Recent Advances in IRS Aided Wireless Communications

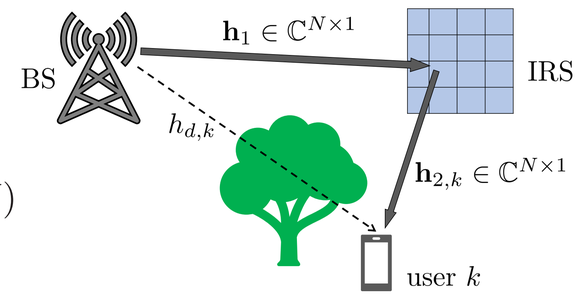
Yashvanth L. (PMRF Ph.D. scholar)

Advisor: Prof. Chandra R. Murthy, *Fellow, IEEE, INAE*

Dept. of Electrical Communication Engineering, Indian Institute of Science, Bangalore

Intelligent Reflecting Surfaces

- **Intelligent reflecting surfaces (IRSs)** for 5G & beyond
  - Optimization of reflection coefficients for coherent reception
- Perks due to IRSs
  - SNR and coverage boost
  - Energy efficiency, & others
- Three-fold overheads
  - Channel estim. scales as $\mathcal{O}(N)$
  - Phase optimization
  - Phase transportation to IRS



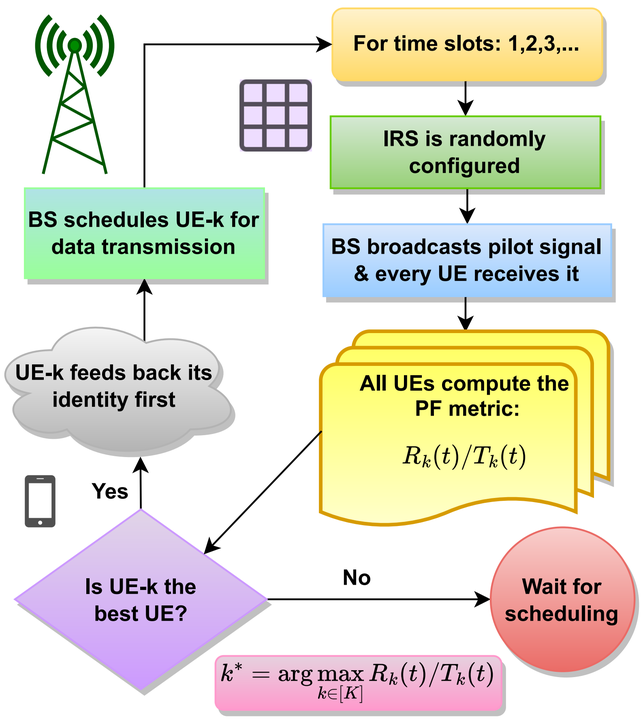
An Opportunistic Comm. Scheme with IRS

Can we obtain optimal benefits without *three-fold* overheads?

Randomly configure the IRS *and* use **opportunistic** comm.

- Use proportional-fair (PF) scheduler & exploit multi-user diversity

- Channel @ UE-k: $h_k = \sqrt{\beta_{r,k}}\mathbf{h}_{2,k}^T\mathbf{\Theta}\mathbf{h}_1 + \sqrt{\beta_{d,k}}h_{d,k}$
- Optimal IRS configuration: $\theta_{n,k}^* = \exp\{j\left(\angle h_{d,k} - \angle(h_{1,n}\times h_{2,k,n})\right)\}$
- Optimal SE: $R_k^{BF} = \log_2\left(1+\gamma\left|\sqrt{\beta_{r,k}}\sum_{n=1}^{N}|h_{1,n}h_{2,k,n}| + \sqrt{\beta_{d,k}}|h_{d,k}|\right|^2\right)$



A scheme with randomized IRS:

- Instantaneous SE @ UE-k:

$$R_k(t) = \log_2\left(1+|h_k(t)|^2\gamma\right)$$

- Avg. SE @ UE-k till time t: $T_k(t)$
- Proportional-fair scheduler:

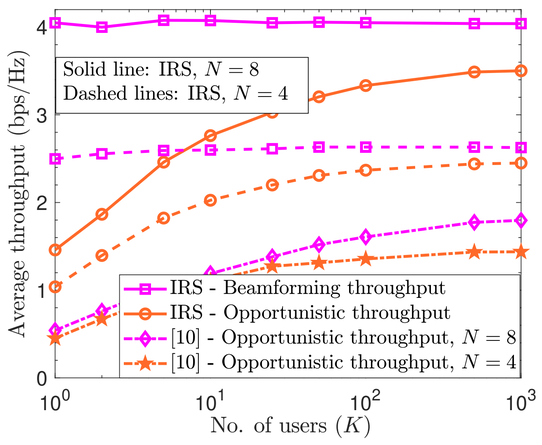
$$k^*(t) = \arg\max_{k\in\{1,\ldots,K\}} \frac{R_k(t)}{T_k(t)}$$

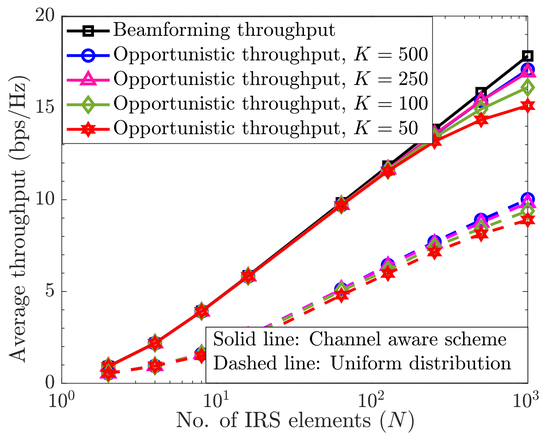
- *Random* IRS becomes *optimal*:

$$\lim_{K\to\infty}\left(R^{(K)} - \frac{1}{K}\sum_{k=1}^{K}R_k^{BF}\right) = 0$$

Key Contributions:

1. Convergence of opportunistic SE to the beamforming SE with K, & N
2. Rate-scaling laws in time-varying i.i.d. and LoS channels
3. Extension results to OFDM and multiple antenna systems





Publications:

1. L. Yashvanth, and Chandra R. Murthy, **Performance Analysis of Intelligent Reflecting Surface Assisted Opportunistic Communications**, *IEEE Transactions on Signal Processing*, vol. 71, March 2023
2. L. Yashvanth, and Chandra R. Murthy, **Comparative Study of IRS Assisted Opportunistic Communications over I.I.D. and LoS Channels**, Proc. *IEEE ICASSP* 2023, Rhodes Island, Greece, June 2023

Acknowledgements

1. Prime Minister's Research Fellowship (PMRF), 2022
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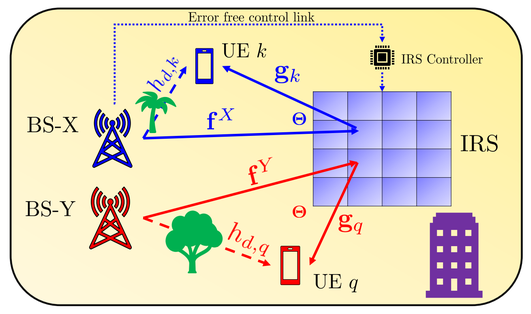
Impact of IRS in Multiple Mobile Operator Sys.

Multiple mobile operators (MO) co-exist in a geographical area

- In-band MO - **X**: *deploys* & *controls* IRS
- Out-of-band MO - **Y** has no IRS
  - **Oblivious** to MO X's IRS
- IRS config. is random for UEs of MO-Y

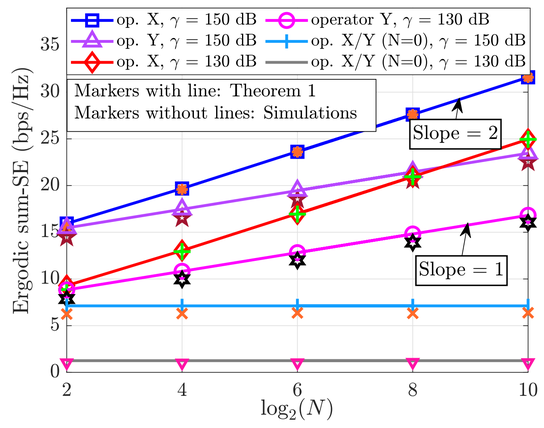


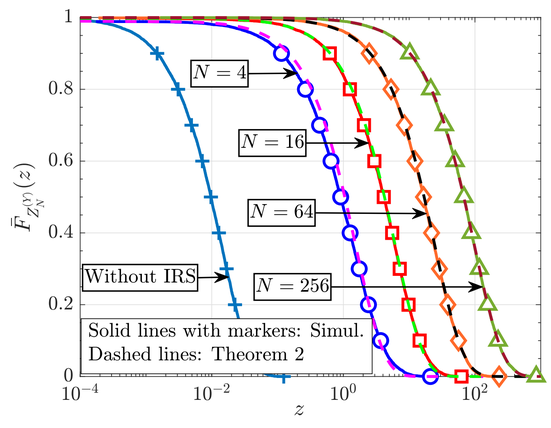
Does an IRS degrade out-of-band performance in TDMA?

Operator X tunes the IRS to **optimally** serve its users

- Does this degrade the performance of UEs served by op. Y?

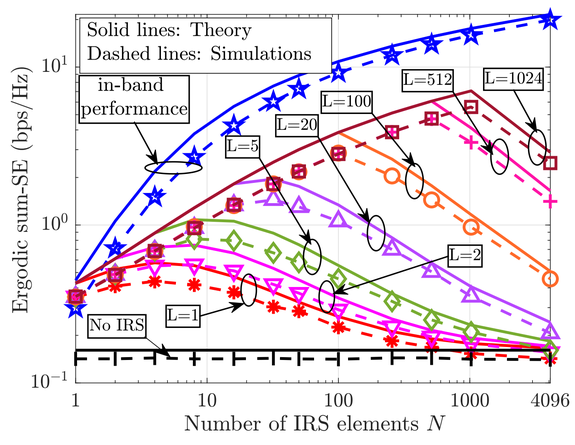
Performance in sub-6 GHz bands:

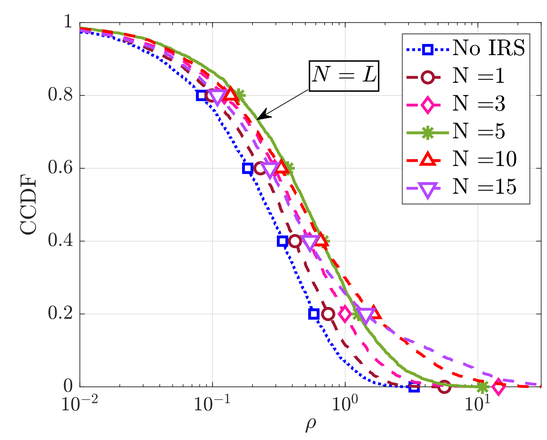




- SE of MO-X scales as $\mathcal{O}(\log(N^2))$: benefit of optimized IRS
- SE of MO-Y scales as $\mathcal{O}(\log(N))$: IRS enhances scattering for OOB ch.
- $1-$ Outage prob. is a seq. of stochastically larger random variables in N

Performance in directional mmWave bands:





- With Prob. L/N, IRS aligns to OOB UE and its SE scales as $\mathcal{O}(\log(N^2))$
- Distributed IRSs offer more DoF and enhances OOB SE much better
- Outage prob. is better even with random IRSs due to diversity benefits

Publications:

1. L. Yashvanth, and Chandra R. Murthy, **On the Impact of an IRS on the Out-of-Band Performance in Sub-6 GHz & mmWave Frequencies**, revised & submitted to *IEEE Transactions on Communications*, Nov 2023
2. L. Yashvanth, and Chandra R. Murthy, **Distributed IRSs Always Benefit Every Mobile Operator**, revision in *IEEE Wireless Comm. Letters*, 2024
3. L. Yashvanth, and Chandra R. Murthy, **Does an IRS Degrade Out-of-Band Performance?**, Proc. *IEEE SPAWC*, Shanghai, China, Sep. 2023

Other Interesting & Solved Problems

1. Minimizing CSI estim. overhead for IRSs exploiting subspace properties
   - L. Yashvanth, and Chandra R. Murthy, **Cascaded Channel Estimation for Distributed IRS Aided mmWave Massive MIMO Systems**, Proc. *IEEE GLOBECOM*, Rio de Janeiro, Brazil, Dec. 2022
2. A majorization-minimization-based IRS phase optim. solver in OFDM Sys.
   - L. Yashvanth, Chandra R. Murthy, and Deepak Battu, **Binary Intelligent Reflecting Surfaces Assisted OFDM Systems**, Proc. *IEEE SPCOM*, Bangalore, India, June 2022

Contact Information

e-mail: yashvanthl@iisc.ac.in, SPC Lab, Dept. of ECE, IISc

https://ece.iisc.ac.in/~cmurthy/doku.php?id=yashvanth_l