Self-Organized Data-Gathering Scheme for Multi-Sink Sensor Networks Inspired by Swarm Intelligence

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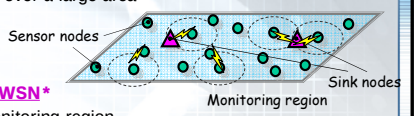
Outline

- Background of Wireless Sensor Networks
  - Benefits and challenges
  - Swarm intelligence
  - Multi-sink configuration
- Proposal of new data-gathering scheme
  - ACO approach to routing in a cluster
  - Application of ant-based clustering
- Performance evaluation through simulation experiments
- Conclusion

What is WSN

- **Wireless Sensor Networks (WSN)**:
  - Composed of a number of sensor nodes
    - Have poor memory capacity, processing power, etc.
    - Communicate with neighborhood via wireless channel
  - Collect data over a large area



Benefits from WSN
- Large monitoring region
- Cheap laid down cost
- Comprehensive data gathering

Challenges WSN is Facing Now

- **Lifetime**
  - Sensor nodes are battery-operated
  - Battery recharge is impossible

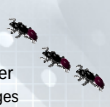
  Power-saving operation
- **Robustness**
  - Poor quality of wireless channels
  - Sensor/Sink nodes are prone to failure

  ·Adaptability
  ·Self-recovery capability
- **Scalability issues**
  - A number of sensor nodes are deployed
  - Centralized control is a difficult scenario

  Emerging property

Strategies for Robust WSN:
Swarm Intelligence

- **Behavior of ants/bees as a swarm**
  - Each agent is simple and unintelligent
    - Estimates only its surroundings
    - Interacts with neighboring agents
    - Obeys the local rules it has as a species
  - Their collective action creates biological order
    - Robust and adaptive to environmental changes
    - Highly scalable



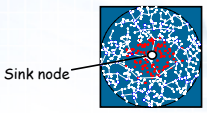
Such a self-organized behavior is well suited to WSN

Swarm intelligence contributes to robust WSN

Strategies for Robust WSN:
Multi-Sink Configuration

- **Single-sink configuration**
  - ✘ Introduce single-failure point
  - ✘ Cause hot spot problem

  unresolved point with swarm intelligence
    - Due to converge-cast (many-to-one communication form)



- **Multi-sink configuration**
  - Distribute load for relaying packets
  - Enhance robustness over sink node failure

Our Goal

Proposal of robust data gathering scheme for WSN

- where multiple sink nodes are deployed
- using swarm intelligence
  - Self-organized behavior

Robustness against what

- Very-poor-quality wireless channels
- Changes in condition of the networks
  - Failures of sensor/sink nodes

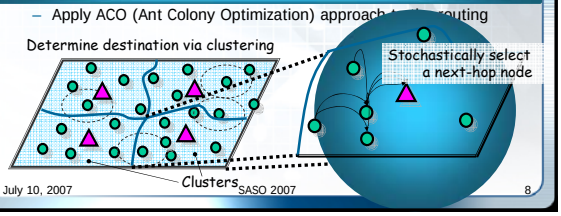
Overview of Proposed Scheme

Divide a WSN into as many clusters as sink nodes

- Sensor nodes that transmit packets to a sink node are dedicated to that cluster
- Adaptive clustering based on "ant-based clustering".
  - Clusters dynamically expand or shrink

Routing is performed in each cluster

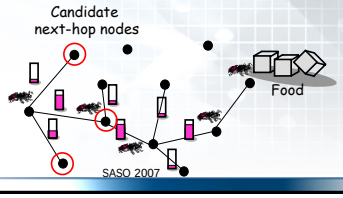
- Apply ACO (Ant Colony Optimization) approach [illegible] routing



Routing in a cluster: Ideas of ACO

ACO: Behavior of ants in their foraging activity

- Find their food, selecting which path to take
  - The higher pheromone value is left, with the higher probability an ant choose to take the path
- Once the ant reaches their food, it follows the trail back to the nest, leaving some pheromone along the trail
  - The amount of pheromone value depends on quality of path



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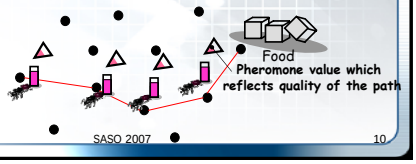


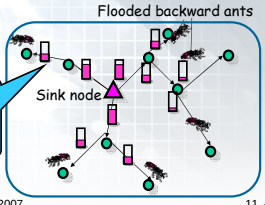
Routing in a cluster: Modification to ACO

- Links which should have higher pheromone in WSN are:
  - Ones Leading to a sink node with small hop
  - Ones whose sensor nodes have sufficient residual power

Construction of pheromone distribution:

- Achieved by **backward ants** flooded from sink nodes
  - Backward ants leave pheromone on the links

Pheromone value a backward ant conveys is decreased:
- hop-by-hop
- at a sensor node with little residual power



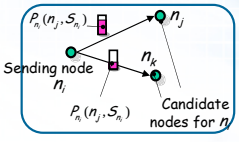
Routing in a cluster: Selecting Next-hop node

ACO approach:

- Stochastically selects a next-hop node
  - Depending on pheromone values on the links to candidate nodes
  - hop-by-hop routing

Probability to choose n_j as a next-hop node:

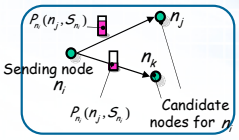
$$P_{n_i}(n_j) = \frac{P_{n_i}(n_j, S_{n_i})^2}{\sum_{k \in N_{n_i}} (P_{n_i}(k, S_{n_i})^2)}$$



Square sum of pheromone values on the links to candidate nodes

Countermeasure against Sensor Node Failure

- **Failure detection is based on soft-state model**
  - Sensor nodes periodically transmit control packets to exchange their pheromone
  - Detect failure if a node cannot receive the packets from another node for a predefined time

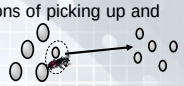


On detecting failure:
Remove the failed node from candidate node set

Ant-based Clustering

- **Swarm intelligence of ants**
  - Larvae or eggs are sorted by their size
    - Ants repeatedly and stochastically pick up and drop eggs based on the similarity with neighboring eggs
  - Cluste[illegible]rge through the iterations of picking up and dr[illegible]ggs
  - [illegible]s not require global information

Substitution for WSN



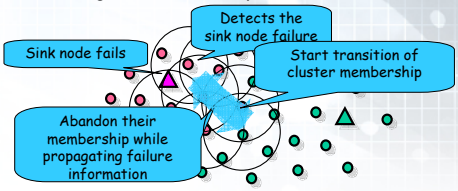
Advantage of belonging a cluster, "cluster pheromone"
defined by pheromone values

- Exchanging Cluster pheromone
- Clustering

} Simultaneous with pheromone exchange

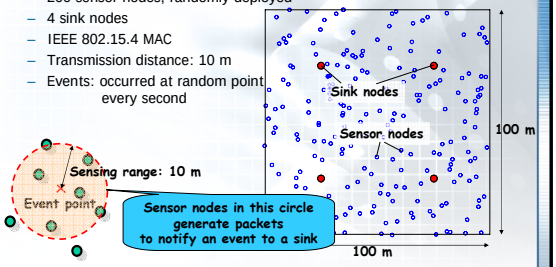
Countermeasure against Sink Node Failure

- **Membership transition at the cluster level**
  1. Detect sink node failure using soft-state model
  2. Propagate this failure information through periodical exchange as a form of cluster pheromone
  3. Change their membership to other cluster



Simulation Model

- **Implement our scheme for the ns-2**
  - 200 sensor nodes, randomly deployed
  - 4 sink nodes
  - IEEE 802.15.4 MAC
  - Transmission distance: 10 m
  - Events: occurred at random point every second

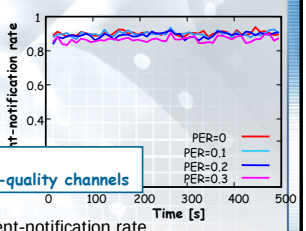


Robustness against Transmission Error

- **Effect of transmission error**

Metric

Event-notification rate: r_e / s_e
s_e: number of generated packets regarding to the event e
r_e: number of received packets by sinks regarding to the event e

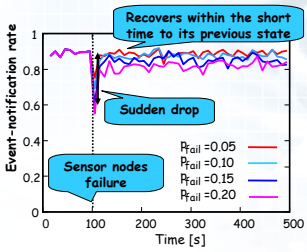


About the same rate even in the very-poor-quality channels

- Have a small effect on event-notification rate

Self-Recovery from Node Failure

- **200 × p_{fail} sensor nodes simultaneously fails at t=100 s**
  - Their positions are randomly distributed
  - Far more serious than what can actually happen in reality

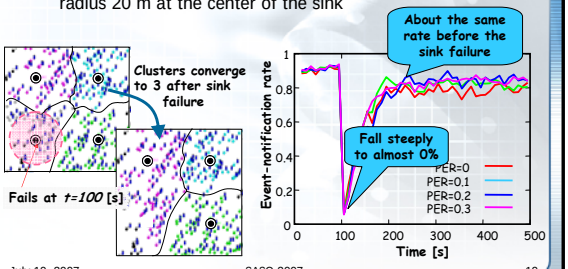


Achieve self-recovery capability

Efficient combination:
- ACO approach
- Soft-state model

Self-recovery after Sink Failure

- Sink node located at the point of (25,25) fails at t=100
  - Limit the area where events occurred to a circular area with a radius 20 m at the center of the sink



Conclusion

- Proposed a novel data-gathering scheme for WSN with multi-sink configuration
  - Self-organized behavior
    - Inspired by swarm intelligence of ants
  - Simulation results showed:
    - Robustness against poor-quality channels
    - self-recovery capability
      - From sensor/sink node failure
- Future works
  - Examine the influences of the parameters
  - Clarify the differences in characteristics between self-organized and centrally controlled sensor networks

- Thank you for your attention