Relay Selection and Resource Allocation in Multi-user Cooperative LTE-A Network with Service Differentiations

Cooperative Group Meeting
Date: September 06, 2011
Outline

- Motivation
- System Model
- Solution Approach
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- Results
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Motivation

● 4G services
  – Person-to-person communication
  – Content delivery
  – Social networking
  – Business services

● Diversified applications and high data rate requirements

● Cell edge throughput and coverage

● MIMO, Carrier aggregation, CoMP

● Cooperative communication
Relay types

- **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
Relay types(2)
System Model

- Consider an LTE-A uplink
- $K$ users are uniformly distributed
- $N$ fixed relays are uniformly distributed at a distance $0.5R$ from the eNodeB
- The destination node (eNodeB) has perfect CSI of SD link and all RD links
- Regenerate and forward
- eNodeB use MRC
Problem Formulation

- 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: $R_{k,n}^m \geq Q_k, \forall k \in \kappa_1$

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: $P_{t,k}^m \geq 0, \forall k, m, n$

\[ R_{k,n}^m = \frac{1}{2} \left[ \log_2 \left( 1 + P_{t,k}^m \alpha_{k,eq}^m \right) \right] \]

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

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

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

\[ \alpha_{k,eq}^m = \begin{cases} \frac{\alpha_{k,n}^m \alpha_{n,D}^m}{\alpha_{k,n}^m + \alpha_{n,D}^m - \alpha_{k,D}^m}, & \text{if cooperative mode is selected} \\ \alpha_{k,D}, & \text{otherwise} \end{cases} \]
**Dual Problem**

- The Lagrangian function of our problem

\[
L(\rho, P_t, \lambda, \mu) = \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m P_{k,n}^m + \sum_{k \in \kappa_1} \lambda_k \left( \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m R_{k,n}^m - Q_k \right) + \mu (P_T - \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{k,n}^m P_{t,k}^m) \\
= \sum_{n=1}^{N} \left[ \sum_{k=1}^{K} \sum_{m=1}^{M} \rho_{k,n}^m R_{k,n}^m + \sum_{k \in \kappa_1} \lambda_k \sum_{m=1}^{M} \rho_{k,n}^m R_{k,n}^m - \mu \sum_{k=1}^{K} \sum_{m=1}^{M} \rho_{k,n}^m P_{t,k}^m \right] - \sum_{k \in \kappa_1} \lambda_k Q_k + \mu P_T
\]  

(29)

- The dual function

\[
g(\lambda, \mu) = \begin{cases} 
\max_{\rho, P_t} & L(\rho, P_t, \lambda, \mu) \\
\text{s.t.} & \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n}^m \leq 1, \forall m \\
& \rho_{k,n}^m \in \{0, 1\}, P_{t,k}^m \geq 0 
\end{cases}
\]
Decomposition

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

\[
L_m(\rho^m, P^m_t) = \begin{cases} 
\sum_{k=1}^{K} \sum_{m=1}^{M} \rho_{k,n}^m R_{k,n}^m + \sum_{k \in \kappa_1} \lambda_k \sum_{m=1}^{M} \rho_{k,n}^m R_{k,n}^m - \mu \sum_{k=1}^{K} \sum_{m=1}^{M} \rho_{k,n}^m P_{t,k}^m \\
\text{s.t. } \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n}^m \leq 1, \\
\rho_{k,n}^m \in \{0, 1\}, P_{t,k}^m \geq 0, \forall k, n
\end{cases}
\]

- Optimal power allocation for a given relay selection and subcarrier assignment

- Applying KKT condition

\[
P_{t,k}^{m*} = \left[ \frac{1 + \lambda_k}{2\mu} - \frac{1}{\alpha_{k,eq}^m} \right]^+
\]
Relay selection and subcarrier allocation

- Substituting the power variables, we have

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

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

- Variable update

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

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

### Simulation Parameters

<table>
<thead>
<tr>
<th>Name of the Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total system bandwidth</td>
<td>1.25 MHz</td>
</tr>
<tr>
<td>Total number of subscribers</td>
<td>64</td>
</tr>
<tr>
<td>Number of UEs</td>
<td>4, 8, 16</td>
</tr>
<tr>
<td>Number of relays</td>
<td>1 to 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)

Graph showing the SI index against the number of relays. The graph compares 'Rate Constrained' and 'Unconstrained' conditions.
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