Hierarchical optimal control method for controlling self-organizing networks with light-weight cost


Optimal control by an external controller

- The fastest convergence of the state (X) of the linear system can be achieved with the optimal control method in our previous work [3].

Approach for light-weight computation

1. Division of network: we divide a network into S sub-networks.
2. Division of controllers’ roles:
   - S sub-controllers observe/control their corresponding sub-networks.
   - This results in smaller computation cost.
   - The central controller manages the interactions among sub-networks.

Potential-based routing [5]

- Self-organizing routing method for WSNs.
  - A node has potential (a scalar value) which determines routes.
  - The fewer hops from the sink node is, the lower the potential value assigned to the node.
  - Convergence needs too many iterations.

The update of node n’s potential value \( \theta_n(t) \):

\[
\theta_n(t + 1) = \theta_n(t) + \beta \left( \theta_n(t) - \theta_{\text{sink}}(t) \right) + \beta \sum_{k \in \mathcal{N}_n} \left( \theta_k(t) - \theta_n(t) \right) + \beta \theta_{\text{sink}}(t)
\]

A node’s own potential:

\[
\theta_n(t) = \sum_{k \in \mathcal{N}_n} \left( \theta_k(t) - \theta_n(t) \right)
\]

Potential differences from neighbor nodes:

- Parameter that determines the weight of the potential value.
- Parameter that determines the weight of the current node.

- “Forward data to a neighbor node with lower potential” can result in data packet collection toward sink nodes.


Potential-based routing with a hierarchical control method

- Central controller
- Sub-controller
- Potential information from all sub-networks
- Feedback inputs for guiding potentials of the sub-network to converge targeted potentials
- Feedback inputs to the sub-network for faster convergence of potentials
- Potential information of a partial set of nodes in the corresponding sub-network

Simulation Evaluation

- We evaluated the convergence speed of potentials in our proposal
- Compared to the non-control scheme

Scenario
1. At 200 step, data packet arrival rates are changed in sensor nodes
2. Potential field is reconstructed where sink nodes receive packets equally
   - We evaluated the convergence time of potentials

Table 1: Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The interval of potential update</td>
<td>1 step</td>
</tr>
<tr>
<td>The interval of controllers’ feedback</td>
<td>1 step</td>
</tr>
<tr>
<td>( k )</td>
<td>20</td>
</tr>
<tr>
<td>( \alpha, \beta, \sigma, r )</td>
<td>((0.4, 0.2, 0.1, 10))</td>
</tr>
</tbody>
</table>

Adaptation of potentials

- The convergence speed is enhanced by 3.12 times compared with the non-control method with lightweight cost

<table>
<thead>
<tr>
<th>Convergence time (step)</th>
<th>Non-control scheme</th>
<th>Non-hierarchical scheme</th>
<th>Hierarchical scheme (our proposal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (step)</td>
<td>721.7</td>
<td>331.0</td>
<td>209.1</td>
</tr>
</tbody>
</table>

Conclusion

- Conclusion
  - Introduction of hierarchical control method to potential-based routing
  - Simulation result showed that our proposal can enhance the convergence speed of potentials with lightweight cost

- Future work
  - Evaluation of the hierarchical method (our proposal) compared with the non-hierarchical method
  - The convergence speed of potentials
  - The computation time for the controller design and the calculation of control inputs
  - Evaluation in the case with large-scale networks