Hot Topics for 6G Wireless Networks

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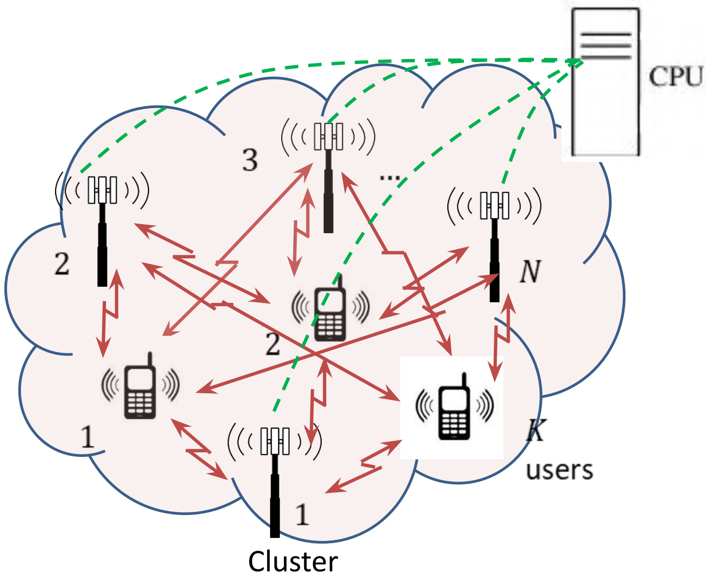
Outline

- Introduction
- Multiple-antenna systems for 6G
- Reflective intelligent surfaces
- Semantic communications
- Robust resource allocation
- Conclusions and ongoing work

Introduction

- 6G wireless networks will be deployed in 5 years or so and feature novel technologies and improvements.
- **Key problems:**
  - Need for higher data rates required by new applications such as virtual reality, datacentres and AI.
  - Need for improved coverage for users/devices with poor channels.
  - Interference mitigation.
  - Sensing of users/devices and combined use with communication.
- In this talk, we will discuss research activities in wireless communication systems at CETUC, PUC-Rio.



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Topics:

- XL-MIMO systems will exploit near-field signal propagation, perform improved interference mitigation and enable much higher data rates in 6G networks.

- Reflective intelligent surfaces (RIS) will be key for sensing tasks and help with extending network coverage and improving data rates.

- Novel coding schemes will employ improved message passing approaches and semantic communication concepts.

- Robust transmit processing is another topic that shall play an important role given the need to deal with imperfect CSI in wireless networks.

Multiple-antenna systems for 6G

- XL-MIMO systems

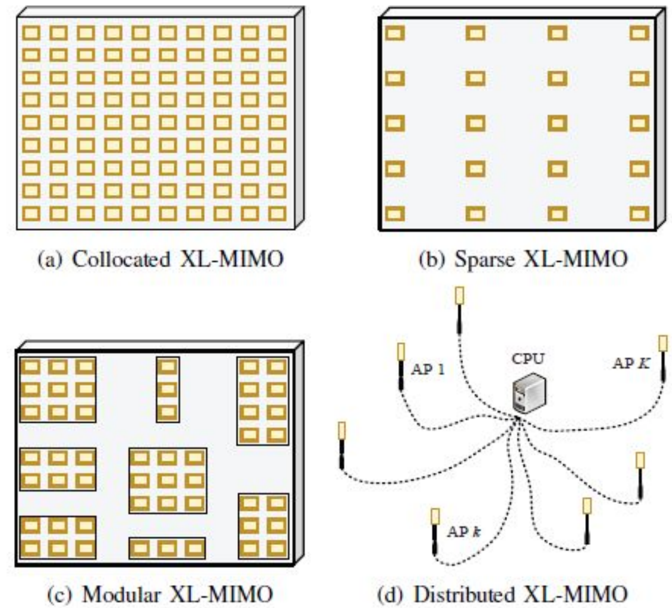
    - Near-field channels with Rayleigh distance

$$r = \frac{D^2}{\lambda},$$

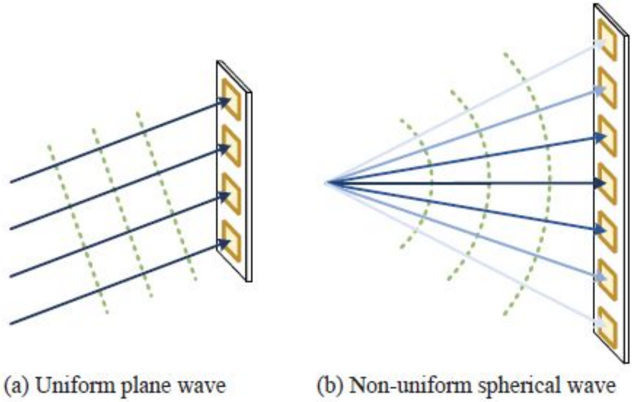
where D is the array dimension and λ is the wavelength.

    - Spherical waves are encountered by arrays

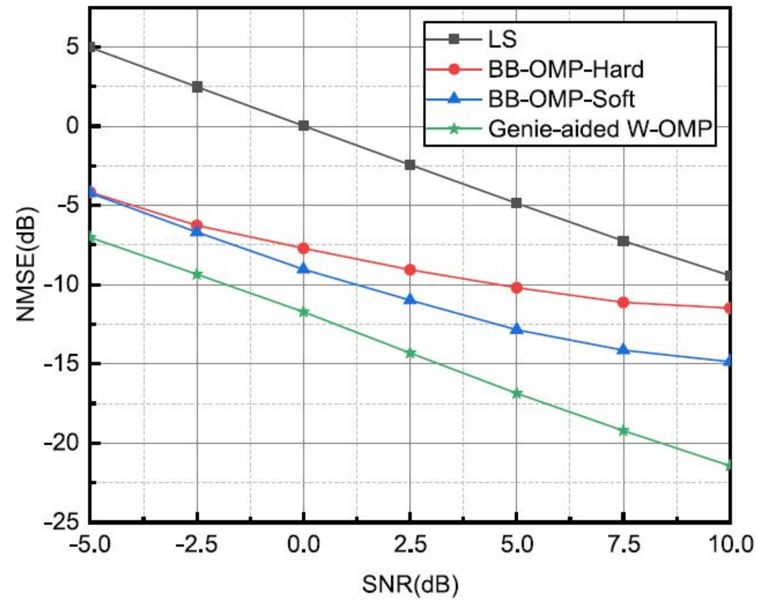
    - Spatial non-stationarity

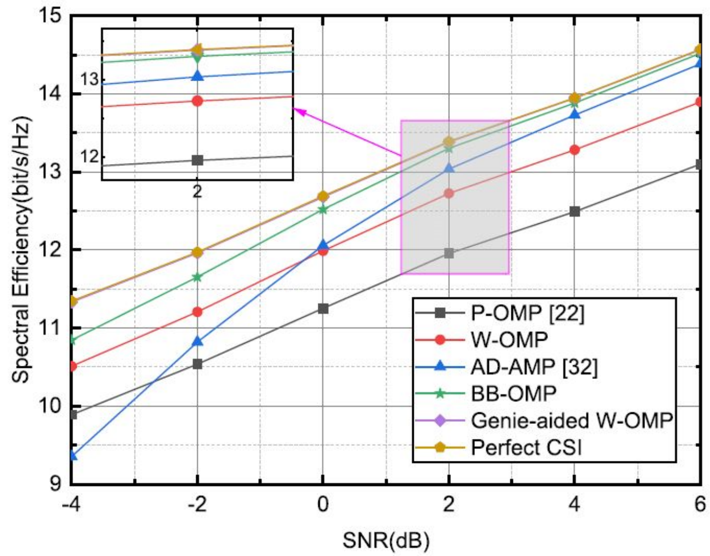


(a) Collocated XL-MIMO (b) Sparse XL-MIMO (c) Modular XL-MIMO (d) Distributed XL-MIMO


(a) Uniform plane wave (b) Non-uniform spherical wave

- XL-MIMO systems with N = 256 antenna elements, f = 60GHz
- Pilot length: Q = 45
- Channel estimation with BB-OMP that exploits near-field scenarios and spatial non-stationarity is best
- Spectral efficiency with MMSE precoder and channel estimates is higher for BB-OMP
- **Interference mitigation that exploits features of XL-MIMO systems is key**





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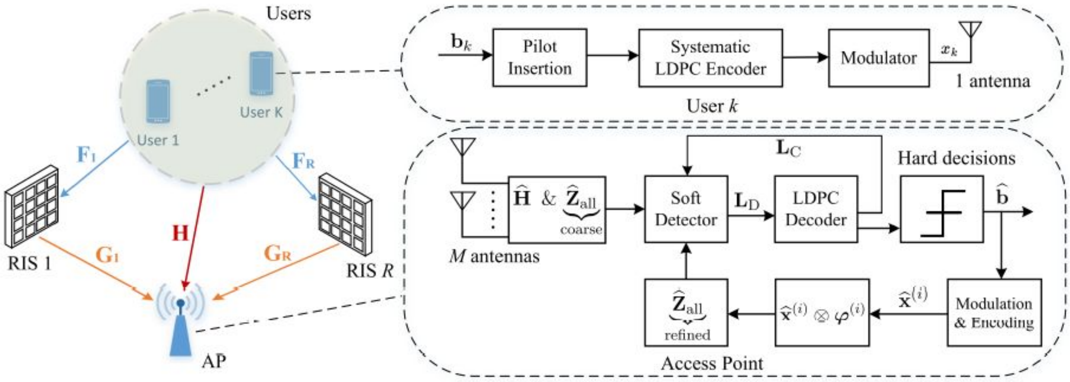
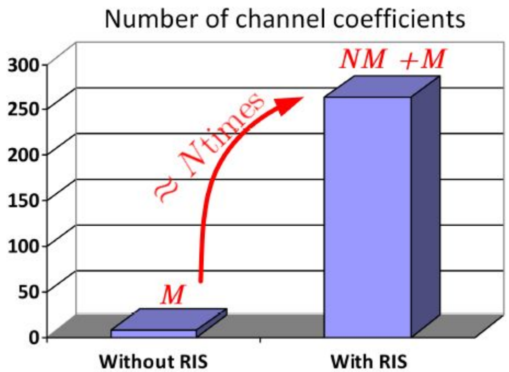
Reflective intelligent surfaces

- RIS are likely to play a key role in future wireless systems for communications and sensing
- RIS include passive, active, beyond-diagonal, stacked and holographic architectures
- RIS can enhance coverage and increase data rates
- Challenges: channel estimation, deployment, computation of reflection parameters and interference mitigation



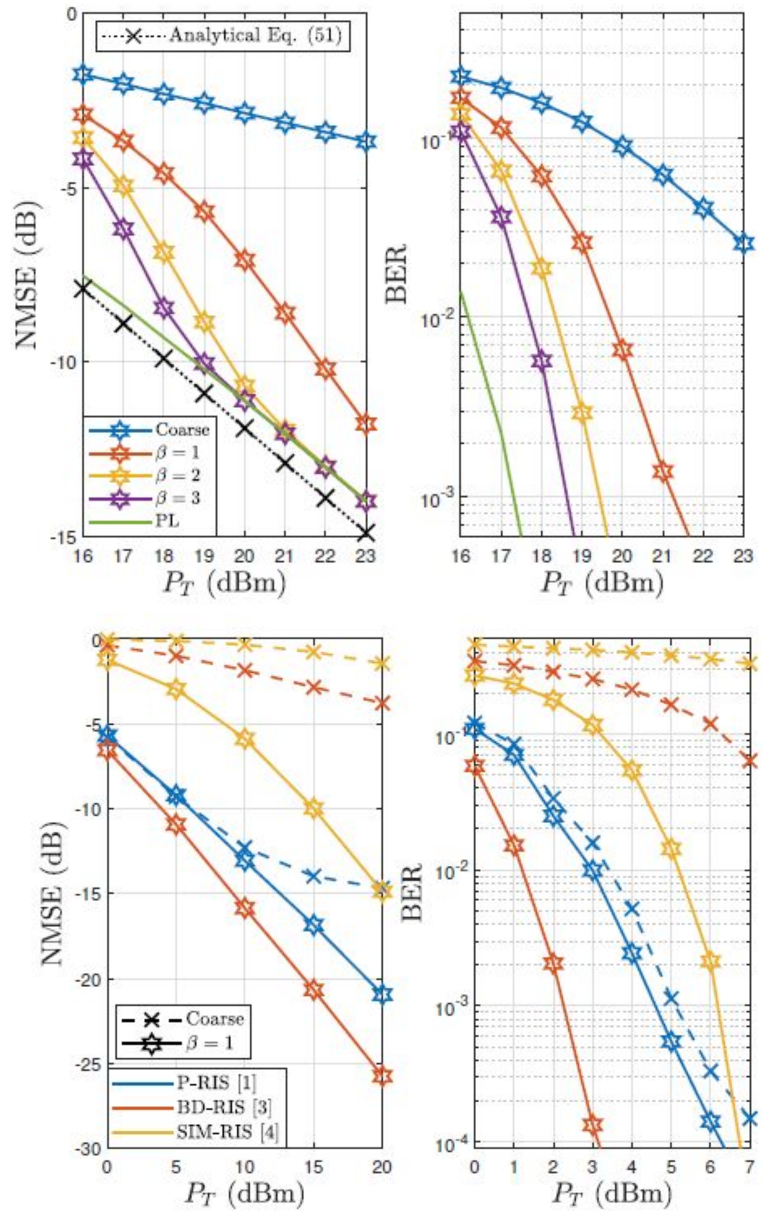


Example with M antennas at the AP and at RIS

- Channel coding and iterative processing can help with channel estimation and interference mitigation.

- **A reduction of the number of required pilots is made possible by channel coding and iterative processing.**

- **Interference mitigation is also enhanced with RIS architectures.**



R. Porto and R. de Lamare, "Iterative Joint Channel Estimation and Detection for Coded Multi-RIS-Assisted Multi-Antenna Systems", IEEE Trans. Communications, 2026 (to appear).

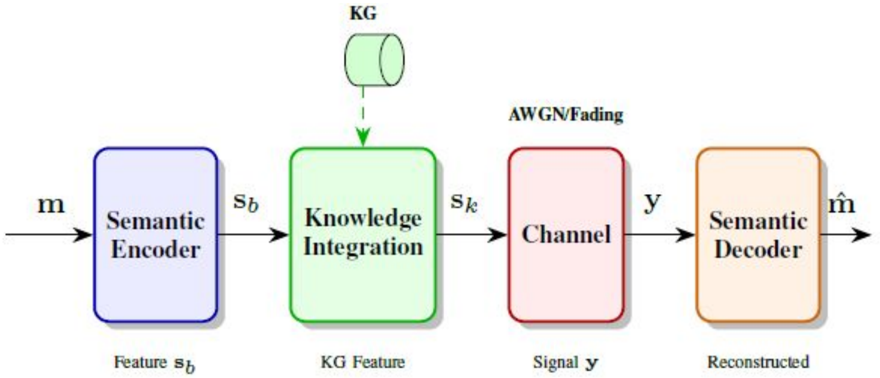
Knowledge-enhanced semantic communication

- Semantic communication focuses on goal-oriented wireless communication. By exploiting semantics, transmission/reception can be enhanced.

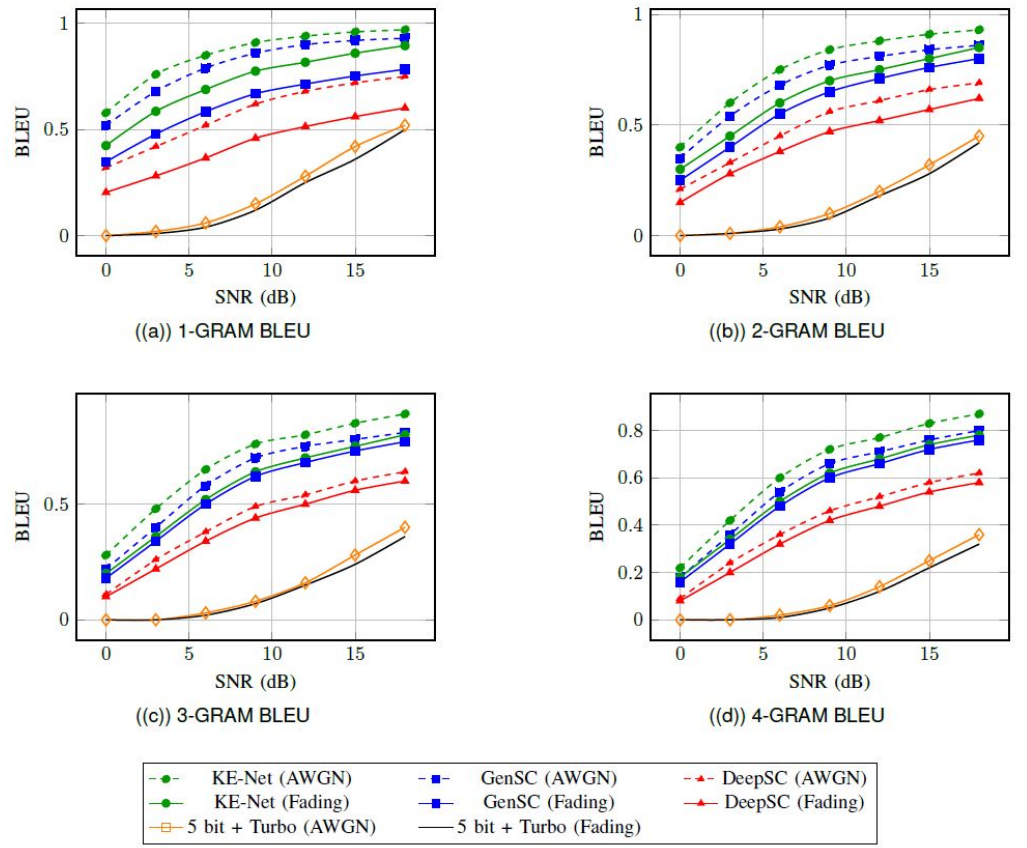
- We propose knowledge-enhanced network (KE-Net) semantic communications to improve semantic transmission accuracy.

- KE-Net exploits graph neural networks and knowledge graphs (KG) for knowledge integration.

- KE-Net employs a multi-objective optimization strategy with semantic loss, knowledge integration loss, reconstruction loss, and channel-aware loss components.



- The evaluation employs a dataset of 50,000 sentences sourced from news articles (40%), social media posts (35%) and technical documents (25%)
- The dataset is partitioned into training (70%, 35,000 sentences), validation (15%, 7,500 sentences), and test (15%, 7,500 sentences) sets
- **The results in terms of BLEU score show that KE-Net outperforms GenSc, DeepSc and a 5-bit+turbo code**



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M. -K. Chang, C. -T. Hsu and G. -C. Yang, ” GenSC: Generative Semantic Communication Systems Using BART-Like Model. ” IEEE Communications Letters,vol. 28, no. 10, pp. 2298-2302, Oct. 2024
H. Touati and R. de Lamare, “Knowledge-Enhanced Network Semantic Communication: A Multi-Objective Optimization Framework for Wireless Communications”, IEEE Trans on Communications, 2026.

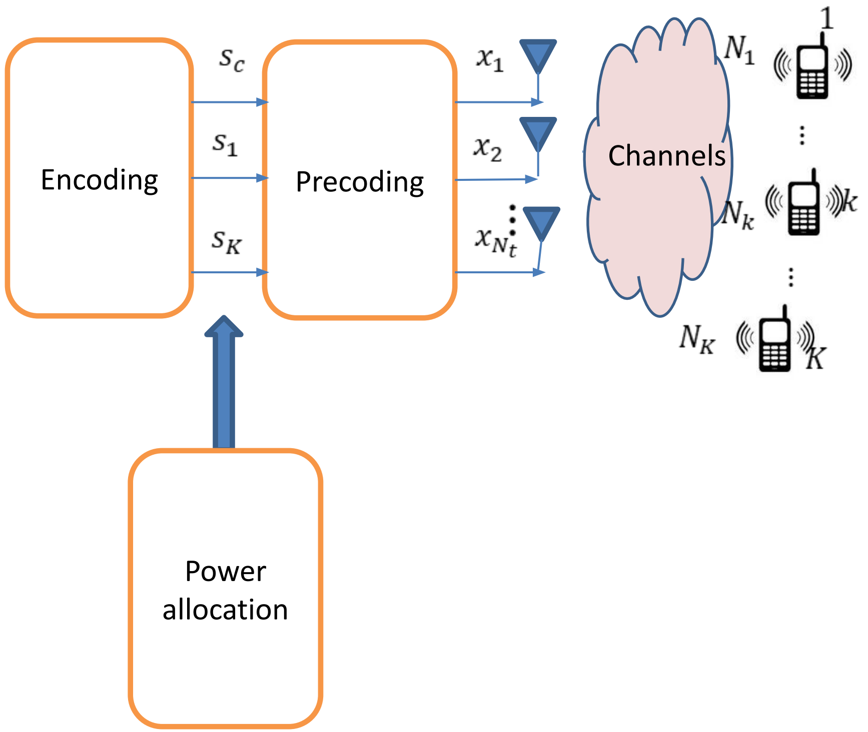
Robust transmit processing

- In wireless systems, imperfect channel state information (CSI) at the transmitter occurs due to estimation errors, feedback and outdated information

- This calls for robust transmit processing strategies that involve precoding, power allocation and user scheduling

- A key strategy is to model the CSI errors using a statistical approach and bound them following a worst-case criterion

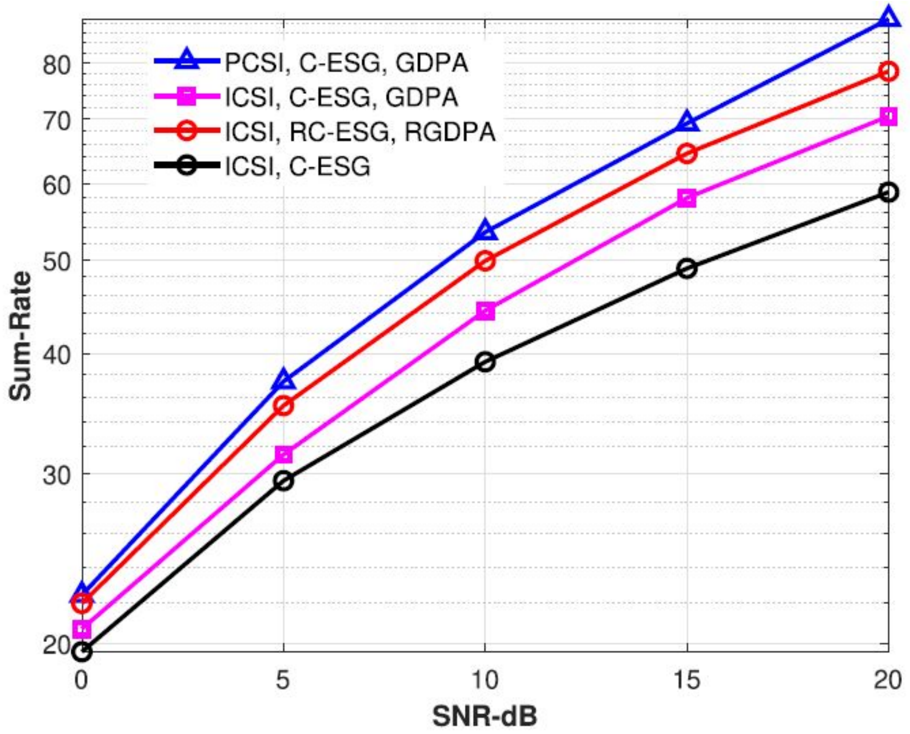
- Robust precoding, power allocation and scheduling algorithms can be developed



- BS with N = 64 antennas, K=16 users and imperfect CSI (ICSI) with $\alpha = 0.1$

- We employ a robust precoder, robust power allocation (RGDPA) and a robust scheduler (RC-ESG) against standard approaches

- **Robust techniques can offer gains of up to 30% against standard techniques while requiring similar cost.**



A. R. Flores and R. C. de Lamare, "Robust Rate-Splitting-Based Precoding for Cell-Free MU-MIMO Systems," in IEEE Communications Letters, vol. 29, no. 6, pp. 1230-1234, June 2025

S. Mashdour, A. R. Flores, S. Salehi, R. C. de Lamare, A. Schmeink and P. R. B. da Silva, "Robust Resource Allocation in Cell-Free Massive MIMO Systems," in IEEE Transactions on Communications, vol. 73, no. 8, pp. 5745-5759, Aug. 2025

Conclusions

- We have discussed several 6G hot topics that are under investigation in our research group at CETUC, PUC-Rio .
- We have developed cost-effective channel estimation techniques for XL-MIMO systems in near-field scenarios that are poised to play a big role in 6G networks.
- We have devised iterative processing strategies for computing the phases and gains of RIS-based systems that can play a big role in sensing and communications.
- We have conceived KE-Net to exploit machine learning techniques to perform cost-effective semantic communications, which focus on the meaning rather than raw data.
- We have devised robust transmit processing techniques including precoding, power allocation and user scheduling that model imperfect CSI and result in significant performance advantages over standard (non robust) approaches..

Ongoing and future work

- Clustered cell-free designs with XL-MIMO systems for interference and broadcast channels.
- Extensions to COMP / multicell processing.
- Interference mitigation that exploits near-field scenarios.
- Semantic communication approaches to machine-type communications
- Distributionally robust techniques for designing precoders, power allocation and user scheduling.

Questions?

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