Optimization of RRU/UE Pairs for Multi-Point to Multi-UE Coordinated (MP2MUC) Transmissions

Yongzhao Li, Simon Armour and Joe McGeehan

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Outline

- Background and problems
- Multi-Point Multi-UE coordinated (MP2MUC) transmission framework
- Time-Frequency-Synchronization (TFS) constraint assisted cooperative partners selection
- Conclusions
- Ongoing and future work
Background and problems

- Features of IMT-Advanced Cellular Networks
  - Low-cost, high-efficiency
  - High mobility and roaming
  - Target peak data rates: 100 Mbps – 1 Gbps (mobility)
  - Improved cell-edge performance

- Geometrically distributed base station (DBS) is a representative of IMT-advanced cellular networks.

- Cooperative transmission by:
  - multiple mobile terminals
  - Multiple distributed radio heads
Background and problems

- **BBU**: Building Baseband Unit
- **RRU**: Remote Radio Unit
- **fiber**
Background and problems

- Enhanced MIMO is considered as an effective physical-layer technique to obtain **cooperative gain**
  - Multi-user MIMO
  - Cooperative (Virtual) MIMO
  - Cooperative beamforming/precoding
  - CoMP: Coordinated Multi-Point transmission/reception (3GPP)
  - Network MIMO (IEEE)

- Common characteristic amongst all these is the adoption of **cooperative transmission**.
The prerequisite for a successful cooperative transmission is the optimization of cooperative partners:

Various prior art (but not all consider both ends of the link):

- Location-based partner selection
- Greedy partner selection
- Auction-theoretic-based partner selection.
- Instantaneous-channel-quality partner selection
- Energy-based partner selection
Background and problems

现有的问题

- MP2MUC 在文献中没有受到太多关注
- Time-frequency synchronization
  - 不同几何分布的RRUs和Ues
  - 多个UE和RRUs 扩大了问题
- UE的负担和复杂性...

目标

- 低UE复杂度的协作伙伴算法优化，考虑MP2MUC传输的同步限制
Optimization of RRU/UE pairs for Multi-Point to Multi-UE Coordinated (MP2MUC) Transmissions

Typical uplink MP2MUC transmission

- Transmit-set of cooperative UEs
- Receive-set of cooperative RRRs
- Data and/or CSI exchanging

MP2MUC transmission framework
Optimization of RRU/UE pairs for Multi-Point to Multi-UE Coordinated (MP2MUC) Transmissions

**MP2MUC transmission framework**

Equivalent virtual MIMO channel model for an RRU/UE pair

- **M** RRUs
- **N+1** UEs

![Diagram showing MRRUs connected to UEs through a network of channels](image)

**Amplify and Forward (AF) factor**

\[ x_n = \frac{g_n}{\sqrt{|g_n|^2 + s_n^2}} \]

**Equivalent non-direct link gain**

\[ \hat{h}_{m,n} = x_n h_{m,n} \]

**Equivalent overall MIMO channel gain**

\[ H = \begin{bmatrix}
    h_{1,0} & \hat{h}_{1,1} & \hat{h}_{1,2} & \cdots & \hat{h}_{1,N} \\
    h_{2,0} & \hat{h}_{2,1} & \hat{h}_{2,2} & \cdots & \hat{h}_{2,N} \\
    \vdots & \vdots & \vdots & \ddots & \vdots \\
    h_{M,0} & \hat{h}_{M,1} & \hat{h}_{M,2} & \cdots & \hat{h}_{M,N}
\end{bmatrix} \]
Collaboration between both multiple UEs and multiple RRUs is considered

*Time-frequency synchronization constraint* is adopted as the prerequisite criteria

Optimization is mainly implemented by the BBU, resulting in a decrease in UE-complexity
Optimization of RRU/UE pairs for Multi-Point to Multi-UE Coordinated (MP2MUC) Transmissions

**Two-step optimization**

1. **UE requests to access the network**
2. **Establish the set of optional RRU/UE pairs**
3. **MP2MU pairs**
4. **Non-MP2MU pairs**

**Open problem**

- **Time-frequency synchronization assisted 1st step optimization**
- **Channel energy constraint based 2nd step optimization**

**Backup construction for optimal RRU/UE pairs set**

**Assign the optimal pair**

Time/frequency compensation can be implemented at the multiple-node end

**Equation**

\[ E_{ave} = \frac{1}{Q} \sum_{q=1}^{Q} Tr(\hat{H}_q \hat{H}_q^H) \]

\[ \hat{E} = \frac{\gamma_{min} N_0}{P_{max}} \]
**TFS constraint assisted RRU/UE pair selection**

**MP2MUC oriented time-frequency synchronization strategy**

Doppler frequency offset compensation for a 2RRU/2UE system

Exact synchronization condition
\[
\begin{align*}
    f_{d11} - x_1 &= f_{d12} - x_2 \\
    f_{d12} - x_1 &= f_{d22} - x_2
\end{align*}
\]

Equivalent matrix expression
\[
Ax = F \quad A = \begin{bmatrix} 1 & -1 \\ 1 & -1 \end{bmatrix}
F = \begin{bmatrix} f_{d11} - f_{d21} \\ f_{d12} - f_{d22} \end{bmatrix} = \begin{bmatrix} f_{d11} & f_{d12} \\ f_{d21} & f_{d22} \end{bmatrix}^T \begin{bmatrix} 1 \\ -1 \end{bmatrix}
\]

Error relaxation
\[
Ax = F + D \quad D = [d_1, d_2]^T
\]

Formulated problem
\[
\min_x (\|D\|^2) = \min_x (\|Ax - F\|^2)
\text{s.t.} \quad \max(\|d_1\|, \|d_2\|) \leq \delta
\]
The adoption of relaxation constraint can increase the probability of successful synchronization.

The computation of optimal compensation values is accomplished in the BBU; hence, there is no burden for the UEs.

By modifying the corresponding parameters a similar time synchronization algorithm can be easily obtained.
Differences between Time and Frequency Offset problems:

- A tolerable residual time offset is allowed in timing synchronization without any relaxation, due to the adoption of a guard interval.
- If the maximum residual time offset of the branches is less than $T_g - \tau_{\text{max}}$, no extra time compensation is needed.
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$f_c = 2$ GHz
$\Delta f = 15$ kHz
$v = 30$~$200$ km/s
Tolerable RFO = 0.01

CP = 4.7 $\mu$s
$\tau_{\text{max}} = 3.0$ $\mu$s
Tolerable RTO = 1.7 $\mu$s
TFS constraint assisted RRU/UE pair selection

An example of two-step optimization of RRU/UE pairs

Initial set of optional RRU/UE pairs

1. RRU_{1,7}/UE_{0.1}
2. RRU_{1,7}/UE_{0.2}
3. RRU_{1,7}/UE_{0.3}
4. RRU_{1,7}/UE_{0,1,2}
5. RRU_{1,7}/UE_{0,1,3}
6. RRU_{1,7}/UE_{0,2,3}
7. RRU_{1,7}/UE_{0,1,2,3}

After TFS constraint selection

1. RRU_{1,7}/UE_{0.1}
2. RRU_{1,7}/UE_{0.2}
3. RRU_{1,7}/UE_{0.3}
4. RRU_{1,7}/UE_{0,1,2}
5. RRU_{1,7}/UE_{0,1,3}
6. RRU_{1,7}/UE_{0,2,3}
7. RRU_{1,7}/UE_{0,1,2,3}

After channel energy constraint selection

1. RRU_{1,7}/UE_{0.1}
2. RRU_{1,7}/UE_{0.2}
3. RRU_{1,7}/UE_{0.3}
4. RRU_{1,7}/UE_{0,1,2}
5. RRU_{1,7}/UE_{0,1,3}
6. RRU_{1,7}/UE_{0,2,3}
7. RRU_{1,7}/UE_{0,1,2,3}

* For simplicity, only multi-RRU/multi-UE pairs are shown in this slide and RRU selection fixed based on location.
TFS constraint assisted RRU/UE pair selection

Performance comparison for Multi-point/Multi-UE pairs

A comparison among all 2RRU/2UE pairs

Pair #1: RRU\(_{1,7}\) / UE\(_{0,1}\)

Pair #2: RRU\(_{1,7}\) / UE\(_{0,2}\)

Pair #3: RRU\(_{1,7}\) / UE\(_{0,3}\)

Pair #1 and Pair #2 are discarded after two-step optimization

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TFS constraint assisted RRU/UE pair selection

Performance comparison for Single-point/Multi-UE pairs

Better performance with lower UE-complexity
Performance comparison for Multi-point/Single-UE pairs

Performance loss with lower UE-complexity

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TFS constraint assisted RRU/UE pair selection
Conclusions

- Applicable for collaboration between both multiple UEs and multiple RRUs (MP2MUC)
  - Compatible for SP2MUC, MP2SUC and SP2SUC
- A possible solution for the time-frequency synchronization in MP2MUC
  - Failed RRU/UE pairs (in terms of synchronization) can be discarded as soon as possible
- Low UE-complexity
- Easy extension to cooperative handoff
High-efficient handshaking protocol design

TFS related work
- Different optimization solving approaches
- The statistical distribution of Doppler/time offset
- The statistical analysis of successful synchronization
- Selection of target function
- Optimization of constraint condition

Incorporation into joint multi-D resource allocation

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MP2MUC, Multi-Point to Multi-User Coordination

BS end
- Single RRU
- Multiple RRUs (cooperative/non-cooperative)

UE end
- Single UE
- Multiple UEs (cooperative/non-cooperative)

Refer to RRU as a transmission point
Optimization of RRU/UE pairs for Multi-Point to Multi-UE Coordinated (MP2MUC) Transmissions

An application in cooperative handoff

Cooperative hard handoff

BBU periodically surveils the quality of backup of optimal RRU/UE pairs set

If there exists some RRU/UE pair which satisfies 2-step optimization constraints

Establish new set of optional RRU/UE pairs

Two-step optimization

Construct new backup of the RRU/UE pairs set

Assign the optimal pair

Cooperative soft handoff

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