Utility Based Radio Resource Allocation in LTE Networks

Ming Li, M.Sc.

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Radio Resource Allocation

• Radio Resource Allocation (RRA): the amount of resources allocated to different users
  – Make the best use of limited resources under time varying channel conditions
  – Fairness, latency reduction, spectral efficiency and system utilization

• Utility-based Radio Resource Allocation
  – Utility reflects actual users’ perceived performance (QoE)
  – Optimization problem: Maximize the aggregated utility, subject to limited resources
QoE examples [1][2]

Figure: Videos with transcoding [1]

Figure: Web browsing (page size of 130 Kbytes) [2]
# Utility functions

## Elastic traffics; Video with transcoding

<table>
<thead>
<tr>
<th>Applications</th>
<th>Properties</th>
<th>Function Type</th>
<th>Utility function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QoE monotonically increases with the data rate; Marginal QoE monotonically decreases with the data rate</td>
<td>Sigmoid Function (Concave part)</td>
<td>[ u(r) = \frac{A}{1 + e^{-\alpha r}} + D ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Utility curves</th>
<th><img src="image_url" alt="Graph" /></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>with A=9, B=-4.5</em></td>
<td></td>
</tr>
</tbody>
</table>
Problem formulation

• The utility function of the user $i$ can be formulated as:

$$u_i(b_i) = \frac{A}{1 + e^{-\alpha_i b_i \sigma_i}} + D \quad (A > 0, \alpha_i > 0)$$

• The goal for the resource allocation is to maximize the aggregated cell utility, which can be expressed as:

$$\max_U, \quad U = \sum_{i \in \{b_i\}} u_i = \sum_i \left( \frac{A}{1 + e^{-\alpha_i b_i \sigma_i}} + D \right) \quad (A > 0, \alpha_i > 0)$$

$$\text{s.t. } \sum_i b_i \leq B, \quad b_i \geq 0; \quad b_i \in \mathbb{R}$$

• The problem is convex and has a strong duality, which can be solved optimally using the Lagrangian decomposition method.
Lagrangian dual problem formulation

• The Lagrangian dual problem is:

\[
\min_{\lambda} \left\{ \max_{\{b_i\}} \left\{ \sum_i \left( \frac{A}{1 + e^{-\alpha_i b_i \sigma_i}} + D \right) - \lambda \left( \sum_i b_i - B \right) \right\} \right\}
\]

s.t. \( \forall b_i \geq 0 \)

• Consider the problem:

\[
q = \sum_i \max_{b_i} \left\{ \frac{A}{1 + e^{-\alpha_i b_i \sigma_i}} + D - \lambda b_i \right\} + \lambda B
\]

\( \forall b_i \geq 0, L_i \) is a concave function and has one and only one maximum \( L_i^* \). Then the dual problem becomes:

\[
\min_{\lambda} q = \min_{\lambda} \left\{ \sum_i L_i^* + \lambda B \right\}
\]

\( q \) has one and only one minimum, which is also the optimal solution to the primal problem.
Solution of the dual problem

Without loss of generality, we assume (\(N\) is the number of active users):

\[ 0 \leq \lambda_1 \leq \lambda_2 \leq \ldots \leq \lambda_N \quad \lambda_i = \frac{A\alpha_i\sigma_i}{4} \]

\(q\) reaches its minimum between \((\lambda_i, \lambda_{i+1})\), and it can be found using the bisection search method.

The solution for the primal problem is:

\[ b_k^* = \begin{cases} 
0, & \forall k \leq i \\
\frac{2}{\alpha_k\sigma_k} \arctanh \left( \frac{\sqrt{A\alpha_k\sigma_k(A\alpha_k\sigma_k - 4\lambda^*)}}{A\alpha_k\sigma_k} \right), & \forall i < k \leq N
\end{cases} \]

Each user \(k\) is assigned

\[ \left\lfloor \frac{b_k}{180\text{KHz}} \right\rfloor \text{ PRBs} \]

Figure: Visualization of function \(q(\lambda) = \sum L_i^* + \lambda B\)
Use **OPNET** discrete event simulation software (v17.5)
Includes modeling of

- E-UTRAN and EPC entities
- Full protocol stack including MAC, RLC, PDCP, GTP etc.
- Mobility models
- IP DiffServ
## Simulation settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eNBs/cells</td>
<td>1 eNBs serving 1 cell</td>
</tr>
<tr>
<td>Channel Model</td>
<td>Path loss: $128.1 + 37.6\log_{10}(d)$, $d$ in km</td>
</tr>
<tr>
<td></td>
<td>Slow fading: Correlated Log normal, zero mean, 8 dB std. and 50 m</td>
</tr>
<tr>
<td></td>
<td>correlation distance</td>
</tr>
<tr>
<td></td>
<td>Fast fading: 3GPP Pedestrian A, 5 km/h</td>
</tr>
<tr>
<td>Mobility Model</td>
<td>Random Direction</td>
</tr>
<tr>
<td>CQI reports</td>
<td>Perfect with 1ms delay</td>
</tr>
<tr>
<td>TCP version</td>
<td>New Reno</td>
</tr>
<tr>
<td>Scenario</td>
<td>15 PRBs (3 MHz)</td>
</tr>
<tr>
<td></td>
<td>8 Video users</td>
</tr>
<tr>
<td></td>
<td>8 FTP users</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>1000s (each run with 5 different seeds)</td>
</tr>
</tbody>
</table>
## Scheduler comparisons [3]

<table>
<thead>
<tr>
<th>Time Domain (Resource Allocation)</th>
<th>UT (Utility based)</th>
<th>PF (Proportion al fair)</th>
<th>MT (Maximum Throughput)</th>
<th>BET (Blind equal throughput)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>( \max \sum_{i=1}^{N} u_i )</td>
<td>( \arg \max \frac{r_i}{R_i} )</td>
<td>( \arg \max r_i )</td>
<td>( \arg \max \frac{1}{R_i} )</td>
</tr>
<tr>
<td>Number of users scheduled</td>
<td>According to algorithm</td>
<td>( N_s = \min (5,N) )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of PRBs assigned per user</td>
<td>( \frac{M}{N_s} )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Frequency Domain (Resource Assignment) : Channel Aware Round Robin

- \( r_i \): Maximum achievable data rate of user \( i \) in current TTI
- \( \bar{R}_i \): Moving average data rate of user \( i \)
- \( N \): Number of users with buffered data
- \( M \): Number of Available PRBs after HARQ
Utility functions used in simulation

\[ u(r) = MOS(r) = \frac{9}{1 + e^{-\alpha r}} - 4.5 \]

\( \alpha = 2 \) for Video users [1]
\( \alpha = 0.3 \) for FTP users

*MOS: Mean Opinion Score*
CCDF curve of MOS

UT: Utility Based
PF: Proportional Fair
MT: Maximum Throughput
BET: Blind Equal Throughput

Video users

FTP users

* each sample is the average MOS over 5 seconds
Average MOS value*

* MOS based on the long time average throughput

UT: Utility Based
MT: Maximum Throughput
PF: Proportional Fair
BET: Blind Equal Throughput
A utility based radio resource allocation framework for LTE is proposed.

The problem is formulated as a convex optimization problem and analytically solved using Lagrangian decomposition method.

The approach is implemented in the simulator. The performance of utility based approach is compared against other schedulers.
Next step: Utility based RRA in Cloud-RAN

Transport network bandwidth $B_{S1}$

Cell bandwidth $B_c$

Figure: LTE C-RAN cluster


Thanks and Any Questions?