

Differences in Robustness of Self-Organized Control and Centralized Control in Sensor Networks Caused by Differences in Control Dependence

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10/29/2008

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Attention to self-organization

Paradigm shift of control process



Self-organization

- Is "emergence of system-wide adaptive structure and functionality from simple local interactions between individual entities" [Prehofer and Bettstetter, 2005]
- Attracts considerable attention from the view point of the applicability to sensor networks

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Motivations

- Robustness**
 - Is "a property that allows a system to maintain its functions despite external and internal perturbations"
 - Is **extremely important** especially for networks in variable environment
- Good robustness of self-organized control is widely reported but:**
 - This is **certainly nontrivial**
 - Why self-organized control is robust?
 - What factors yield robustness?
- Compare robustness of self-organized control and centralized control**
 - Using sensor network scenario
 - Quantitatively demonstrate the advantage of robustness
 - Yield insight why and how self-organized control achieve good robustness

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What is WSN

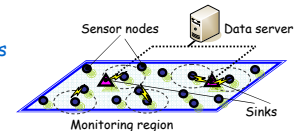
Wireless Sensor Network (WSN)

- Composed of a number of sensor nodes
 - Have miniature sensing devices
 - Ex., Moisture, temperature, acceleration
 - Communicate with neighboring nodes via wireless channel
 - Sense their ambient surroundings
 - Send the data to a sink
- Collect data over a large area



Perturbations WSN faces

- Transmission error
- Sensor node failures



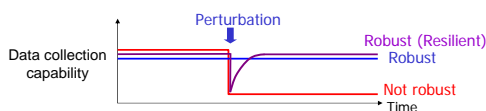
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Robustness in sensor network

- Robustness**
 - Property which allows a **system** to maintain its **functionality** despite **perturbations**
- Robustness in sensor networks**
 - Perturbation: Packet loss, link disconnection, node & sink failure
 - System: Sensor network
 - Function: Data collection



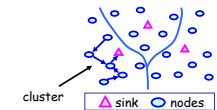
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Centralized control in our comparison

- Cluster-based approach**
 - Sensor nodes are divided into as many clusters as sinks
 - Routing is performed in each cluster
- Control station manages network**
 - Gather and integrate control information from each node
 - Positions, residual power, etc. of nodes.
 - Draw a whole picture of the network
 - Manage clusters and routes based on the picture
- Countermeasures against node failures**
 - Each node periodically transmits hello message
 - A node detects failure if a node cannot receive the message from another node for a predefined time
 - Failure indication is sent to the control station



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Self-organization in Nature

- **Ants or Bees**
 - Each agent is simple and unintelligent
 - Interacts with neighboring agents
 - Obeys the local rules it has as a species
- **Their collective action creates biological order**
 - Allocating tasks
 - Finding shortest path to their food



Many researchers have tried to derive advantageous properties from biological system: **Bio-inspired Control**

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Self-organized control in our comparison

- **Cluster-based approach**
 - Same as the centralized control
 - Sensor nodes are divided into some clusters
 - Routing is performed in each cluster
 - Combination of two swarm intelligence of ants
 - Ant-based clustering for clustering
 - Ant colony optimization (ACO) for routing

These are mediated by "pheromone"

- Fault management
 - Failure detection is same as that of centralized control
 - There is no explicit failure indication

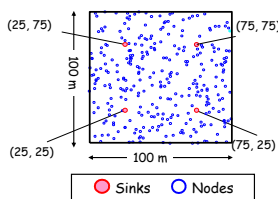
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Simulation settings

- 100x100m² monitoring region
- 300 nodes
- 4 sinks
- 10m transmission range
- Data packets is transmitted every 10 seconds to a sink
- Using network simulator ns-2



Metric of robustness

Data-collection rate: r/s

where

- r : Number of packets received by sinks
- s : Number of packets transmitted

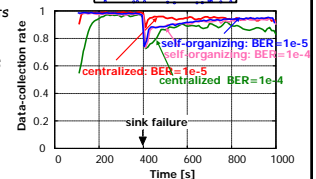
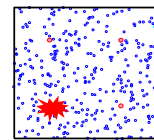
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Recovery from sink failure

- **If a sink fails...**
 - Self-organized control
 - Adjacent node detects sink failure
 - Form of clusters change gradually
 - Centralized control
 - Control station detects failure immediately
 - Clusters' reconstruction starts
- **Small BER:**
 - Concentrated control recovers performance quickly
- **Large BER:**
 - Performance recovery of concentrated control becomes slow



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Influence of link disconnection

- Link of the rate of p_{link} was disconnected for 100 seconds to 500 seconds at random

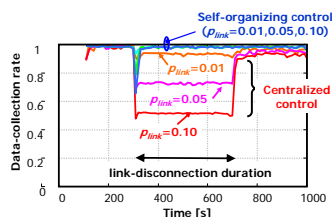


- **Centralized control**

- Control station performs control based on the erroneous information

- **Self-organized control**

- Error of each node does not influence the whole network



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Dependence on control information

- **Dependence**
 - Term used by **Fault Management**
 - Error of a certain object causes the error of other objects.
- **Control information**
 - Information exchanged between entities for cooperation
- **Problem about control information**
 - Control information does not arrive at control station
 - Contents of the control information itself are erroneous



Dependence is major factor of the difference in the robustness between self-organized and centralized control

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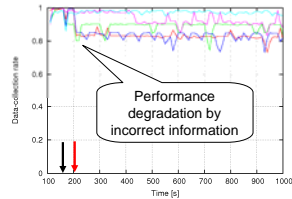
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False-recovery information

- 160 sec: A node near the sink (25, 25) fails
- 200 sec: Injection of incorrect information
"Node has recovered!"

- **Centralized control**
 - Performance deteriorates for the control based on incorrect information
- **Self-organized control**
 - No performance degradation resulting from incorrect information



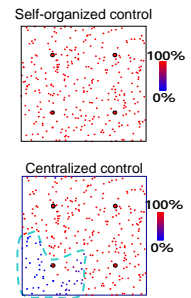
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Influence of incorrect information

- **Errors are contained in the control information obtained from each node**
 - Reliability of each node is not so high
 - Cannot recognize change of network composition precisely
- **Self-organized control**
 - The control information from a node influences only in the neighborhood
- **Centralized control**
 - Control station understands the state of the whole network based on the information from each node



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Conclusion and future work

- **Characteristic of self-organized control and centralized control was compared**
 - Evaluated by simulations for sensor network system
- **Robustness of self-organized control**
 - Control information is exchanged locally
 - Influence of erroneous information is small
- **Fragility of centralized control**
 - Control station integrates individual control information and understands the state of the whole network
 - Erroneous information affects the whole system
- **Future work**
 - Quantification of dependency strength
 - Generalization of results

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Thank you !

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