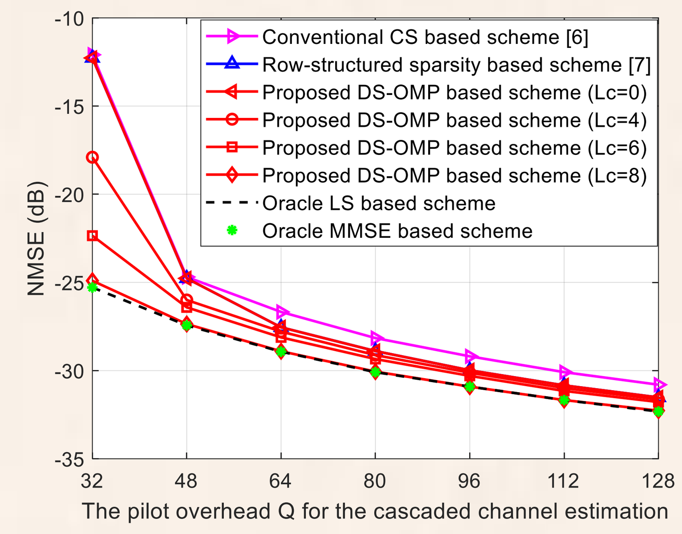


Fig. 3. NMSE performance comparison against the pilot overhead Q with SNR = 10 dB

- Estimation error：conventional CS-based > row-structured sparsity = DS-OMP schemes with Lc equal to 0 > DS-OMP with Lc larger than 0. (Lc = number of common paths between different users and RIS)
- Increasing Lc , SNR values, pilot overhead all lead to reduced estimation errors.

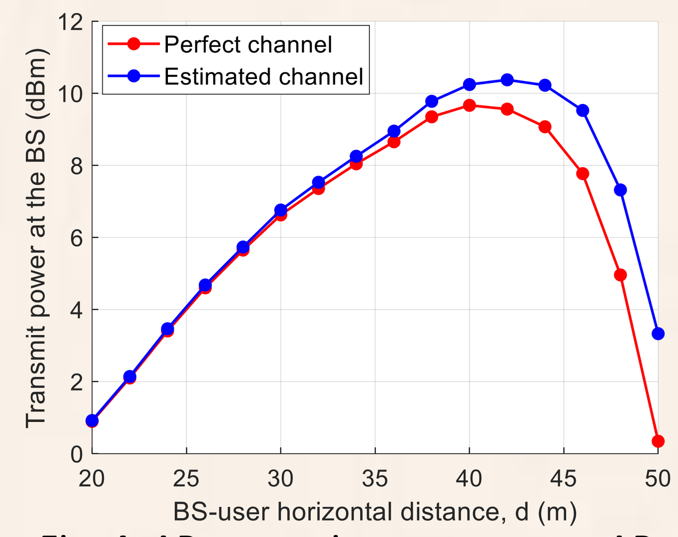


Fig. 4. AP transmit power versus AP-user horizontal distances

- The required transmit power decreases as the user approaches the RIS or BS.
- Power needed for estimated channel is always larger than perfect channel.

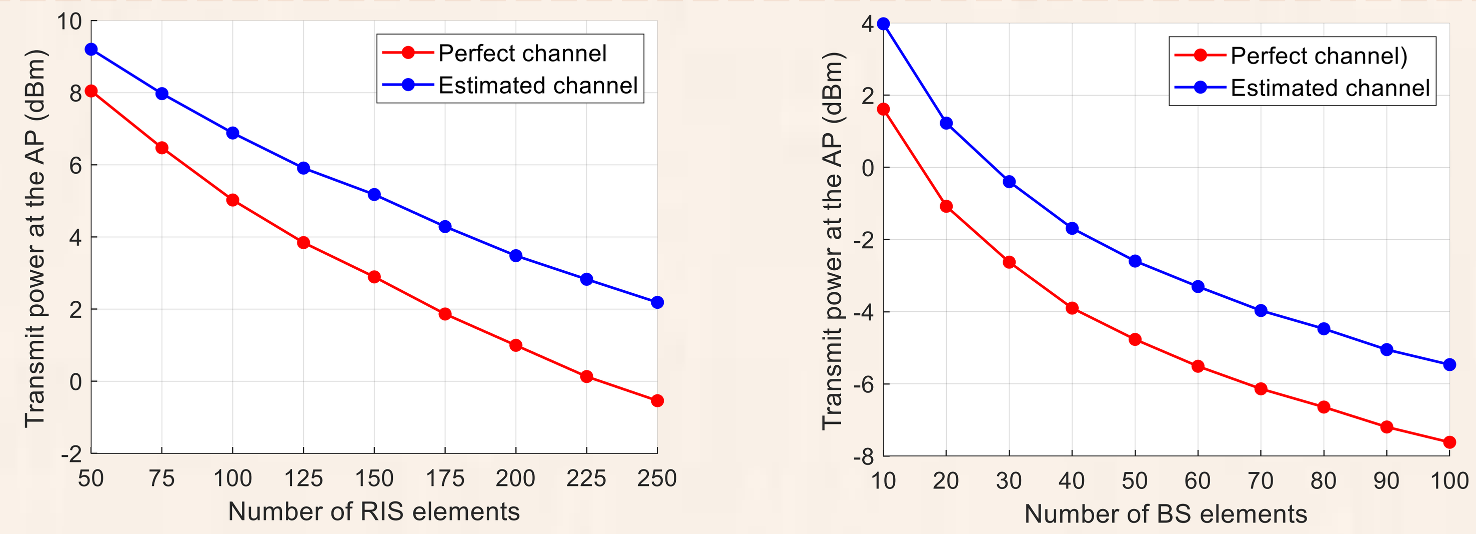
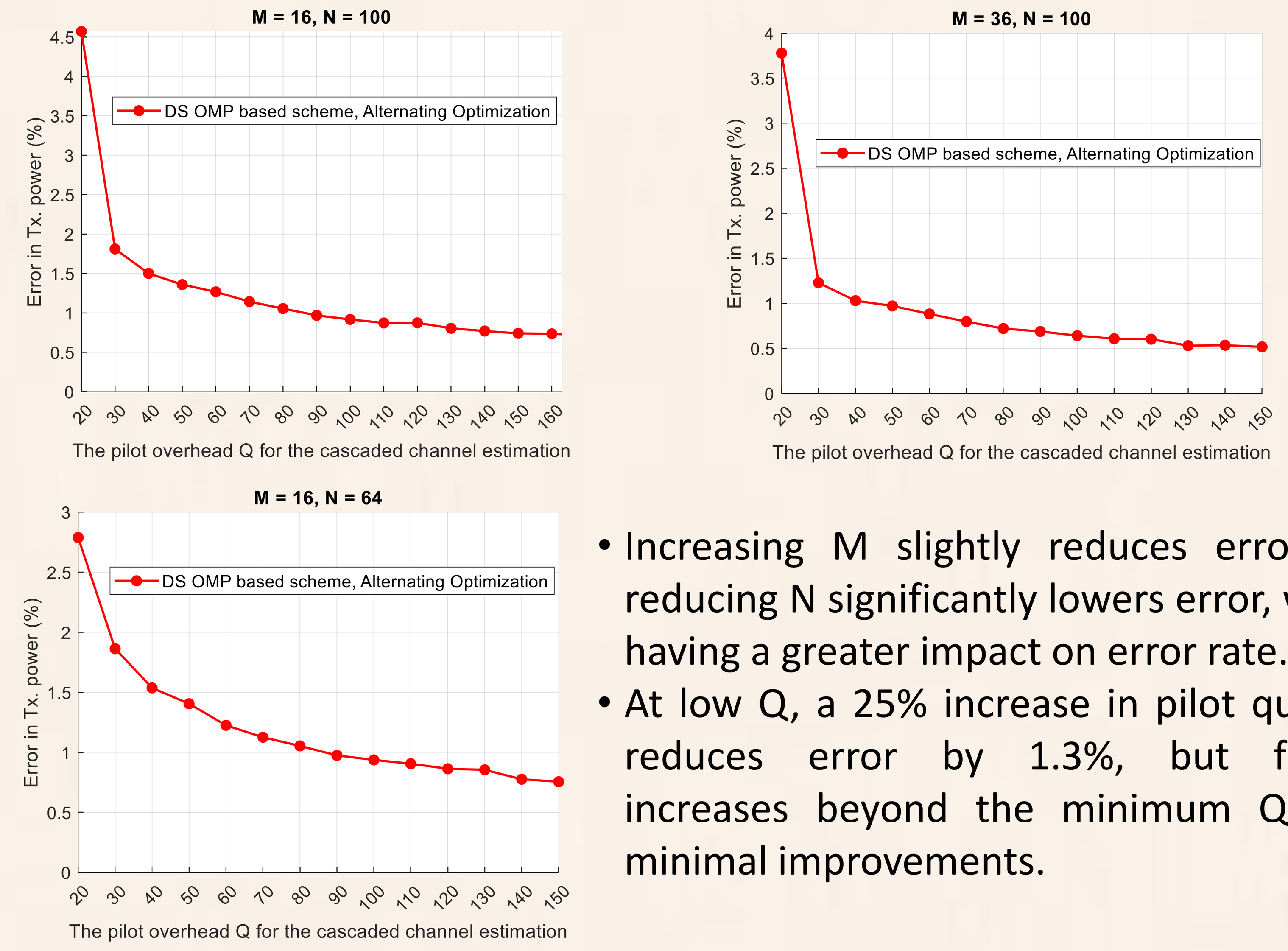


Fig. 5. AP transmit power versus number of RIS elements & BS elements

- Estimated channel require higher transmit power than perfect channel.
- Increasing RIS elements or BS antennas reduces transmit power requirements.



- Increasing M slightly reduces error, but reducing N significantly lowers error, with N having a greater impact on error rate.
- At low Q, a 25% increase in pilot quantity reduces error by 1.3%, but further increases beyond the minimum Q offer minimal improvements.

Fig. 6. Error in transmit power versus number of pilot overhead Q with different combination of BS antennas (M) and RIS elements (N)

Reference

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Conclusion

We successfully employ compressed sensing and alternating optimization technique for channel estimation and configuring BS beamforming and RIS phase adjustments in a single-user system. Increasing the number of BS antennas and RIS elements reduces transmission power, with RIS having a greater impact. A 25% increase in pilot overhead reduces estimation error by 1.3% before reaching the minimum requirement. To conclude, RIS minimizes interference and enhances energy efficiency, making it essential for future 6G communication systems.