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

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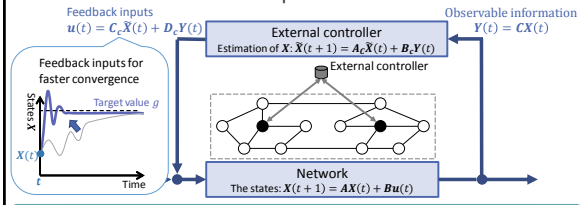
Controlling self-organizing networks

- Self-organizing systems
  - Global pattern emerges through local interactions among components
  - Pros: High scalability, adaptability, flexibility, robustness
  - Cons: Non-controllability
    - Global optimality is not guaranteed
    - Emergence and adaptation to environmental changes is slow

- **Controlling self-organizing systems**
  - Self-organizing systems are controlled through some constraints provided by an '**external controller**'
  - Achieving the desired state of the system rapidly with light-weight cost is a very challenging task

Optimal control by an external controller

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

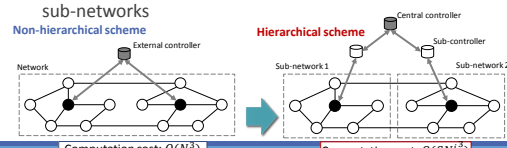


It is difficult for only one controller to collect and manage information of the entire network due to the considerable computation cost

[3] N. Kuze, D. Kominami, K. Kashima, T. Hashimoto, and M. Murata, "Enhancing convergence with optimal feedback for controlled self-organizing networks," to be presented at IEEE 80th Vehicular Technology Conference, Sep. 2014.

Approach for light-weight computation

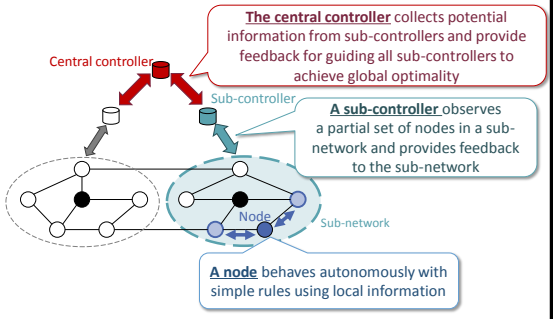
1. **Division of network**: we divide a network into S sub-networks
2. **Division of controllers' roles**:
   - S sub-controllers observe/control their corresponding sub-networks
     - This results in smaller computation cost
   - The central controller manages the interactions among sub-networks



Computation cost: $O(N^3)$ (N: # of all nodes)

Computation cost: $O(SN^{i3})$ (N^i: # of sub-network i)

System overview



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

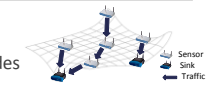
The update of node n's potential value $\theta_n(t)$

$$\theta_n(t+1) = \underbrace{(\alpha+1)\theta_n(t) - \alpha\theta_n(t-1)}_{\text{Node } n\text{'s own potential}} + \beta\sigma \underbrace{\sum_{k\in Nb(n)} \{\theta_k(t) - \theta_n(t)\}}_{\text{Potential differences from neighbor nodes}} + \beta\sigma f_n(t)$$

Flow rate at node n

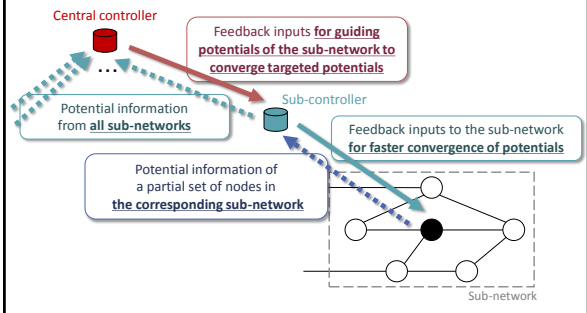
α: Parameter that determines the weight of the past potential value
β, σ: Parameter that determines the weight of flows
$Nb(n)$: The set of neighbor nodes of node n

- "**Forward data to a neighbor node with lower potential**" can result in data packet collection toward sink nodes



[5] D. Kominami, M. Sugano, M. Murata, and T. Hatauchi, "Controlled and self-organized routing for large-scale wireless sensor networks," ACM Transactions on Sensor Networks, vol.10, no.1, pp.13:1-13:27, Nov. 2013.

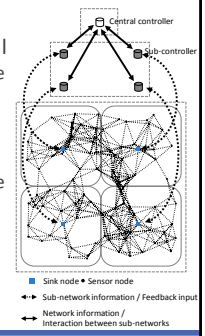
Potential-based routing with a hierarchical control method



Simulation Evaluation

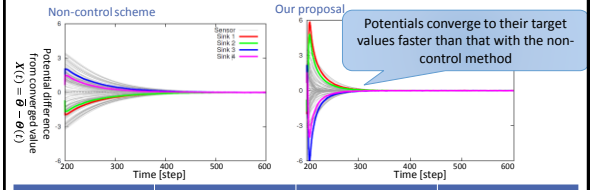
- We evaluated the convergence speed of potentials in our proposal
  - Compared to the non-control scheme
- Scenario
  1. At 200 step, data packet arrival rates are changed in sensor nodes
  2. Potential field is reconstructed where sink nodes receive packets equally
     - We evaluated **the convergence time of potentials**

Parameter	Value
The interval of potential updates	1 step
The interval of controllers' feedback	1 step
k	20
$(\alpha, \beta, \sigma, r)$	(0.4,0.2,0.1,10)



Adaptation of potentials

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



	Non-control scheme	Non-hierarchical scheme [3]	Hierarchical scheme (our proposal)
Convergence time [step]	721.7	231.0	209.1

[3] N. Kuze, D. Kominami, K. Kashima, T. Hashimoto, and M. Murata, "Enhancing convergence with optimal feedback for controlled self-organizing networks," to be presented at IEEE 80th Vehicular Technology Conference, Sep. 2014.

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