Potential-Based Downstream Routing for Wireless Sensor Networks

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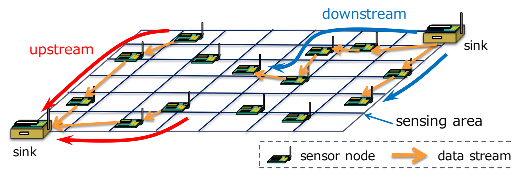
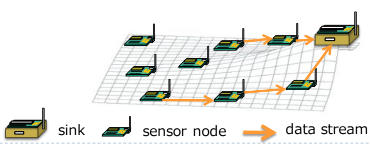
Research background

- Multi-sink wireless sensor network
  - Consist of radio devices with sensors (sensor nodes)
    - Sensor nodes deliver data to one of sinks in a multi-hop manner
- The demand for bi-directional communication
  - Upstream: Sensing data
  - Downstream: Query, specific command



Potential-based upstream routing

- Each node has a scalar value as a potential
  - Sinks have the maximum potential
  - Sensor nodes with smaller hop-count to a sink have a larger potential obtained by local message exchange
- Data can reach one of sinks by nodes forwarding it to a neighbor node with a larger potential
- High scalability, robustness, and load balancing[1]

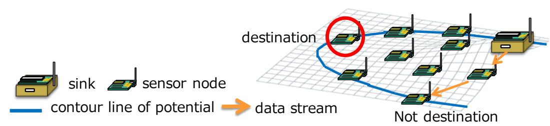


[1] D. Kominami, M. Sugano, M. Murata and T. Hatauchi, "Controlled potential-based routing for large-scale wireless sensor networks," in Proc. of ACM MSWiM, pp. 187-196, June 2011.

Motivation and goal of our research

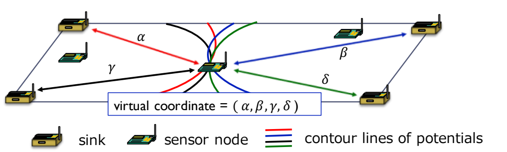
- Sinks need to send a message to a certain node
  - Control message in order to change the sensing rate
    - In case that the sink receives an abnormal upstream data
- Potential-based routing protocols do not assume downstream data delivery
  - Downstream data cannot reach the destination node through the gradient of the potential field

Goal: realizing downstream routing with retaining the advantage of potential-based routing



Key idea

- Trilateration based node identification
  - A combination of distance from 3 fixed points identifies the location uniquely
- Potentials mean virtual distance from a sink
  - More than 3 potentials determined by different potential fields are necessary to identify the node's location
  - We define virtual coordinate as a set of more than 3 potentials



Overview of our method

1. Potential fields construction
   - Multiple sinks construct potential fields respectively
2. Collecting destinations' virtual coordinates from upstream sensing data delivery
   - Sinks collect virtual coordinates to know that of destinations
     - All sinks share all virtual coordinates via wired link
3. Downstream routing using virtual distance calculated from virtual coordinates
   ① The sink nearest to the destination starts to send a downstream data
   ② Next hop is selected according to virtual distance to the destination
   ③ When a relaying sender is in local minimum, it selects next hop according to a gradient of one of potential fields

Definition of virtual distance

- Relay nodes calculate and use potential distance $\underline{Dist(n,d)}$ from its neighbor $\underline{n}$ to destination $\underline{d}$

$$Dist(n,d) = \sqrt{\sum_{i=1}^{N} (F_i(n) - F_i(d))^2}$$

- Relay nodes calculate and use other potential distance $\underline{Gap(n,d)}$ when no neighbor has smaller $\underline{Dist(n,d)}$ than the sender's one

$$Gap(n,d) = |F_i(n) - F_i(d)|, \arg\min_{1 \le j \le N} F_j(d)$$

Simulation settings to evaluate data delivery ratio

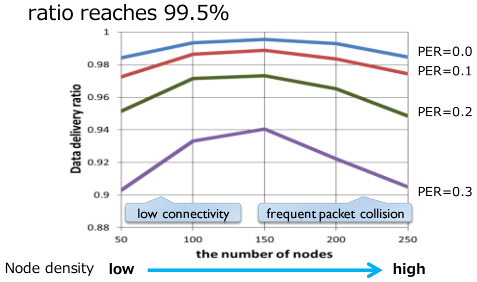
- Simulator: OMNet++(ver.4.1)[2]
- Network model
  - Sensing area: 600m×600m square domain
  - 4 sinks are located at the 4 corners of the area
  - 50～250 sensor nodes are deployed at random places
- Traffic model
  - Data generation ratio
    - Upstream: 1 / 100 $[s^{-1}node^{-1}]$
    - Downstream: 1 / 300 $[s^{-1}sink^{-1}]$
- Evaluation metric
  - Data delivery ratio of downstream routing

Radio range	100 m
TTL	15
Bandwidth	100 kbps
Packet error rate	0.0～0.3
Update potential	100 s

[2] A. Varga, "Omnet++," in Modeling and Tools for Network Simulation, pp.35–59, Springer, 2010.

Evaluation of data delivery ratio

- In an appropriate node density, data delivery ratio reaches 99.5%

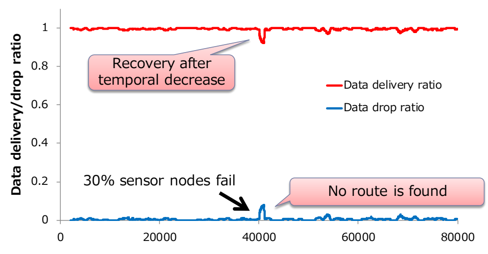


Simulation settings to evaluate robustness

- Evaluation of data-delivery robustness against nodes' failures
  - 45 sensor nodes out of 150 sensor nodes fail
  - One sink out of 4 sinks fails
- Memorization time
  - Sensor nodes memorize their neighbors' virtual coordinates for 100 seconds after they received it
  - Sinks memorize sensor nodes' virtual coordinates for 2500 seconds after they received it
- Evaluation metric
  - Delivery ratio of data generated from $(t-1000)$ to t at each time t

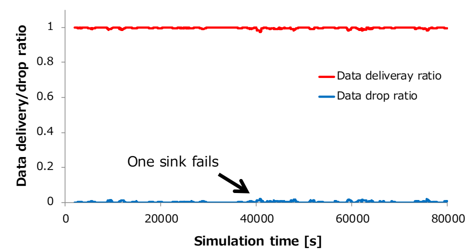
Robustness against 30% sensor nodes' failures

- Our method is highly robust against sensor nodes failure



Robustness against sink failure with sinks sharing virtual coordinates

- Very little decrease occurs even if a sink fails



Conclusion and future work

- We propose a potential-based downstream routing
  - Data delivery ratio reaches 99.5%
  - Our method is highly robust against node failures
- Power consumption and load balancing are not taken into consideration
  - Evaluate power consumption of the downstream routing when a potential field for load balancing is constructed