An Implementation of the Contract Net Protocol Based on Marginal Cost Calculations

By Tuomas Sandholm
1993
Introduction

- Formalization of the bidding and awarding decision process
  - Formalization based on marginal cost calculations based on local agent criteria
  - Network as whole functions more effectively
  - CNP is extended to allow for clustering of tasks, to deal with the possibility of a large number of announcement and bid messages
  - Implementation of TRACONET is asynchronous, distributed and autonomous
Formal model

- Announcing
- Bidding
- Awarding decisions
- This model covers (differently from CNP)
  - Calculation of marginal costs
  - Clustering tasks into sets to be negotiated over as atomic bargaining items
  - Solving the problem of announcement message congestion
Vehicle routing problem

Dispach center 1
Dispach center 2
Dispach center 3
Dispach center 4
Dispach center 5
Vehicle routing problem

- Geographically dispersed dispatch centers
  - Overlapping working areas
- Deliveries initiated by factories
- Certain number of vehicles

- Routing problem
  - Vehicle attributes: cost per km, max duration, max length, max load weight, max volume
  - Optimization task
Solving the problem

- Each center – intelligent agent
  - Solves its own local routing problem
- Negotiates with each other
  - Exchanges with delivery tasks when it is profitable
  - Negotiation is real time
  - No global optimization
Message passing

AGENT 1

AGENT 2

AGENT 3

AGENT 4

AGENT 5

Winner

Looser

Looser

Looser

Looser

Winner
TRACONET architecture

- Each involved party can make a bid
- Announcements are not sent to every agent
- No fixed hierarchy
- Agent can act both as a manager and as a contractor
Agent structure

- Bidder
- Announcer
- Local control loop
- Agent
- Awarder
- Award taker
- Local Optimizer
Agent structure

- Bargaining system
  - Announcer
  - Bidder
  - Awarder
  - Award taker

- Local optimizer
  - Counting of marginal costs of a set of deliveries (to remove or to add)
  - Optimizing all deliveries
  - Removing and adding sets of deliveries to agent’s routing solution
Local control

- Agent’s routing solutions are made
- Start of LCL
  - Invoke of bidder, awarder, award taker, announcer
- Exiting/entering network dynamically
  - Joining
  - Exiting problems
    - Will not receive award (needs listening phase)
    - Other agents could be making a bid and will not receive even looser message (send “looser” messages)
Announcing

- \( c_{rem}(T) \) – marginal cost saved if the delivery set \( T \) is removed from routing solution

- \( c'_{rem}(T) \) – heuristic approximation of \( c_{rem}(T) \)

Randomly choose one of the deliveries ending in another center's main operation area.
\( T = \{ \text{the chosen delivery} \} \).
Maximum price of the announcement \( c_{max} = c'_{rem}(T) \).
For all centers except this center itself
  If the end stop of the delivery is in the center's main operation area
    Then send an announcement to the center.

- But (!) \( c_{rem}(T_1 \cup T_2) \neq c_{rem}(T_1) + c_{rem}(T_2) \)
Bidding

- Reads the announcements from other agents
- Needs to estimate $c_{\text{add}}(T_b)$

\[
c_{\text{add}}^{-}(T_b) = \min_{B \subseteq B_{\text{pos}}}(f\left(T_b \cup T_{\text{cur}} \cup T_{z \in B}\right) - f\left(T_{\text{cur}} \cup T_{z \in B}\right))
\]

\[
c_{\text{add}}^{+}(T_b) = \max_{B \subseteq B_{\text{pos}}}(f\left(T_b \cup T_{\text{cur}} \cup T_{z \in B}\right) - f\left(T_{\text{cur}} \cup T_{z \in B}\right))
\]

\[
c_{\text{add}}^{all}(T_b) = f\left(T_b \cup T_{\text{cur}} \cup T_{z \in B_{\text{pos}}}\right) - f\left(T_{\text{cur}} \cup T_{z \in B_{\text{pos}}}\right)
\]

\[
c_{\text{add}}^{\text{non}}(T_b) = f\left(T_b \cup T_{\text{cur}}\right) - f\left(T_{\text{cur}}\right)
\]
Bidding (semi-opportunistic calculation)

- heuristic approximation is used for calculation of $f'$, for which $f(T) \leq f'(T)$ for any task set $T$

- $f'(T \cup T_{\text{cur}})$ is calculated from $f'(T_{\text{cur}})$ assuming that none of the agent’s unsettled bids are awarded

- Evaluation $c'_{\text{add}}(T)$ may lead to unbeneficial contracts

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Read in all received announcements and call this set $A$.  
For each announcement $a \in A$

Call the set of deliveries in $a$ $T_a$ and the maximum price $c_{\text{max}}$.  
If $f'(T_{\text{cur}} \cup T_a \cup T_{\text{pos}}) < \infty$ (Feasibility check; $T_{\text{pos}}$ defined w.r.t. a potential bid $b$ with the deliveries of $a$.)

Set $c_{\text{bid}} = c'_{\text{add}}(T_a)$.  
If $c_{\text{bid}} < c_{\text{max}}$

Send a bid with the identifier of the announcement, the name of this center and cost $c_{\text{bid}}$.  

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Awarding

- Award is given for agent with most inexpensive bid
- After awarding, $T_b$ is removed from agents $T_{cur}$ and transportation current solution.
- If timeout – sends «looser» messages to all
- Agent checks if the awarding still beneficial to itself
Awarding

- Needs to estimate $c_{\text{rem}}(T_b)$

\[
c_{\text{rem}}^+(T_b) = \max_{B \subseteq B_{\text{pos}}} \left( f\left( T_{\text{cur}} \cup T_z \right) - f\left( (T_{\text{cur}} - T_b) \cup T_z \right) \right)
\]

\[
c_{\text{rem}}^-(T_b) = \min_{B \subseteq B_{\text{pos}}} \left( f\left( T_{\text{cur}} \cup T_z \right) - f\left( (T_{\text{cur}} - T_b) \cup T_z \right) \right)
\]

\[
c_{\text{rem}}^{\text{all}}(T_b) = f\left( T_{\text{cur}} \cup T_{z_{\text{pos}}} \right) - f\left( (T_{\text{cur}} - T_b) \cup T_{z_{\text{pos}}} \right)
\]

\[
c_{\text{rem}}^{\text{non}}(T_b) = f\left( T_{\text{cur}} \right) - f\left( T_{\text{cur}} - T_b \right)
\]
Awarding (semi-opportunistic calculation)

- heuristic approximation is used for calculation of $f''$, for which $f(T) \leq f''(T)$ for any task set $T$
- $f''(T_{cur} - T)$ is calculated from $f''(T_{cur})$ assuming that none of the agent's unsettled bids are awarded
- Evaluation $c'_rem(T)$ may lead to unbeneifical awards

Taking awards

- An agent's award taker reads the awards and inserts the deliveries from the awards to the agent's deliveries $T_{cur}$ and its transportation solution.
## Experimental results

<table>
<thead>
<tr>
<th>Dispatch center</th>
<th>Deliveries</th>
<th>Vehicles</th>
<th>Average delivery length</th>
<th>Cost savings in 15 minutes</th>
<th>Cost savings in 30 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>65</td>
<td>10</td>
<td>121 km</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>A2</td>
<td>200</td>
<td>13</td>
<td>169 km</td>
<td>12%</td>
<td>18%</td>
</tr>
<tr>
<td>A3</td>
<td>82</td>
<td>21</td>
<td>44 km</td>
<td>31%</td>
<td>34%</td>
</tr>
<tr>
<td>B1</td>
<td>124</td>
<td>18</td>
<td>145 km</td>
<td>11%</td>
<td>23%</td>
</tr>
<tr>
<td>B2</td>
<td>300</td>
<td>15</td>
<td>270 km</td>
<td>9%</td>
<td>15%</td>
</tr>
<tr>
<td>Total</td>
<td>771</td>
<td>77</td>
<td>187 km</td>
<td>11%</td>
<td>17%</td>
</tr>
</tbody>
</table>

*Table 1. Columns 2 - 4 characterize the one week real vehicle and delivery data of the experiments, and the last two columns show results of the negotiations.*
Questions?