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

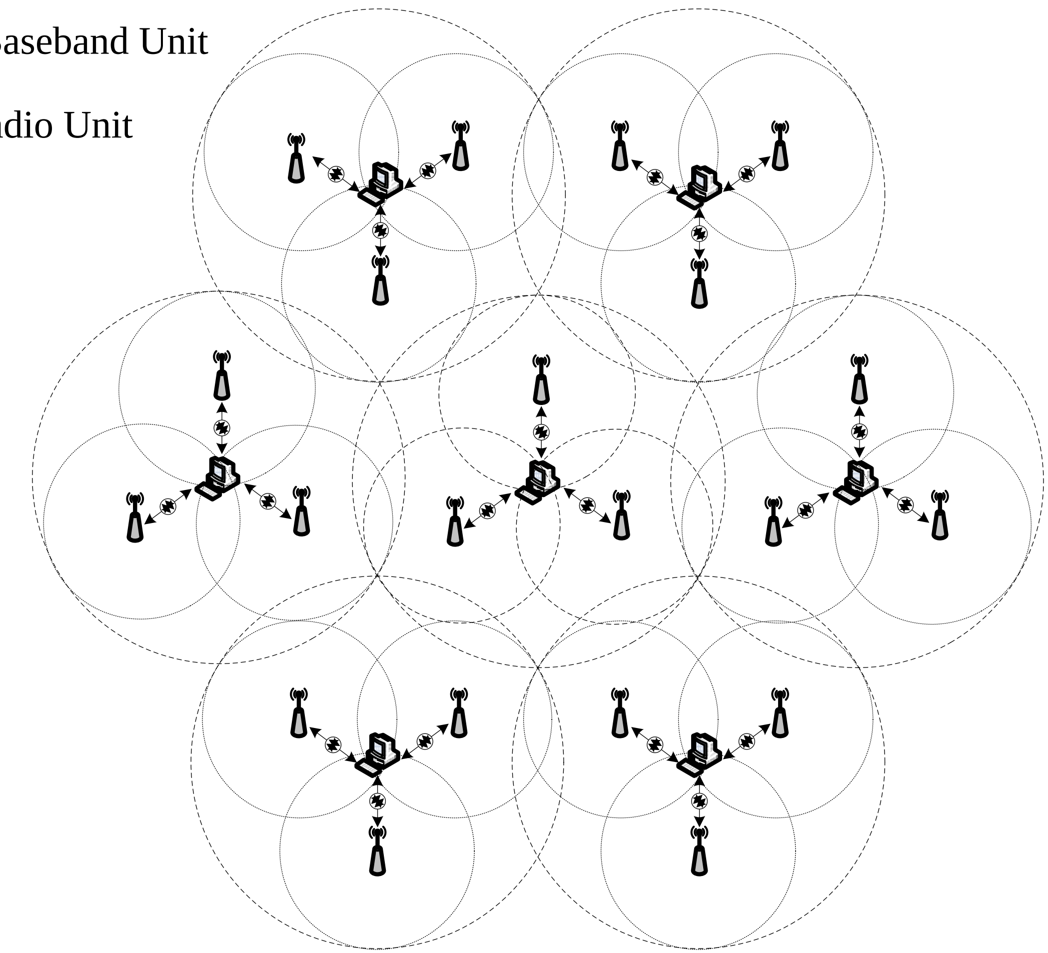
- Features of IMT-Advanced Cellular Networks
  - Low-cost, high-efficiency
  - High mobility and roaming
  - Target peak data rates: 100 Mbps – 1 Gbps (mobility)
  - Improved cell-edge performance
- Geometrically distributed base station (DBS) is a representative of IMT-advanced cellular networks.
- **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**.

Background and problems

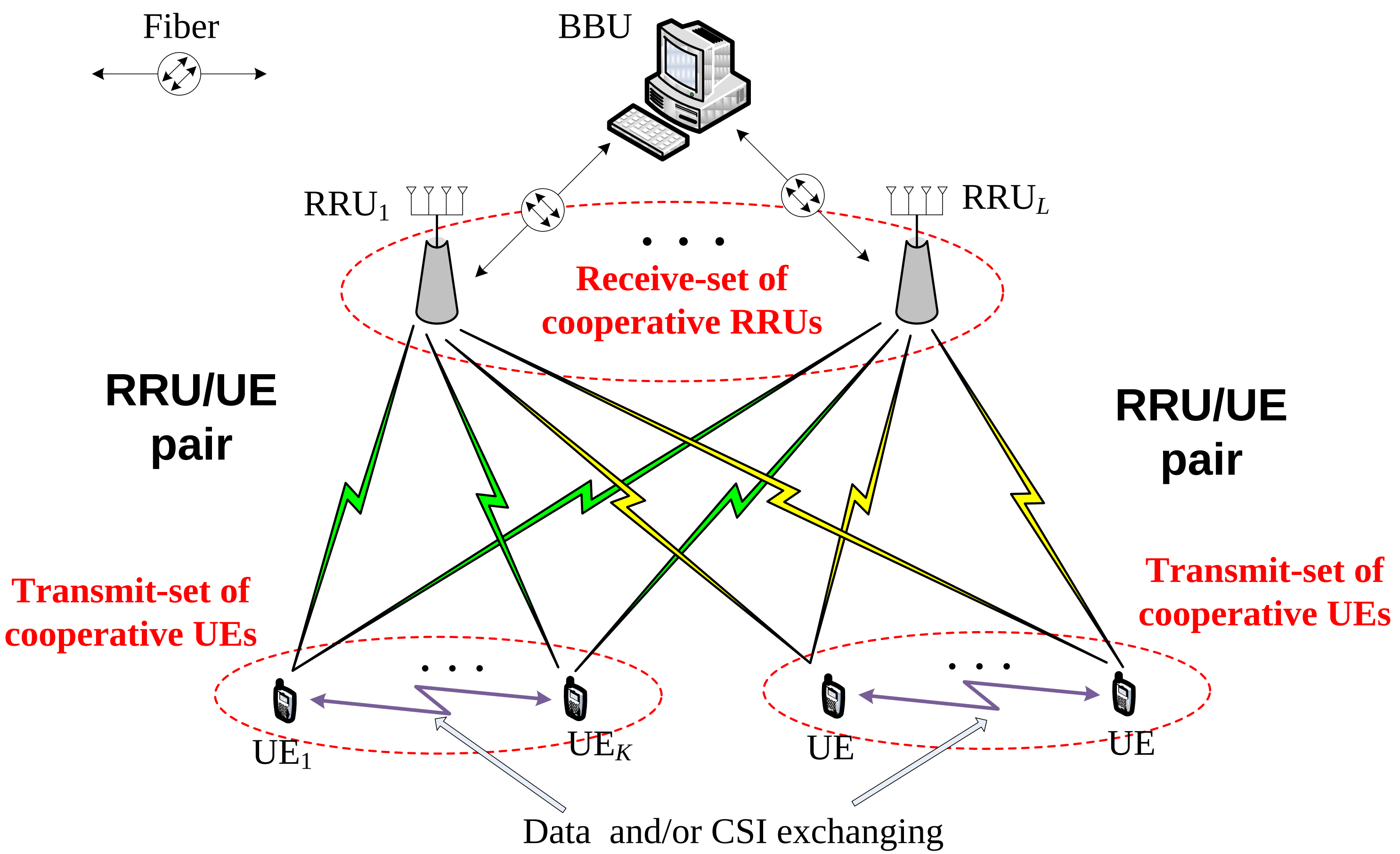
- The prerequisite for a successful cooperative transmission is the optimization of cooperative partners:
- Various prior art (but not all consider both ends of the link):
  - *Location-based partner selection*
  - *Greedy partner selection*
  - *Auction-theoretic-based partner selection.*
  - *Instantaneous-channel-quality partner selection*
  - *Energy-based partner selection*

Background and problems

- Existing Problems
  - MP2MUC has not received much attention in the literature
  - Time-frequency synchronization
    - Differently geometrically distributed RRUs and Ues
    - Multiple UEs and RRUs expands the problem
  - UEs' burden and complexity…
- Objective
  - Low UE-complexity optimization of cooperative partners algorithms for MP2MUC transmissions taking into account synchronisation limitations

MP2MUC transmission framework

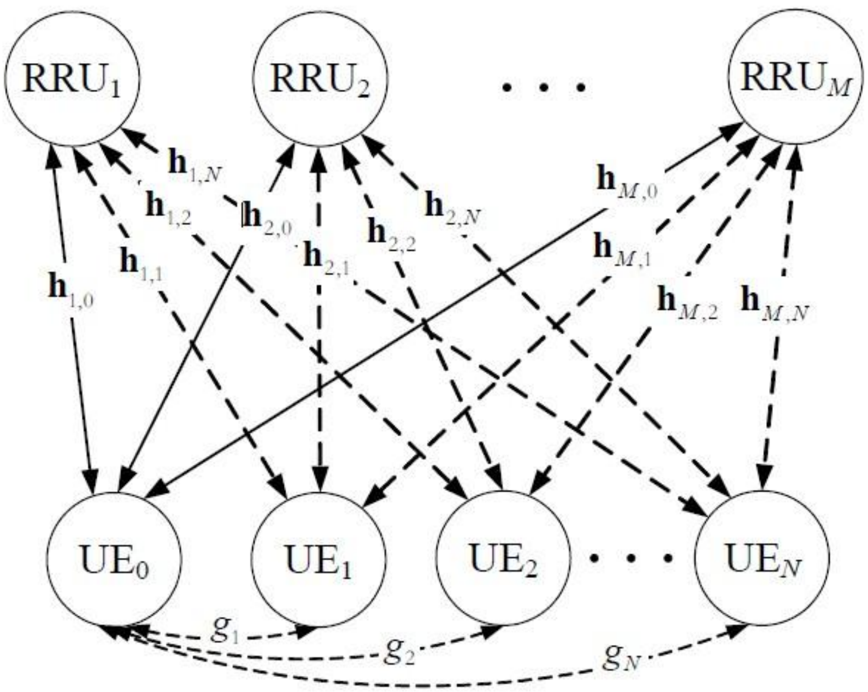
Typical uplink MP2MUC transmission



MP2MUC transmission framework

Equivalent virtual MIMO channel model for an RRU/UE pair

M RRUs



N+1 UEs

Amplify and Forward (AF) factor

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

Equivalent non-direct link gain

$$\hat{\mathbf{h}}_{m,n} = x_n \mathbf{h}_{m,n}$$

Equivalent overall MIMO channel gain

$$\mathbf{H} = \begin{bmatrix} \mathbf{h}_{1,0} & \hat{\mathbf{h}}_{1,1} & \hat{\mathbf{h}}_{1,2} & \cdots & \hat{\mathbf{h}}_{1,N} \\ \mathbf{h}_{2,0} & \hat{\mathbf{h}}_{2,1} & \hat{\mathbf{h}}_{2,2} & \cdots & \hat{\mathbf{h}}_{2,N} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \mathbf{h}_{M,0} & \hat{\mathbf{h}}_{M,1} & \hat{\mathbf{h}}_{M,2} & \cdots & \hat{\mathbf{h}}_{M,N} \end{bmatrix}$$

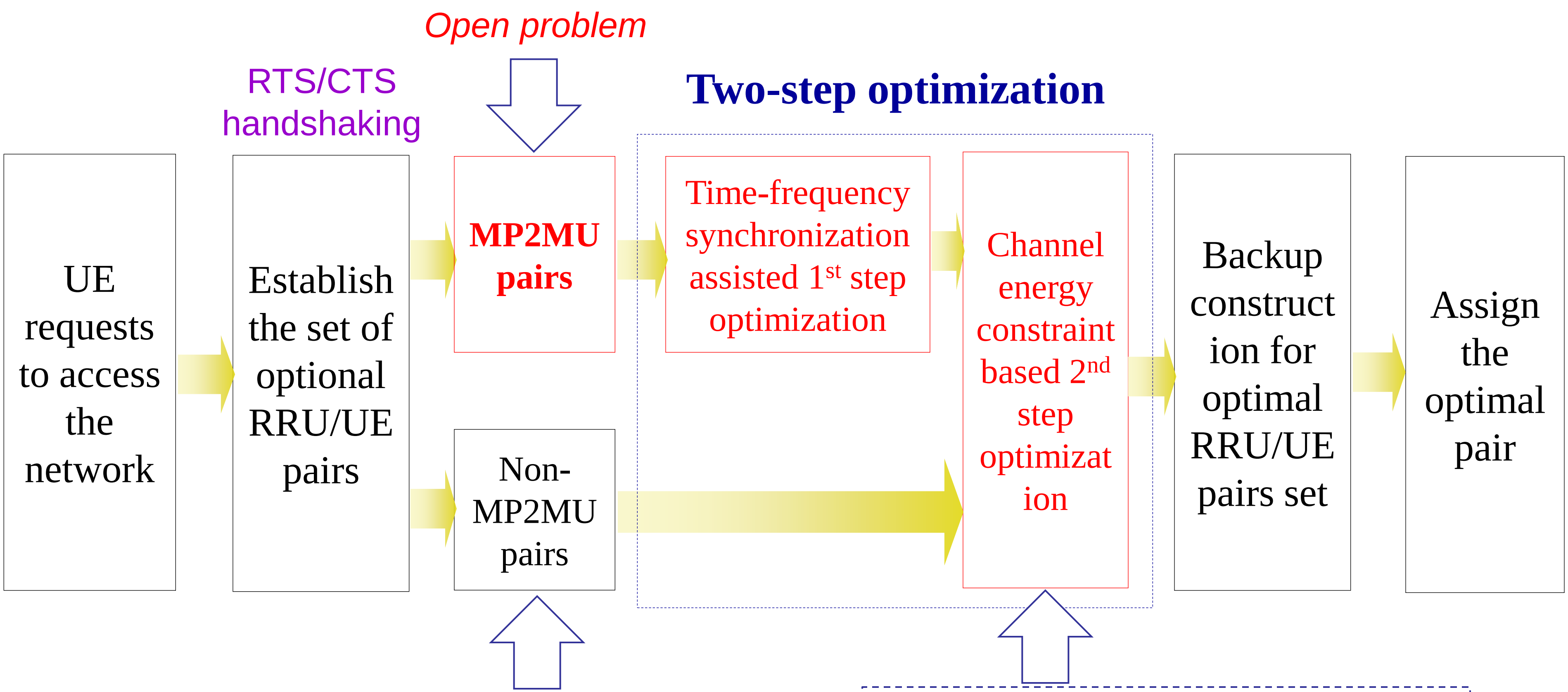
TFS constraint assisted RRU/UE pair selection

Major considerations

- 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

TFS constraint assisted RRU/UE pair selection

Two-step optimization

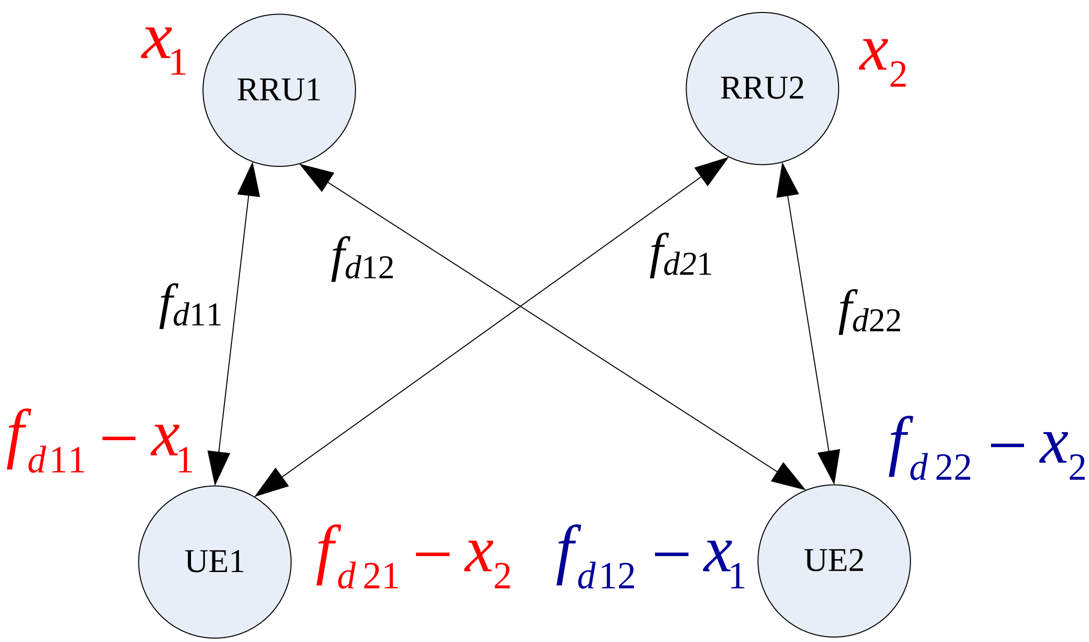


Time/frequency compensation can be implemented at the multiple-node end

$$E_{ave} = \frac{1}{Q}\sum_{q=1}^{Q} Tr(\tilde{\mathbf{H}}_q \tilde{\mathbf{H}}_q^H) \qquad \hat{E} = \frac{\gamma_{\min} N_0}{P_{\max}}$$

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

$$\begin{cases} f_{d11}-x_1 = f_{d21}-x_2 \\ f_{d12}-x_1 = f_{d22}-x_2 \end{cases}$$

Equivalent matrix expression

$$\boldsymbol{Ax}=\boldsymbol{F} \qquad \boldsymbol{A}=\begin{bmatrix}1 & -1\\ 1 & -1\end{bmatrix}$$

$$\boldsymbol{F}=\begin{bmatrix} f_{d11}-f_{d21} \\ f_{d12}-f_{d22}\end{bmatrix}=\begin{bmatrix} f_{d11} & f_{d12} \\ f_{d21} & f_{d22}\end{bmatrix}^T\begin{bmatrix}1\\ -1\end{bmatrix}$$

Error relaxation

$$\boldsymbol{Ax}=\boldsymbol{F}+\boldsymbol{D} \qquad \boldsymbol{D}=[d_1,d_2]^T$$

Formulated problem

$$\min_{\boldsymbol{x}}\left(\|\boldsymbol{D}\|^2\right)=\min_{\boldsymbol{x}}\left(\|\boldsymbol{Ax}-\boldsymbol{F}\|^2\right)$$

$$\text{s.t.}\quad \max(|d_1|,|d_2|)\le\delta$$

TFS constraint assisted RRU/UE pair selection

MP2MUC oriented time-frequency synchronization strategy

- 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

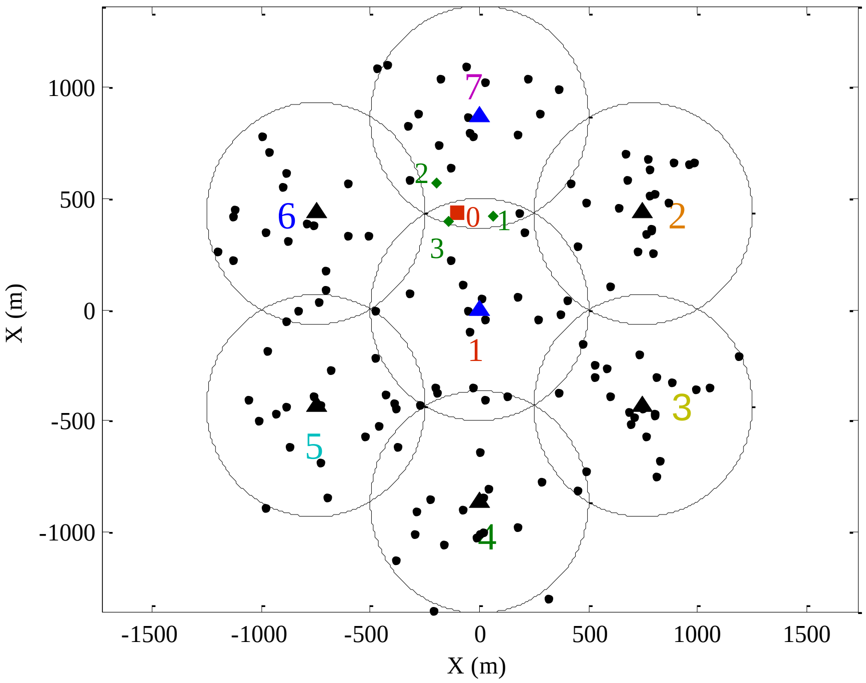
TFS constraint assisted RRU/UE pair selection

MP2MUC oriented time-frequency synchronization strategy

- 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 $T_g - \tau_{max}$, no extra time compensation is needed.

TFS constraint assisted RRU/UE pair selection

Network layout



f_c =2 GHz

Δf=15 kHz

v=30~200 km/s

Tolerable RFO=0.01

CP=4.7 μs

τ_{max}=3.0 μs

Tolerable RTO=1.7 μs

■ Desired UE_0

▲ Cooperative RRU_1 RRU_7

◆ Cooperative UE_1 UE_2 UE_3

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

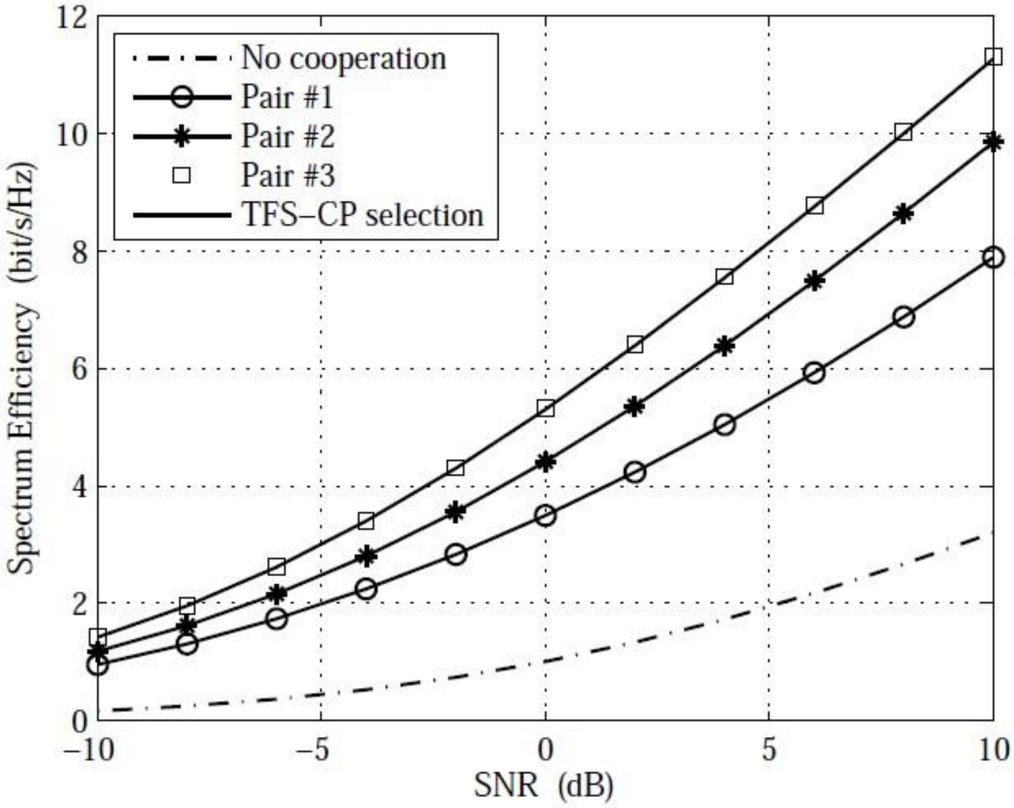
① $RRU_{1,7}$ /$UE_{0.1}$ ② $RRU_{1,7}$ /$UE_{0,2}$ ③ $RRU_{1,7}$ /$UE_{0,3}$
④ $RRU_{1,7}$ /$UE_{0,1,2}$ ⑤ $RRU_{1,7}$ /$UE_{0,1,3}$ ⑥ $RRU_{1,7}$ /$UE_{0,2,3}$ ⑦ $RRU_{1,7}$ /$UE_{0,1,2.3}$

* 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: $RRU_{1,7}$ / $UE_{0,1}$

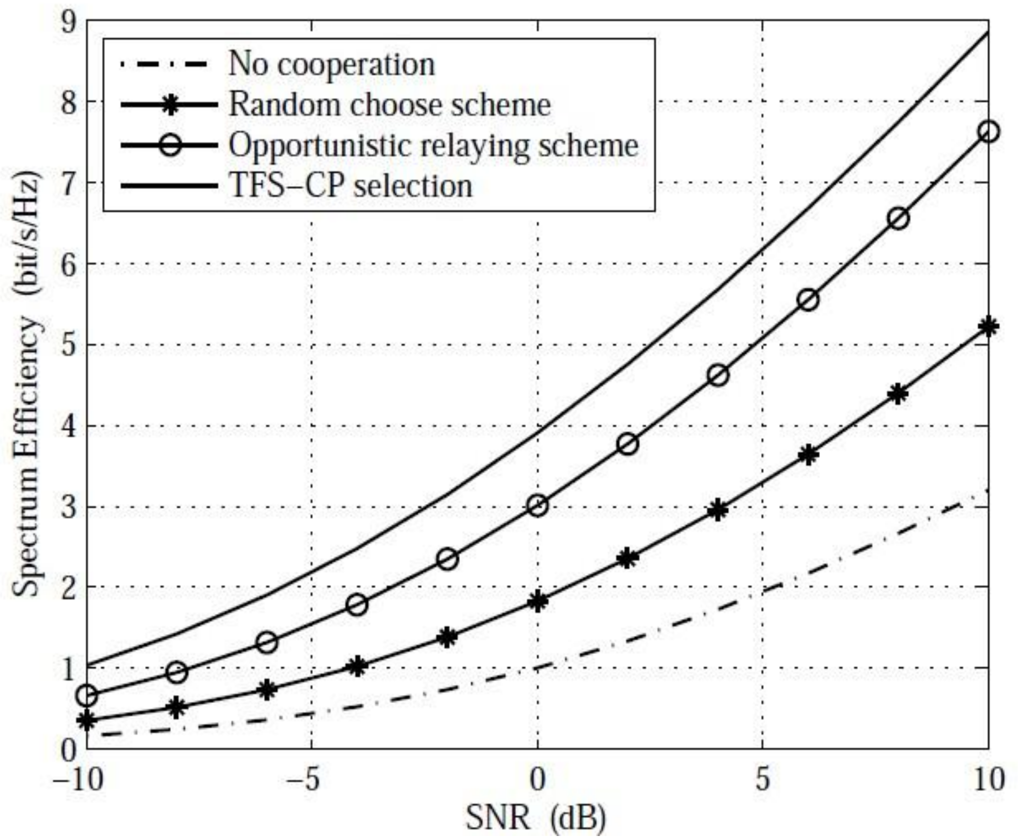
Pair #2: $RRU_{1,7}$ / $UE_{0,2}$

Pair #3: $RRU_{1,7}$ / $UE_{0,3}$

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

TFS constraint assisted RRU/UE pair selection

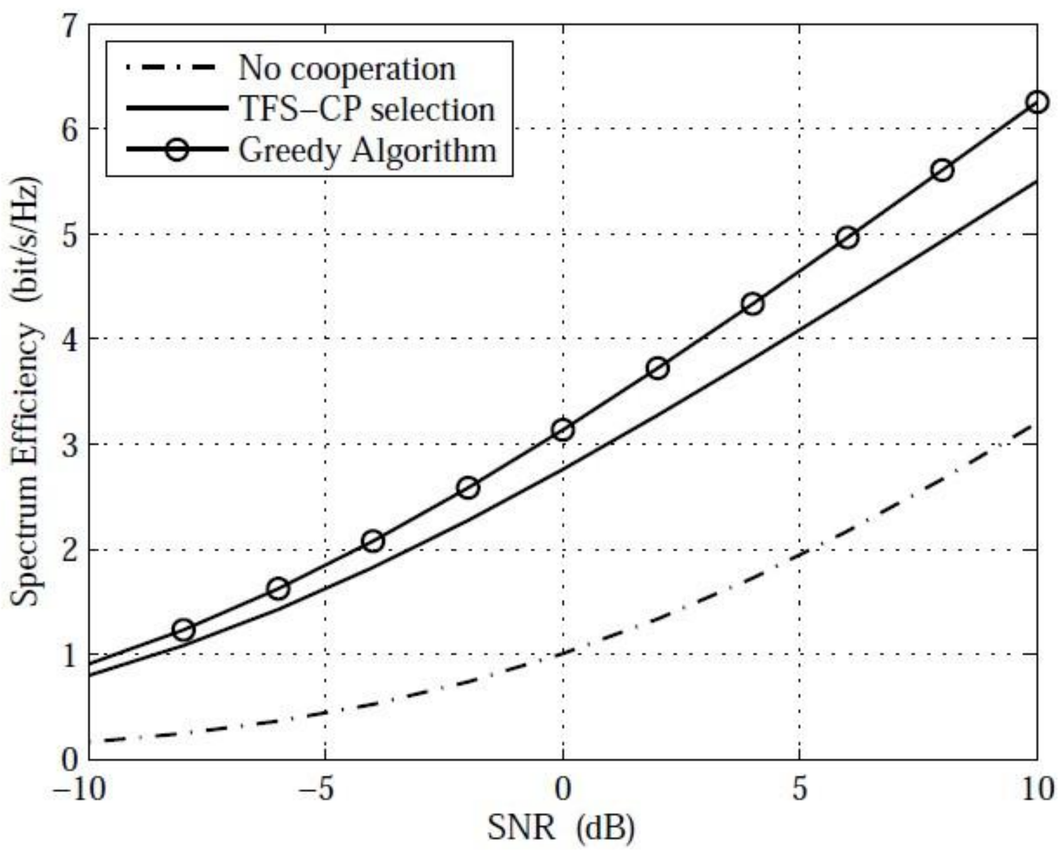
Performance comparison for Single-point/Multi-UE pairs



Better performance with lower UE-complexity

TFS constraint assisted RRU/UE pair selection

Performance comparison for Multi-point/Single-UE pairs



Performance loss with lower UE-complexity

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

Ongoing and future work

- 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
- …

Q&A

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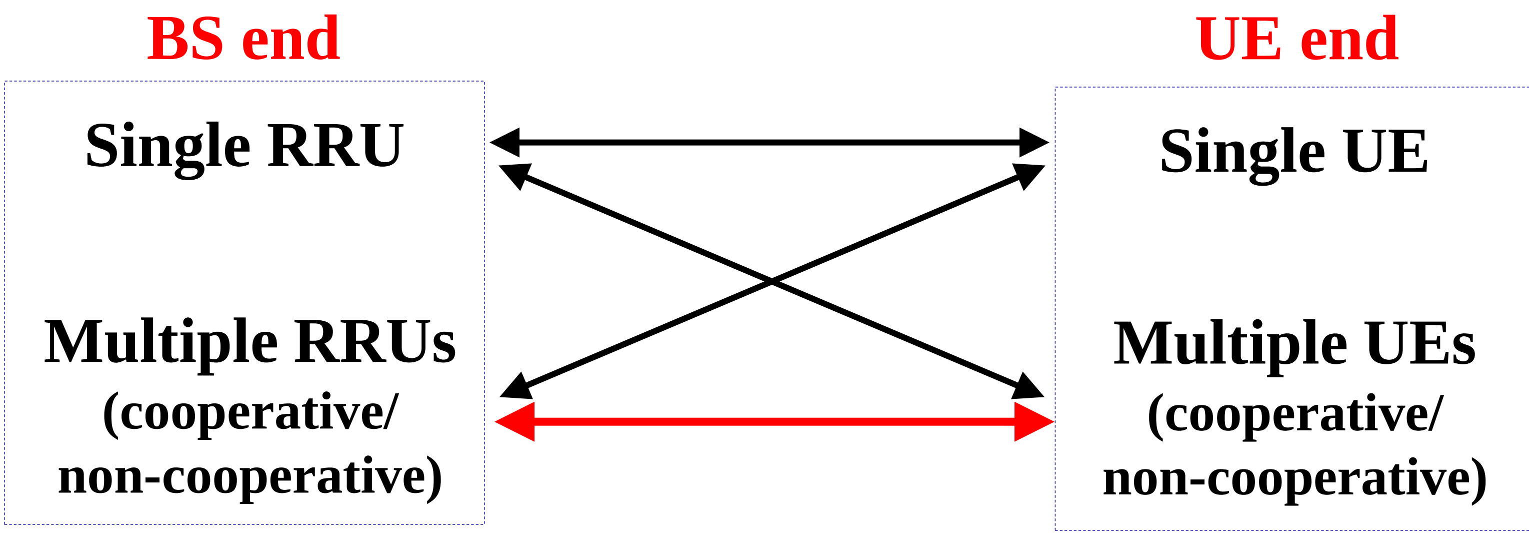
MP2MUC transmission framework

MP2MUC，Multi-Point to Multi-User Coordination



Refer to RRU as a transmission point

An application in cooperative handoff