Joint Resource Allocation in Multi-user Cooperative LTE-A Network with Service Differentiations

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Outline

- Motivation
- Previous Work
- System Model
- Solution Approach
- Simulation Parameters
- Results
- Conclusion
Motivation

- 4G network services
- Diversified applications and high data rate requirements
- Cell edge throughput and coverage
- MIMO, Carrier aggregation, CoMP
- Cooperative communication
Previous works

- **Type-I**
  - RS can help a remote UE which is far away from eNodeB
  - Needs to transmit its own reference signal, control information for eNodeB
  - RS has the full functions of an eNodeB except backhauling

- **Type-II**
  - RS help a local UE unit which is located within the coverage of eNodeB
  - UE has a direct communication with eNodeB
  - Does not transmit common reference signal or control information
Previous works
System Model

- Consider an LTE-A uplink
- $K$ users are uniformly distributed
- $N$ fixed relays are uniformly distributed at a distance $\delta R$ from the eNodeB
- The destination node (eNodeB) has perfect CSI of SD link and all RD links
- Regenerate and forward
- eNodeB use MRC
Our objective is to maximize the total system throughput

\[
(P1) \quad \max_{\rho, P_t} \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m R_{k,n}^m
\]

subject to

- **c1:** $\rho_{k,n}^m \in \{0, 1\}, \forall k, m, n$
- **c2:** $\sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n}^m = 1, \forall m$
- **c3:** $R_k \geq q_k, \forall k \in \kappa_1$
- **c4:** $\sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m P_{t,k}^m \leq P_T$
- **c5:** $P_{t,k}^m \geq 0, \forall k, m, n$
Dual Problem

- The Lagrangian function of our problem

\[
L(\rho, P_t, \lambda, \mu) = \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m R_{k,n}^m + \sum_{k \in \kappa1} \lambda_k \left( \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m R_{k,n}^m - Q_k \right) + \mu (P_T - \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m P_{t,k}^m)
\]

(29)

= \sum_{n=1}^{N} \left[ \sum_{k=1}^{K} \sum_{m=1}^{M} \rho_{k,n}^m R_{k,n}^m + \sum_{k \in \kappa1} \lambda_k \sum_{m=1}^{M} \rho_{k,n}^m R_{k,n}^m - \mu \sum_{k=1}^{K} \sum_{m=1}^{M} \rho_{k,n}^m P_{t,k}^m \right] - \sum_{k \in \kappa1} \lambda_k Q_k + \mu P_T

- Decomposition

- Dual problem can be decomposed into M subproblem at each subcarrier which can be solved independently given lambda and mu

- Each subproblem is solved in two phases
  - Optimal power allocation for a given relay selection and subcarrier assignment
  - Joint relay selection and subcarrier assignment for the given optimal power allocation
Suboptimal Algorithm

Algorithm 3 Pseudo code for Suboptimal Algorithm 2

Initialization
a. set $R_k = 0, S_k = 0, \forall k$ and $A = 1, 2, ..., M.$

STEP 1: RC users
while $A \neq 0$ and $R_k < R_Q$ for any $k \in \kappa_1$ do
  a. Select user $k^* = \arg \max_{k \in \kappa_1} (R_Q - R_k)$.
  b. For the found $k^*$, find $(n^*, m^*) = \arg \max_{n,m \in n_k} R_{k^*,n}^n$.
  c. Assign the subcarrier $m^*$ to $(n^*, k^*)$.
  d. Update $S_{k^*} = S_{k^*} \cup m^*$, $A = A - m^*$ and $R_{k^*} = R_{k^*} - R_{k^*,m^*}$.
end while

STEP 2: Power Refinement for RC users
a. Refine power using power refinement method stated in Section-IV.

STEP 3: Subcarrier Adjustment
for each user $k \in \kappa_1$ do
  while $R_k > R_Q$ do
    a. Find $m = \arg \min_{m \in n_k} (R_k^n)$
    b. If $(R_k - R_{k,m}^n) \geq R_Q$ then
      b. Update $S_k = S_k - m$, $A = A \cup m$, $R_k = R_k - R_{k,m}^n$.
    end if
  end while
end for

STEP 4: BE users
while $A \neq 0$ do
  a. Find $(n^*, k^*, m^*) = \arg \max_{n,k,m \in n_{K1},n_k,m \in n_k} R_{k^*,n}^{n,m}$
  b. Update $S_{k^*} = S_{k^*} \cup m^*$, $A = A - m^*$ and $R_{k^*} = R_{k^*} - R_{k^*,m^*}^n$.
end while

STEP 5: Power Refinement for BE users
a. Refine power using power refinement method stated in Section-IV.
Power Refinement Method

- After relay selection and subcarrier assignment using equal power
- Optimal power allocation is performed for a given subcarrier-relay assignment

\[
\max_{P_t} \sum_{k=1}^{K} \sum_{m=1}^{M} R_{k,n}^m
\]

\[c1: R_k > Q_k, \forall k \in k1\]

\[c2: \sum_{k=1}^{K} \sum_{m=1}^{M} P_{t,k}^m \leq P_T\]
Power Refinement Method 2

\[ x_k = \frac{1 + \lambda_k}{2\mu} = P^{m*} + \frac{1}{\alpha_{k,eq}} \]

\[ |S_k| x_k = \sum_{m \in S_k} \left[ P^m_{t,k} + \frac{1}{\alpha_{k,eq}} \right] \]

\[ x_k = \frac{1}{|S_k|} \left[ P_{t,k} + \sum_{m \in S_k} \frac{1}{\alpha_{k,eq}} \right] \]

\[ P_{t,k}^{m*} = \left[ x_k - \frac{1}{\alpha_{k,eq}} \right]^{+} \]
# Computational Complexity

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal</td>
<td>$O(KM^2N)$</td>
</tr>
<tr>
<td>Optimal without RC</td>
<td>$O(TKM^N) = O(KM^N)$</td>
</tr>
<tr>
<td>Suboptimal</td>
<td>$O(KM^N)$</td>
</tr>
<tr>
<td>Suboptimal with power refinement M1</td>
<td>$O(KM^N + KM^2)$</td>
</tr>
<tr>
<td>Suboptimal with power refinement M2</td>
<td>$O(KM^N)$</td>
</tr>
</tbody>
</table>
# Numerical Results

## Simulation Parameters

<table>
<thead>
<tr>
<th>Name of the Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total system bandwidth</td>
<td>2.5 MHz</td>
</tr>
<tr>
<td>Total number of RB</td>
<td>13</td>
</tr>
<tr>
<td>Total number of subscribers</td>
<td>156</td>
</tr>
<tr>
<td>Number of UEs</td>
<td>8</td>
</tr>
<tr>
<td>Number of relays</td>
<td>2, 4, 6, 8</td>
</tr>
<tr>
<td>Total power available at UE</td>
<td>23 dBm</td>
</tr>
<tr>
<td>Total power available at relay</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Noise power spectral density</td>
<td>-174 dBm per Hz</td>
</tr>
<tr>
<td>Path loss exponent</td>
<td>3.76</td>
</tr>
</tbody>
</table>

## Power Delay Profile of Extended ITU Ped. B Model

<table>
<thead>
<tr>
<th>Delays (ns)</th>
<th>Power(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>-0.9</td>
</tr>
<tr>
<td>800</td>
<td>-4.9</td>
</tr>
<tr>
<td>1200</td>
<td>-8</td>
</tr>
<tr>
<td>2300</td>
<td>-7.8</td>
</tr>
<tr>
<td>3700</td>
<td>-23.9</td>
</tr>
</tbody>
</table>
Results
Results(2)
Conclusion

- Our approach provides user satisfaction by sacrificing some amount of total system throughput
- It supports heterogeneous traffic
- The computational complexity of our algorithm is higher, but the base station can easily perform the optimization
\[ P_{k,n}^m = \frac{1}{2} \left[ \log_2 (1 + P_{t,k}^m \alpha_{k,eq}^m) \right] \]

\[ P_{s,k}^m + P_{r,n}^m = P_{t,k}^m \]

\[ P_{s,k}^m = \begin{cases} \frac{\alpha_{k,n}^m}{\alpha_{k,n}^m + \alpha_{n,D}^m - \alpha_{k,D}^m} P_{t,k}^m, & \text{if cooperative mode is selected} \\ P_{t,k}^m, & \text{otherwise} \end{cases} \]

\[ P_{r,n}^m = \begin{cases} \frac{\alpha_{k,n}^m - \alpha_{k,D}^m}{\alpha_{k,n}^m + \alpha_{n,D}^m - \alpha_{k,D}^m} P_{t,k}^m, & \text{if cooperative mode is selected} \\ 0, & \text{otherwise} \end{cases} \]

\[ \alpha_{k,eq}^m = \begin{cases} \frac{\alpha_{k,n}^m \alpha_{n,D}^m}{\alpha_{k,n}^m + \alpha_{n,D}^m - \alpha_{k,D}^m}, & \text{if cooperative mode is selected} \\ \alpha_{k,D}^m, & \text{otherwise} \end{cases} \]
Relay selection and subcarrier allocation

- Substituting the power variables, we have

\[ H_{k,n}(\lambda, \mu) = \frac{1}{2}(1 + \bar{\lambda}_k)[\log_2(1 + P_{t,k}^{m*} \alpha_{k,eq}^m)] - \mu P_{t,k}^{m*} \]

\[ \rho_{k,n}^m = \begin{cases} 
1, (n^*, k^*) = \arg \max_{n,k} H_{k,n} \\
0, \text{otherwise}
\end{cases} \]

- Variable update

\[ \lambda_k(t + 1) = \left[ \lambda_k(t) + \eta(t) \left( \sum_{n=1}^{N} \sum_{m=1}^{M} \rho_{k,n}^m(t) R_{k,n}^m(t) - Q_k \right) \right]^+ \]
\[ \mu(t + 1) = \left[ \mu(t) + \theta(t) \left( \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m(t) P_{t,k}^m(t) - P_T \right) \right]^+ \]