Cooperative Communications for 5G Wireless Systems

Jayamuni Mario Shashindra S. Silva
University of Alberta
jayamuni@ualberta.ca

January 23, 2020
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

46% CAGR 2017–2022

Exabytes per Month

2017 2018 2019 2020 2021 2022
12 19 29 41 57 77

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


Problem Statement

• Major Goals
  • Improve spectral efficiency.
  • Analyse CCI, CSI, pilot contamination, and antenna correlation.
  • Obtain closed form results.
## Significance and contribution

<table>
<thead>
<tr>
<th>Limitations of [2,3,4]:</th>
<th>This Work:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Perfect CSI [2,3].</td>
<td>• Multiple TWRNs.</td>
</tr>
<tr>
<td>• single cell [2,3,4].</td>
<td>• CCI, Imperfect CSI, and pilot contamination.</td>
</tr>
<tr>
<td>• No antenna correlation [2,3,4].</td>
<td>• Antenna correlation.</td>
</tr>
<tr>
<td></td>
<td>• Closed-form solutions.</td>
</tr>
</tbody>
</table>

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**


Problem Statement

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

Analytical Results

• Interference on the PU

\[ I_{1,k} = P_{1,k} \text{Tr} \left( F_{1}^{H} F_{1} \right) + P_{2,k} \text{Tr} \left( F_{2}^{H} F_{2} \right) \leq I_t. \]  \hspace{1cm} (1)

\[ I_{2,k} = P_{R_k} \text{Tr} \left( G_{k}^{H} G_{k} \right) \leq I_t. \]  \hspace{1cm} (2)

• Power scaling method-2

\[ P_{i,k} = \frac{E_{i,k}}{N_i}. \]  \hspace{1cm} (3)

• Optimum power allocation

\[ E_{1,k}^* = \frac{C_k}{(1 + \delta) N} I_t. \]  \hspace{1cm} (4)
Analytical Results

• Asymptotic Sum rate

\[ \hat{R}_k^{\infty,*} = \left( 1 - \frac{\Gamma\left( N N_{R_k} \frac{I_t}{\eta_k E_{R_k}} \right)}{\Gamma\left( N N_{R_k} \right)} \right) N_{R_k} \log \left( 1 + \frac{D_k N_{R_k}}{(1 + \delta) N I_t} \right) \]  

N- Number of PU antennas

\( \eta_k \)- Pathloss between PU and the relay

Spatial multiplexing
Outage Probability
Asymptotic SINR
Results

- Asymptotic rate depends on $N_{R_k}$
- Cut-off value for antennas.
Research Problem 3:

NOMA-Aided Multi-Way mMIMO Relaying


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.

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

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

- N^{th} decoding at k^{th} user
- Amplification factor
- Effect of SIC
- Effect of imperfect SIC
- Effects of pilot training
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]

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

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