Cooperative Communications for 5G Wireless Systems

Jayamuni Mario Shashindra S. Silva
University of Alberta

jayamuni@ualberta.ca

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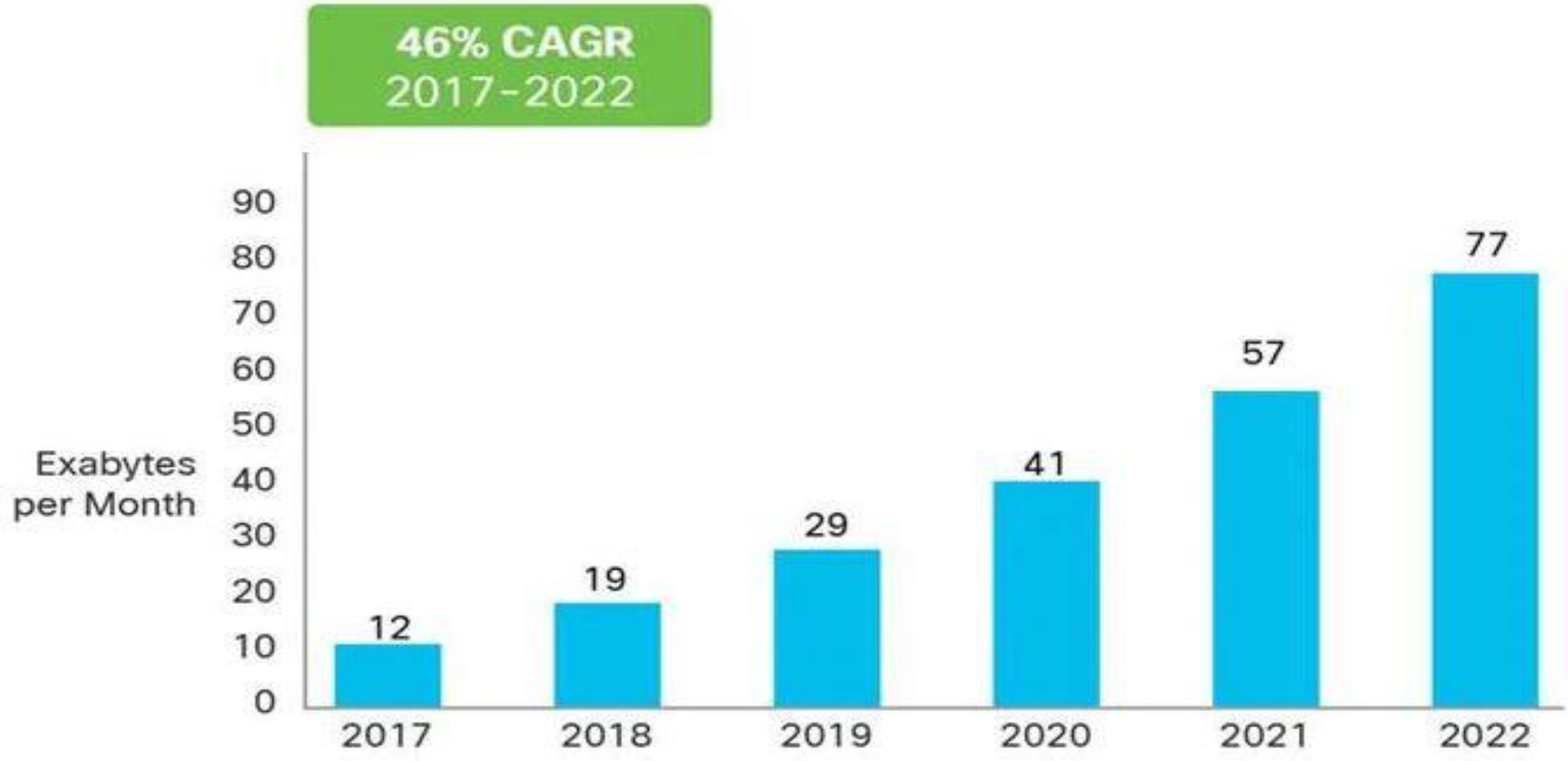
Overview

1. Introduction
   1. Wireless industry
   2. Cooperative communication technologies
2. Contributions
   1. Massive MIMO TWRNs
   2. Relay selection in cognitive TWRNs
   3. NOMA for MWRNs
   4. Machine learning for relay selection
3. Future Work
4. Conclusions

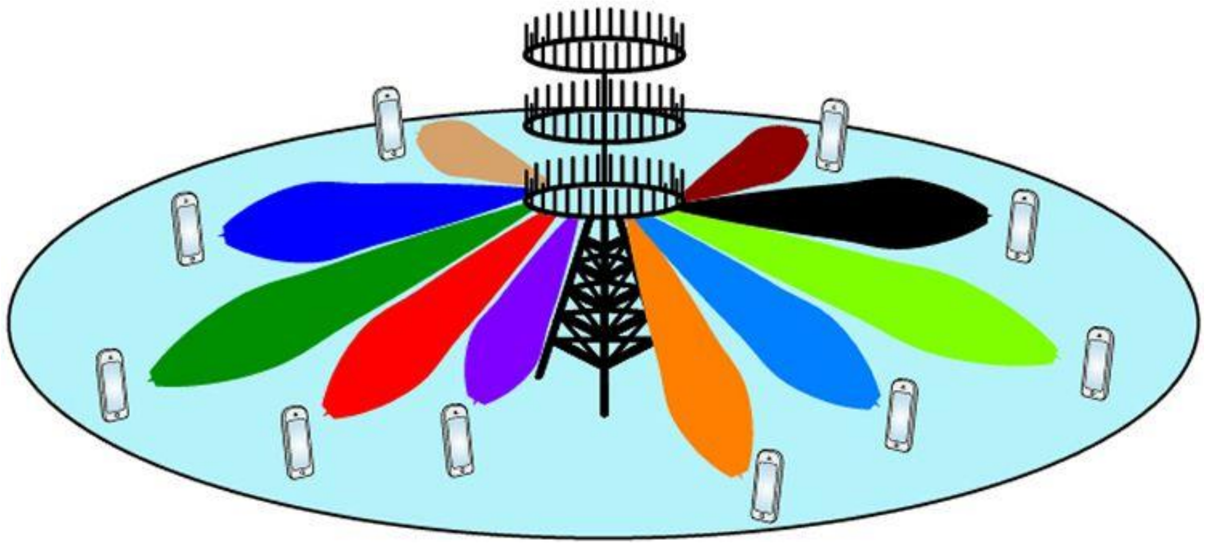
Demand for Wireless Data



[1] (2019) Cisco visual networking index: Global mobile data traffic forecast update, 2017–2022 white paper. Cisco Systems, Inc. [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-738429.html

Massive MIMO

- Large number of antennas.
- Linear beamforming.
- High SE and high EE.
    - SE- Number of bits per second in a unit of bandwidth.
    - EE- Number of bits per unit energy consumption



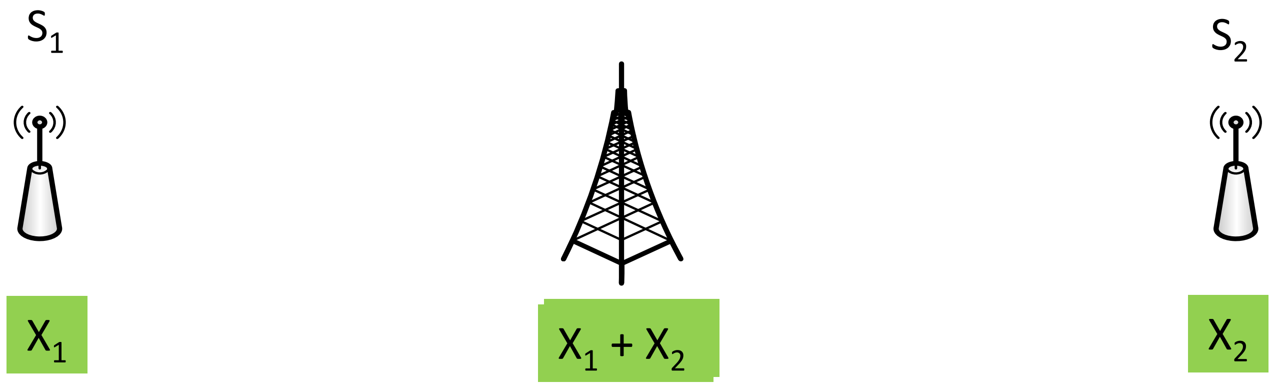
https://5g.co.uk/guides/what-is-massive-mimo-technology/

Cooperative Communications

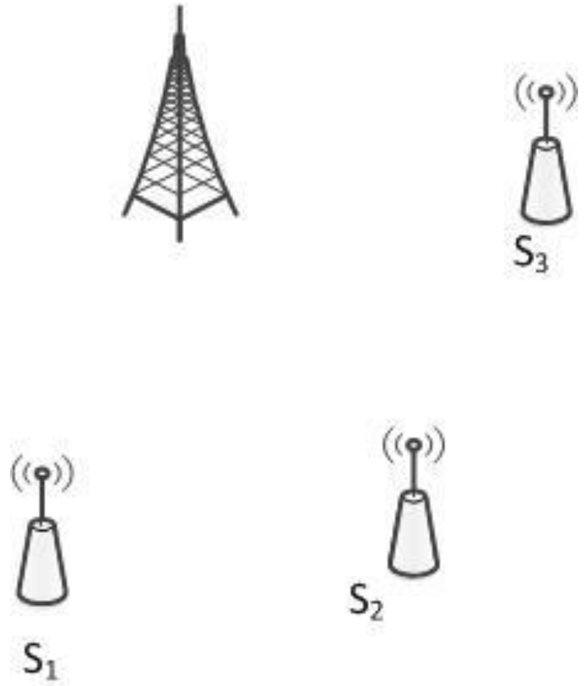
- Improves
  - Connectivity.
  - Spectrum efficiency.
  - Energy efficiency.
  - Flexibility.

- Two-way Relay networks (TWRNs).
- Multi-way relay networks (MWRNs).
- Relay selection.
- Cognitive Radio (CR).
- Non-orthogonal multiple access (NOMA).

TWRNs and MWRNs



- Only two time slots



- Data exchange among multiple users

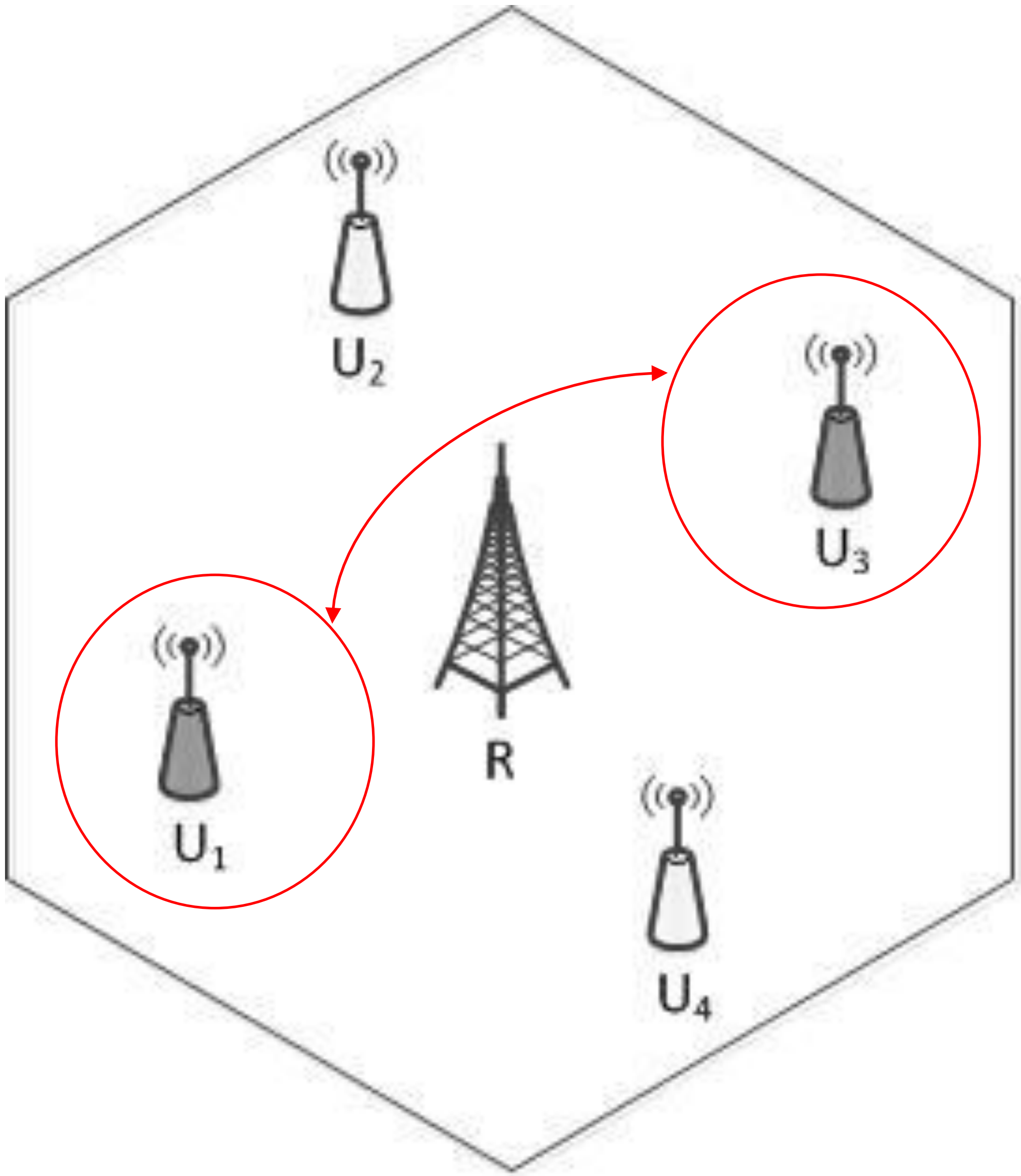
Research Problem 1:

Performance Analysis of mMIMO TWRNs with Channel Imperfections

[P1] S. Silva, G. Amarasuriya, C. Tellambura and M. Ardakani, "Massive MIMO two-way relay networks with channel imperfections," 2016 IEEE International Conference on Communications (ICC), Kuala Lumpur, 2016, pp. 1-7.
[P2] S. Silva, G. A. A. Baduge, M. Ardakani and C. Tellambura, "Performance Analysis of Massive MIMO Two-Way Relay Networks With Pilot Contamination, Imperfect CSI, and Antenna Correlation," in IEEE Transactions on Vehicular Technology, vol. 67, no. 6, pp. 4831-4842, June 2018.

Problem Statement

- Major Goals
  - Improve spectral efficiency.
  - Analyse CCI, CSI, pilot contamination, and antenna correlation.
  - Obtain closed form results.



Significance and contribution

- Limitations of [2,3,4]:
  - Perfect CSI [2,3].
  - single cell [2,3,4].
  - No antenna correlation [2,3,4].

- This Work:
  - Multiple TWRNs.
  - CCI, Imperfect CSI, and pilot contamination.
  - Antenna correlation.
  - Closed-form solutions.

[2] H. Cui et al., "Multi-pair two-way amplify-and-forward relaying with very large number of relay antennas," IEEE Trans. Wireless Commun., vol. 13, no. 5, May 2014.
[3] S. Jin et al., "Ergodic rate analysis for multipair massive MIMO two-way relay networks," IEEE Trans. Wireless Commun., vol. 14, no. 3, Mar. 2015.
[4] J. Yang et al., "Spectral and energy efficiency for massive MIMO multi-pair two-way relay networks with ZFR/ZFT and imperfect CSI," in 2015 21st Asia-Pacific Conference on Communications (APCC), Oct. 2015.

Summary of Results

- Obtain closed-form solutions for sum rate.
- Mitigate CCI using massive MIMO.
- Analyse effect of pilot contamination.
- Analyse effect of Imperfect CSI.
- Analyse the detrimental effect of antenna correlation.

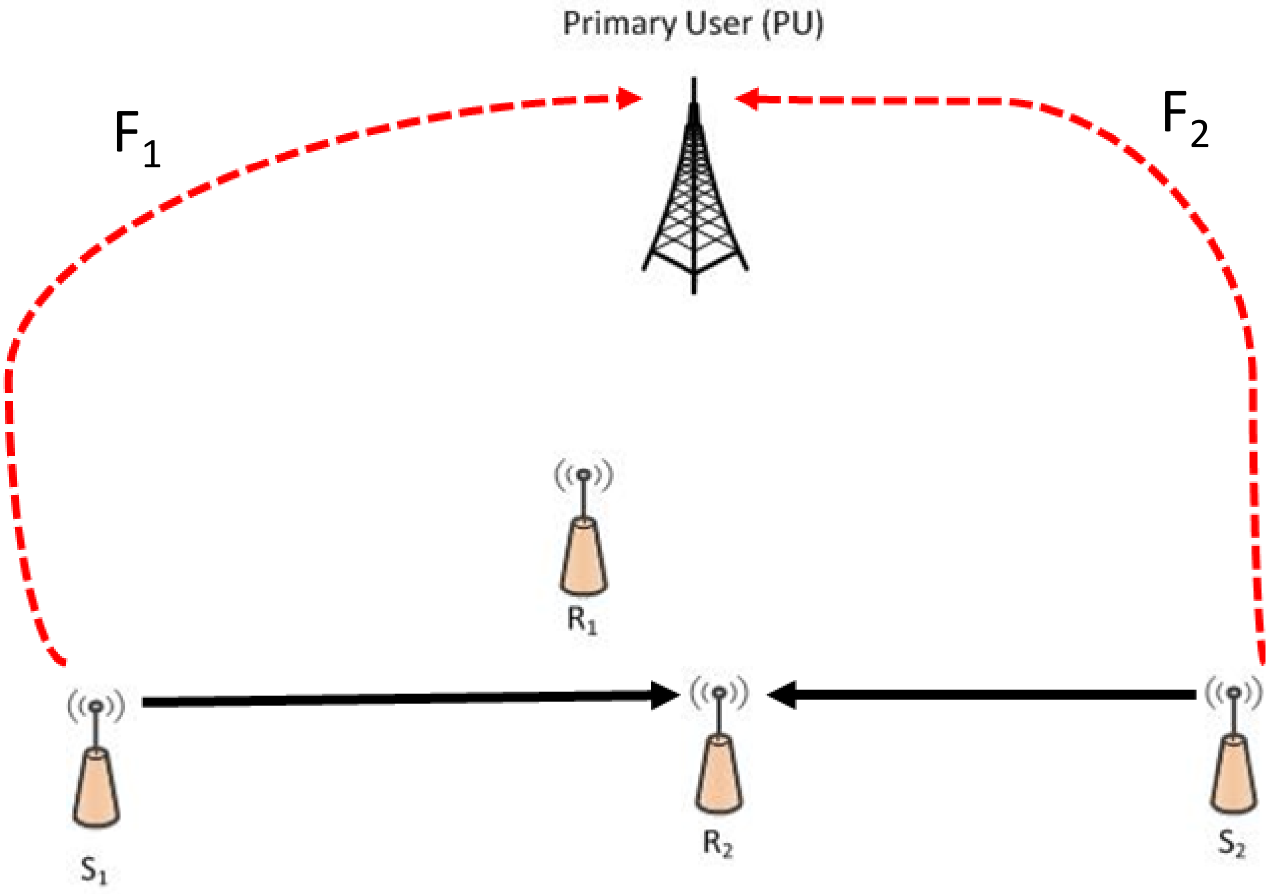
Research Problem 2:

Massive MIMO and Relay Selection in Cognitive TWRNs

[P3] S. Silva, M. Ardakani and C. Tellambura, " Interference Suppression and Energy Efficiency Improvement with Massive MIMO and Relay Selection in Cognitive Two-way Relay Networks," in *IEEE Transactions on Green Communications and Networking, 2020*.
[P4] S. Silva, M. Ardakani and C. Tellambura, "Relay Selection for Cognitive Massive MIMO Two-Way Relay Networks," 2017 IEEE Wireless Communications and Networking Conference (WCNC), San Francisco, CA, 2017, pp. 1-6

Problem Statement

- Major Goals
  - Cognitive TWRNs.
  - Improve SE
  - Analyse EE



Time slot 1

Significance and contribution

- Past Works:
  - Three time slots [5,6].

- This Work:
  - Only two time slots.
  - Interference controlled by power scaling.
  - Relay selection
  - Energy efficiency analysis.

[5] T. T. Duy et al., "Exact outage probability of cognitive two-way relaying scheme with opportunistic relay selection under interference constraint," IET Communications, vol. 6, no. 16, Nov. 2012.
[6] K. B. Fredj et al., "Performance of spectrum-sharing constrained two-way relaying," in 2014 IEEE Wireless Communications and Networking Conference (WCNC), Apr. 2014.

Analytical Results

- Interference on the PU

$$I_{1,k} = P_{1,k}\mathbf{Tr}\left(\mathbf{F}_1^H\mathbf{F}_1\right) + P_{2,k}\mathbf{Tr}\left(\mathbf{F}_2^H\mathbf{F}_2\right) \leq I_t. \quad (1)$$

$$I_{2,k} = P_{R_k}\mathbf{Tr}\left(\mathbf{G}_k^H\mathbf{G}_k\right) \leq I_t. \quad (2)$$

- Power scaling method-2

$$P_{i,k} = \frac{E_{i,k}}{N_i}. \quad (3)$$

- Optimum power allocation

$$E_{1,k}^{*} = \frac{C_k}{(1+\delta)\,N} I_t. \quad (4)$$

Analytical Results

- Asymptotic Sum rate

$$\bar{\mathcal{R}}_k^{\infty,*} = \left(1 - \frac{\Gamma\left(NN_{R_k}, \frac{I_t}{\eta_k E_{R_k}}\right)}{\Gamma\left(NN_{R_k}\right)}\right) N_{R_k} \log\left(1 + \frac{D_k N_{R_k}}{(1+\delta)\,N} I_t\right) \quad (5)$$

Spatial multiplexing

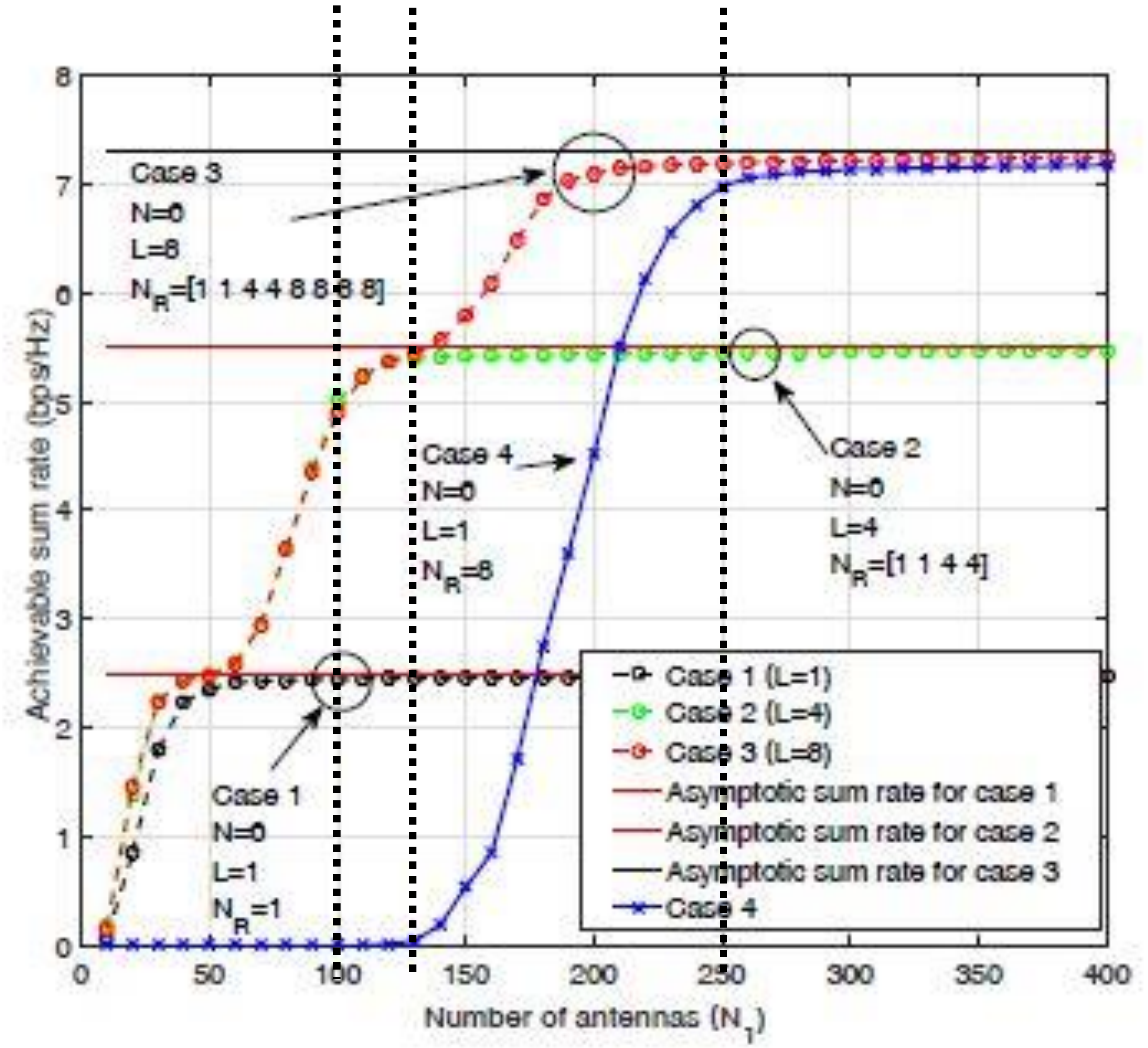
Outage Probability

Asymptotic SINR

N- Number of PU antennas

η_k - Pathloss between PU and the relay

Results



- Asymptotic rate depends on N_{R_k}
- Cut-off value for antennas.

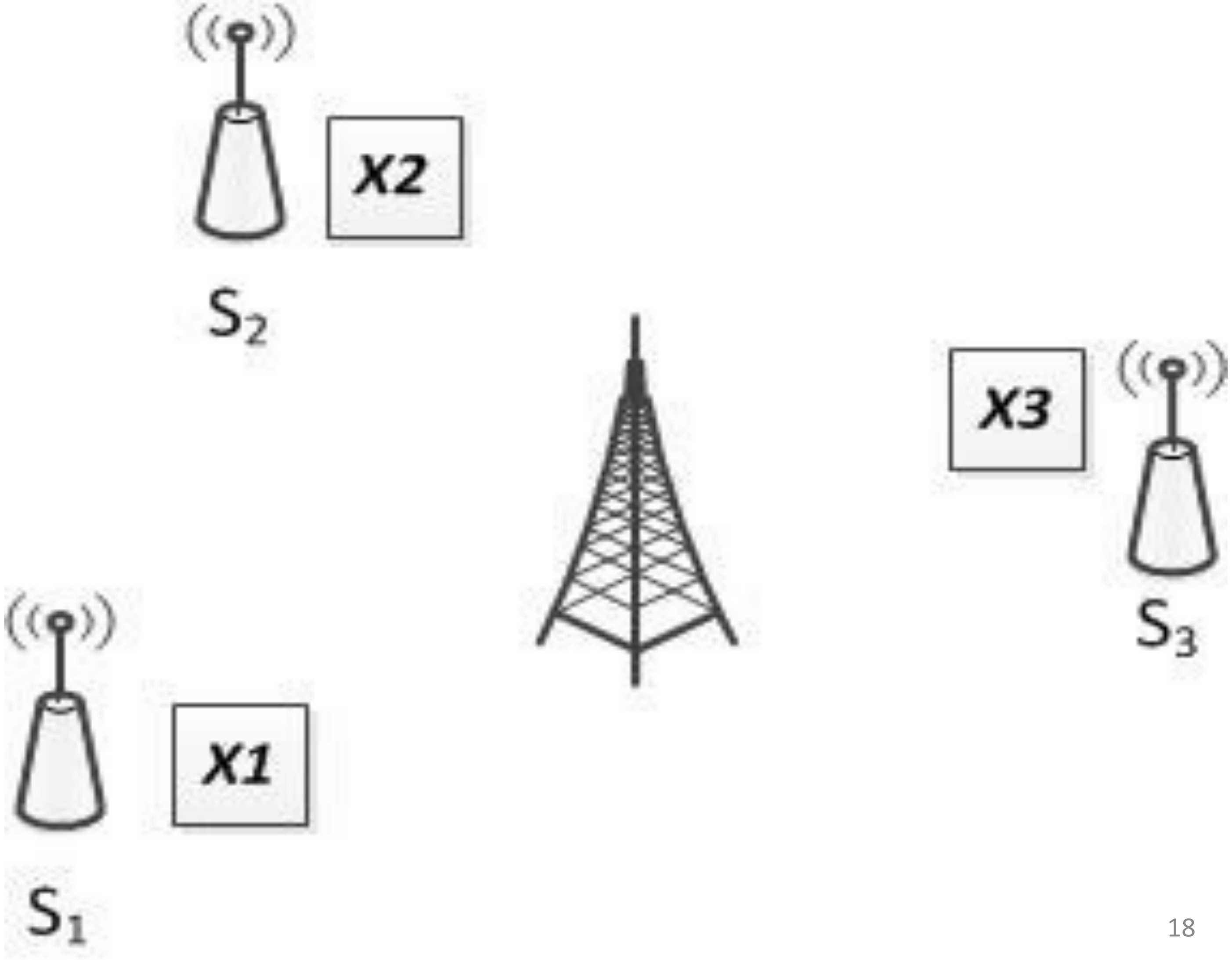
Research Problem 3:

NOMA-Aided Multi-Way mMIMO Relaying

[P5] S. Silva, G. A. A. Baduge, M. Ardakani and C. Tellambura, "NOMA-Aided Multi-Way massive MIMO Relay Networks," 2019 IEEE International Conference on Communications (ICC), Shanghai, China, 2019, pp. 1-6.
[P6] S. Silva, G. A. A. Baduge, M. Ardakani and C. Tellambura, "NOMA-Aided Multi-Way Massive MIMO Relaying," accepted for publication in IEEE Transactions on Communications, 2020.

Problem Statement

- Major Goals
  - Reduce time-slot growth from O(K) to O(1)
  - Improve SE.



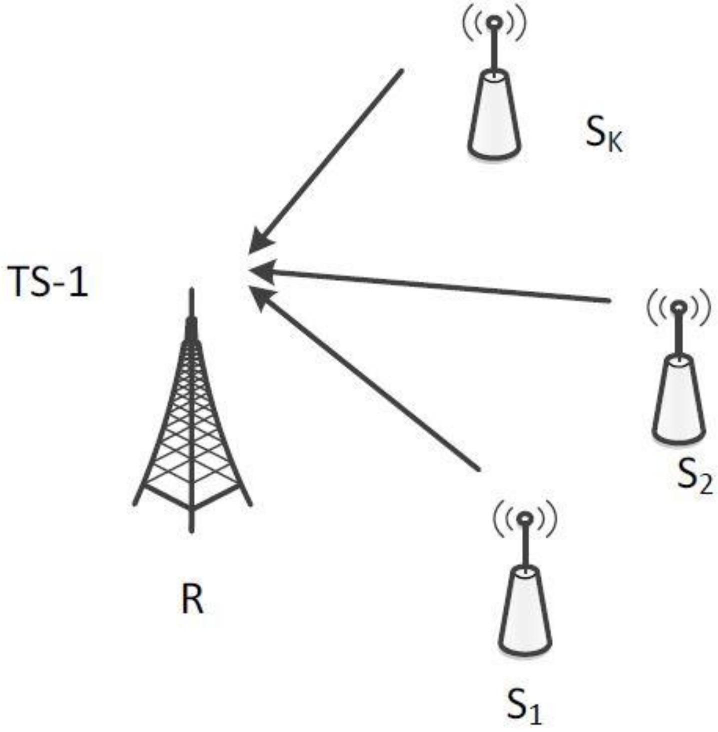
Significance and contribution

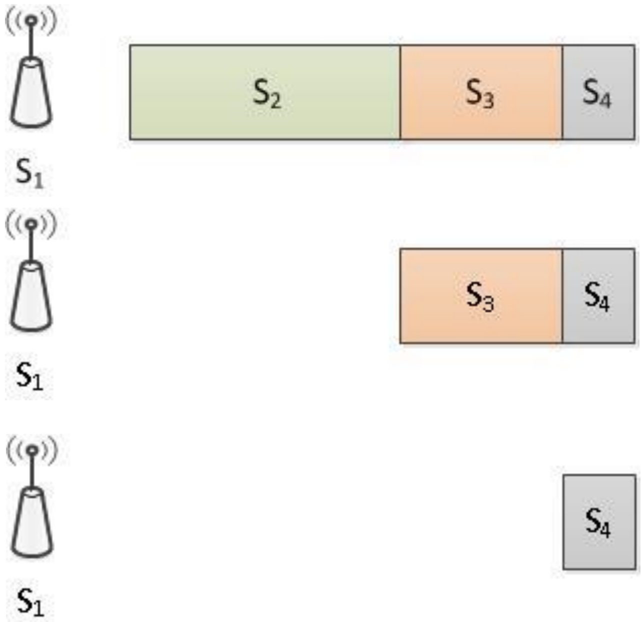
- Past Works:
  - Requires K time slots [7].
  - Reduces to K/2 [8].

- This Work:
  - **Two time slots.**
  - Power allocation for user fairness.
  - Imperfect successive interference cancellation.
  - Energy efficiency.

[7] D. P. Kudathanthirige et al., "Multicell multiway massive MIMO relay networks," IEEE Trans. Veh. Technol., vol. 66, no. 8, Aug. 2017
[8] C. D. Ho et al., "On the performance of zero-forcing processing in multi-way massive MIMO relay networks," IEEE Commun. Lett., vol. 21, no. 4, Apr. 2017.

Proposed MWRN scheme





$$\gamma_{1,2} = \frac{P_2}{P_3 + P_4 + \sigma^2}$$

$$\gamma_{1,3} = \frac{P_3}{P_4 + \sigma^2}$$

$$\gamma_{1,4} = \frac{P_4}{\sigma^2}$$

Analytical Results

- Sum rate

$$\mathcal{R}_{k,f_k(n)} = \frac{(T_C - \tau)}{2T_C} \log\left(1 + \frac{\Psi^2 P\alpha_{f_k(n)} M_{k,n}^2}{\Psi^2\left(P\alpha_{f_k(n)} N_{k,n} + \sum_{m=n+1}^{K-1} P\alpha_{f_k(m)} P_{k,m} + \sum_{m'=1}^{n-1} P\alpha_{f_k(m')} R_{k,m'} + \sigma_R^2 Q_k\right) + \sigma_k^2}\right).$$

N^{th} decoding at k^{th} user

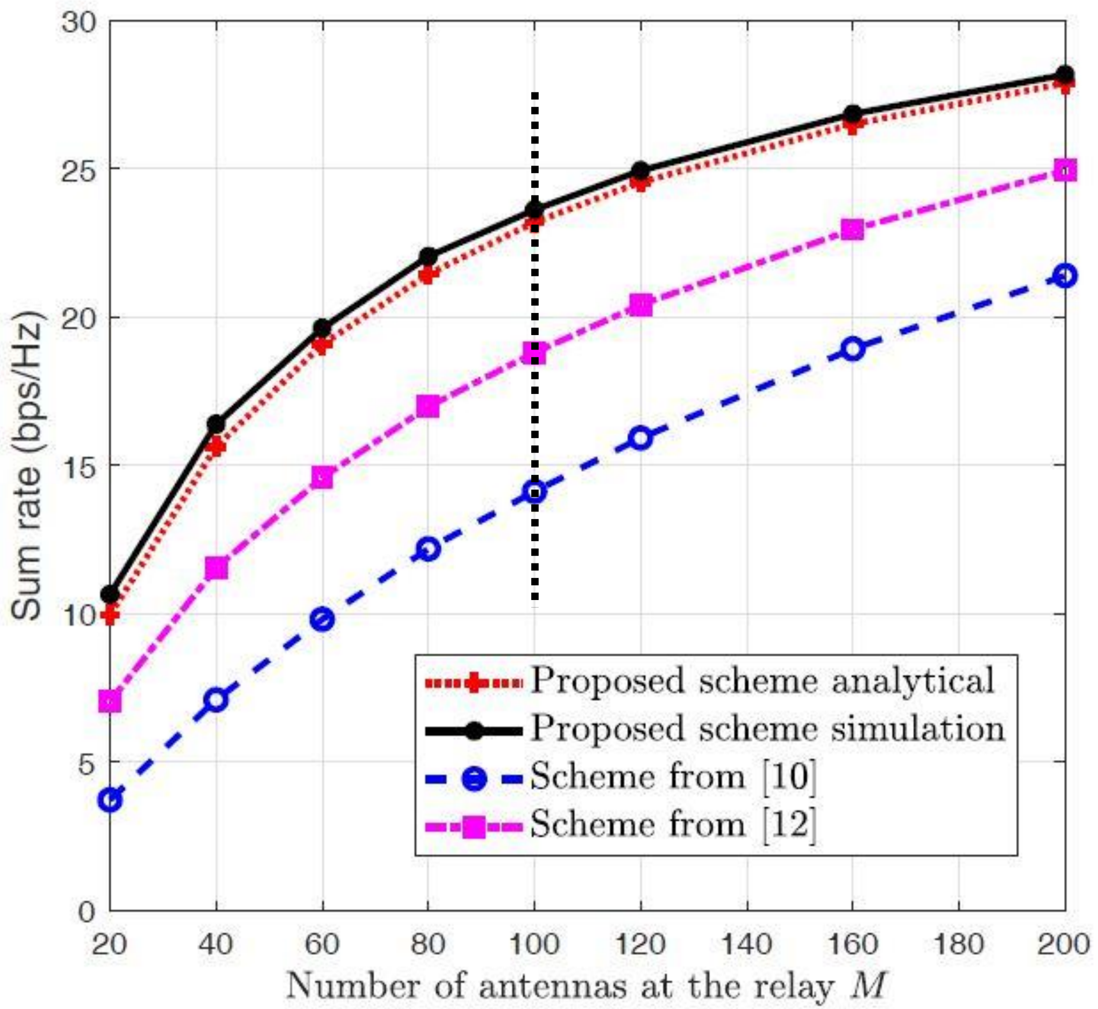
Effects of pilot training

Amplification factor

Effect of SIC

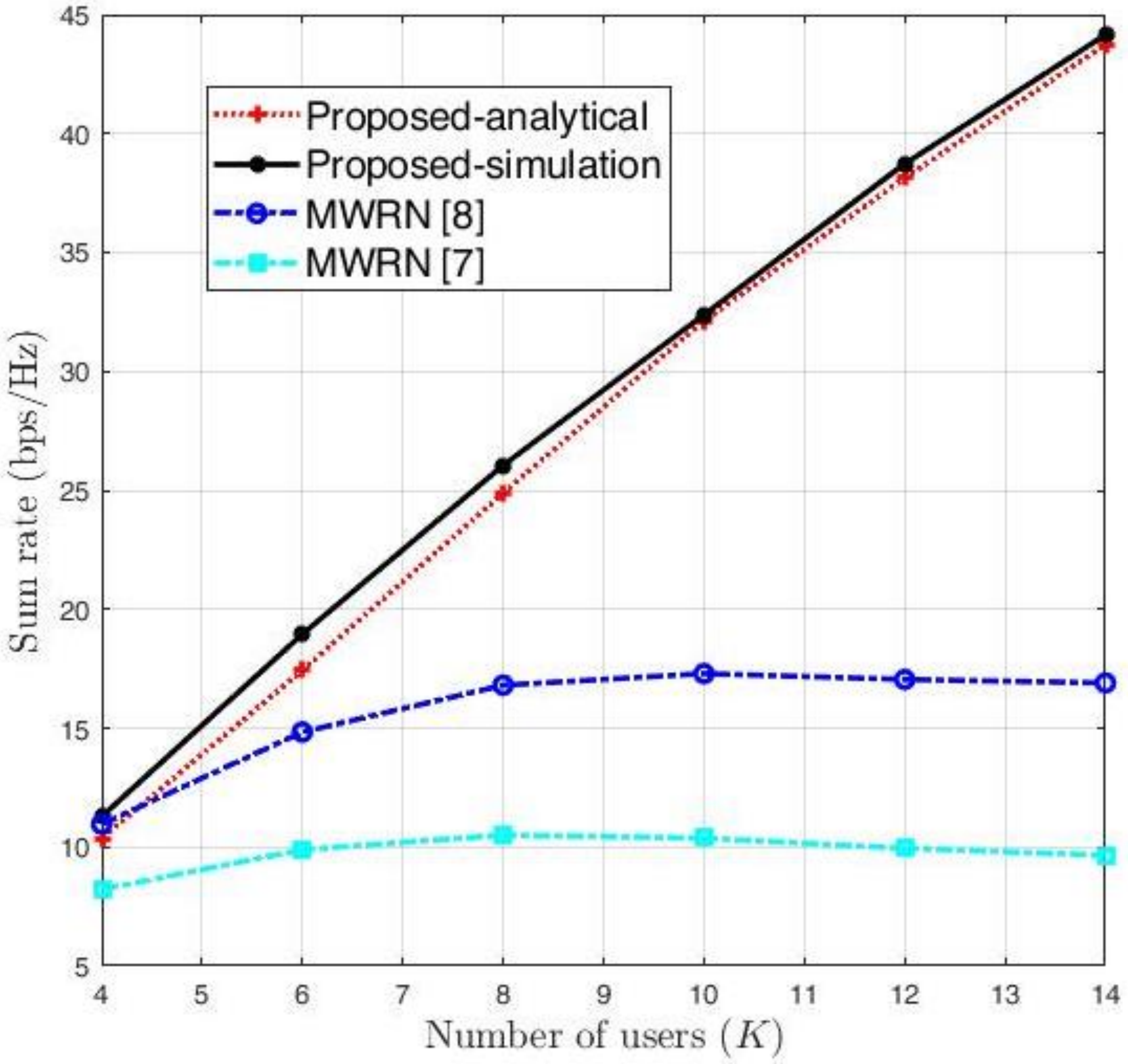
Effect of imperfect SIC

Results



- At 100 antennas
  - 27% gain
  - 65% gain

Results



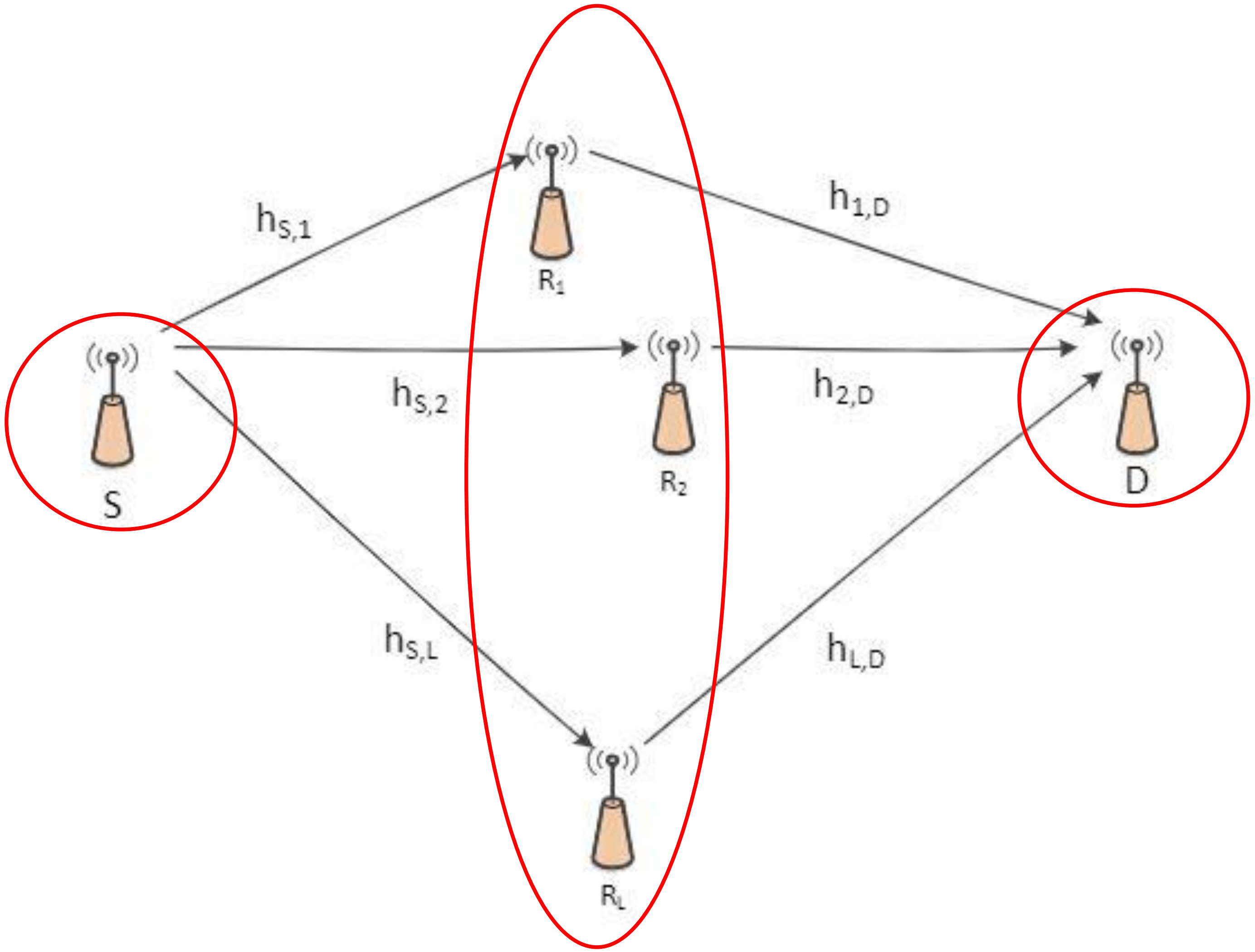
- Sum rate increases with the number of users !

Research Problem 4:

Machine Learning for Multiple Relay Selection

Problem Statement

- Major Goals
  - Reduce relay selection complexity.
  - Achieve full diversity order.
  - Obtain high accuracy.



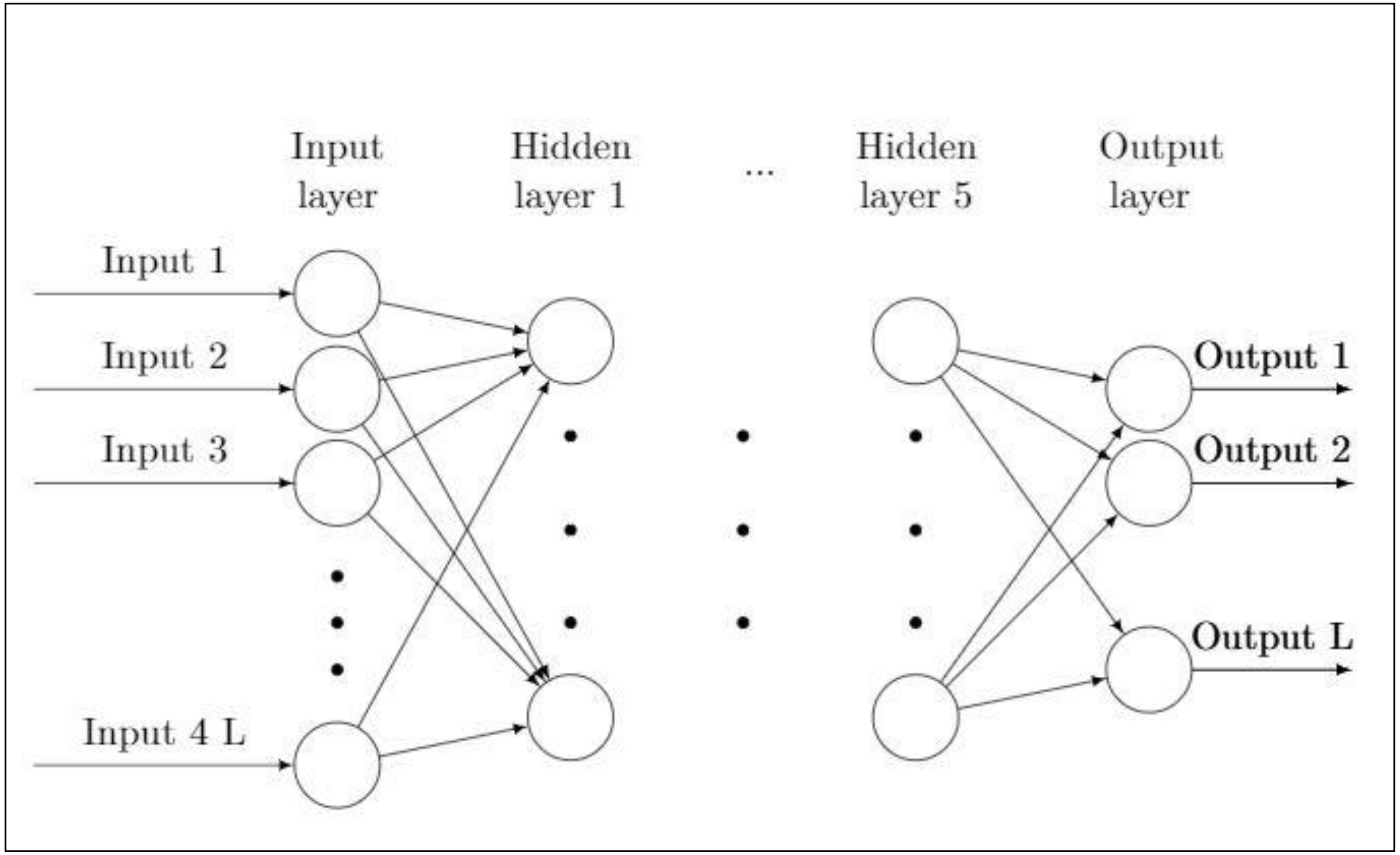
Significance and contribution

- Past Works with ML:
  - ML for antenna selection[10]
  - ML for multiple relay selection [11].

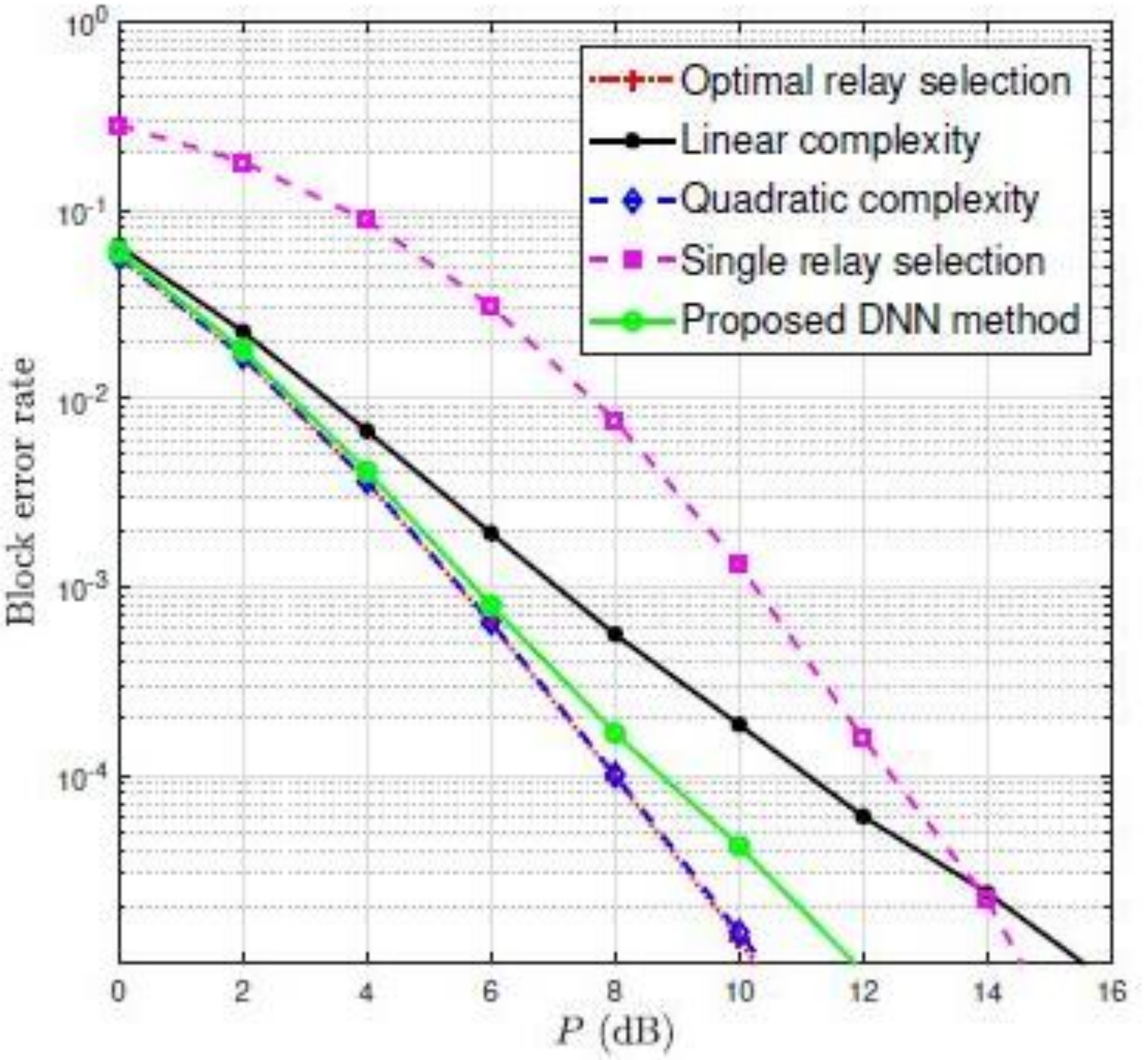
- This Work:
  - Full diversity.
  - Linear complexity.
  - 96% classification accuracy.
  - 99% sum rate accuracy.

[9] Y. Jing et al., “Single and multiple relay selection schemes and their achievable diversity orders,” IEEE Trans. Wireless Commun., vol. 8, no. 3, pp. 1414–1423, Mar. 2009.
[10] J. Joung, “Machine learning-based antenna selection in wireless communications,” IEEE Communications Letters, vol. 20, no. 11, pp. 2241–2244, Nov 2016.
[11] A. Gouissem et al., “Machine-learning based relay selection in AF cooperative networks,” in 2019 IEEE Wireless Communications and Networking Conference (WCNC), April 2019, pp. 1–7.

Deep Neural Network (DNN) based Solution

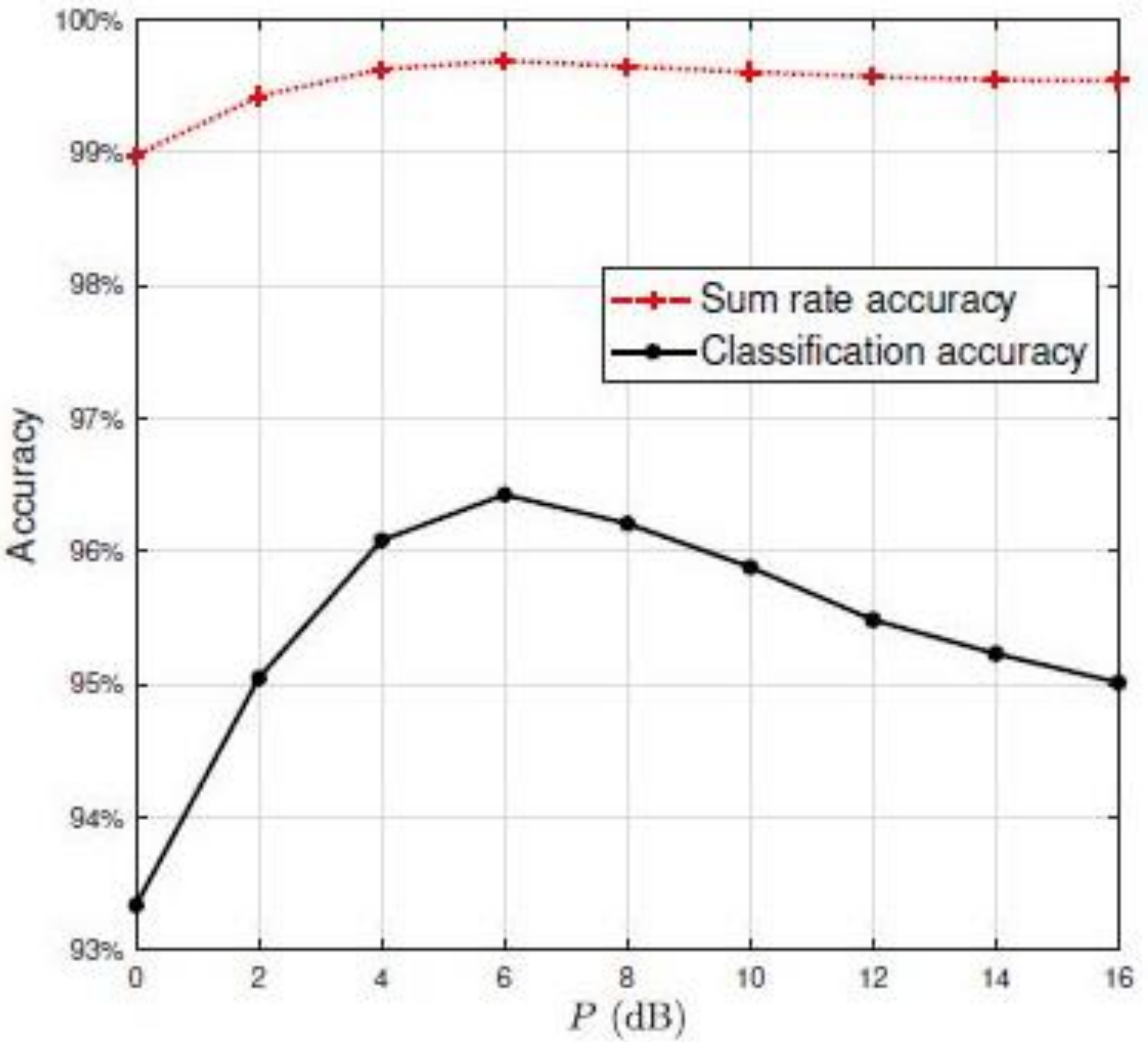


Results



- Optimal diversity order.

Results



- 99% sum rate accuracy.
- 96% classification accuracy.

Future work

- Multi-pair TWRNs in a cell free massive MIMO system.
- TWRNs and relay selection under overlay and interweave CR systems.
- Power allocation to achieve different data rates for MWRN users.
- Other machine learning methods for relay selection.

Conclusions

- In mMIMO multi-pair TWRNs, the performance is degraded by CCI, pilot contamination, imperfect CSI, and antenna correlation.
- TWRN operation is possible in underlay cognitive settings.
- Full data exchange in MWRNs can be enabled in two time slots.
- Machine learning can be successfully utilized to design multiple relay selection schemes.

Thank You