Utility-based Resource Management in Future Mobile Communications Considering QoE

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Utility-based resource allocation

- **Resource Allocation (RA):** 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 Resource Allocation**
  - Utility reflects actual users’ perceived performance (QoE)
  - Optimization problem: Maximize the aggregated utility, subject to limited resources
QoE examples

Figure: MOS over data rate [1][2]
## Utility functions

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

*with $A=9$, $B=-4.5$*
General overview

Goal: max \( U = \sum_c \sum_i u_{i,c} (b_{i,c}) \)

Transport network rate \( R_{S1} \)

\[
\sum_c \sum_i r_{i,c} = \sum_c \sum_i b_{i,c} \cdot \sigma_{i,c} \leq R_{S1}
\]

Cell bandwidth \( B_c \)

\[
\sum_i b_{i,c} \leq B_c \quad \forall c
\]

<table>
<thead>
<tr>
<th>Case</th>
<th>aGW traffic shaping</th>
<th>Radio scheduler</th>
</tr>
</thead>
<tbody>
<tr>
<td>No S1 bottleneck</td>
<td>-</td>
<td>Optimal algorithm</td>
</tr>
<tr>
<td>Only S1 bottleneck</td>
<td>Lagrangian relaxation solved by bisection search</td>
<td>Two heuristics (Centralized/Coordinated MAC scheduler)</td>
</tr>
<tr>
<td>Both S1 and some cells are bottleneck</td>
<td>Lagrangian relaxation solved by projected subgradient method</td>
<td></td>
</tr>
</tbody>
</table>
Lagrangian relaxation

- Maximize the aggregated utility in the cell cluster, which can be expressed as:

\[
\max \left\{ U = \sum_c \sum_i u_{i,c} (b_{i,c}) \right\}
\]

s.t. \( \sum_i b_{i,c} \leq B_c \ \ \forall c; \sum_c \sum_i b_{i,c} \cdot \sigma_{i,c} \leq R_{S1} \)

- It can be solved optimally using the Lagrangian decomposition method.
  - Hessian matrix positive definite -> Problem is convex
  - Slater’s condition fulfilled -> Strong duality holds

\[
f = \min_{\{\lambda\}} \left\{ \max_{\{b\}} \left\{ \sum_c \sum_i u_{i,c} (b_{i,c}) - \sum_c \lambda_c \left( \sum_i b_{i,c} - B_c \right) - \lambda_0 \left( \sum_c \sum_i b_{i,c} \cdot \sigma_{i,c} - R_{S1} \right) \right\} \right\}
\]

\[
= \min_{\{\lambda\}} \left\{ \sum_c \sum_i \max_{\{b\}} \left\{ u_{i,c} (b_{i,c}) - \left( \lambda_c + \lambda_0 \cdot \sigma_{i,c} \right) b_{i,c} \right\} + \sum_c \lambda_c \cdot B_c + \lambda_0 \cdot R_{S1} \right\}
\]

\[
= \min_{\{\lambda\}} \left\{ \sum_c \sum_i L_{i,c} + \sum_c \lambda_c \cdot B_c + \lambda_0 \cdot R_{S1} \right\}
\]

- Subgradient projection method is applied
  - with modified Polyak’s step size
Extensions

\[ \max \left\{ U = \sum_c \sum_i \omega_{i,c} \cdot u_{i,c} \left( r_{i,c} \right) \right\} \]

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>Delay sensitive traffics (Real-time)</th>
<th>Rate sensitive traffics (Non Real-time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility Functions</td>
<td>[ u_{i,c} \left( r_{i,c} \right) = \frac{u'(d_{i,c})}{\lambda_{i,c}} \cdot r_{i,c} ]</td>
<td>[ u_{i,c} \left( r_{i,c} \right) = \frac{A}{1 + e^{-\alpha_{i,c} r_{i,c}}} \cdot r_{i,c} + B ]</td>
</tr>
<tr>
<td>Optimatization Model</td>
<td>Linear Programming</td>
<td>Concave Optimatization</td>
</tr>
</tbody>
</table>

End-to-end Delay (seconds) vs MOS

GSM EFR codec

MOS of E-model
1. ITU-T recommendation G.1070: Opinion model for videotelephony applications (04/2007)
Thanks and Any Questions?