An autonomous data gathering scheme adaptive to sensing requirements for industrial environment monitoring

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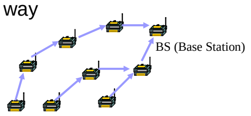
Agenda

- Research background
  - Monitoring of shaft furnace in steel plant
- An autonomous data gathering scheme
  - Adaptive sensing task engagement using response threshold model
  - Energy efficient transmission and sleep scheduling using pulse-coupled oscillator model
- Simulation results and demonstration
- Conclusion and future work

Wireless sensor networks (1)

- A data gathering scheme for wireless senor networks must be:
  - Energy-efficient
    A sensor node is typically powered by a battery that cannot be easily replaced
  - Fully-distributed, self-organizing
    A large number of sensor nodes are often deployed and distributed in an uncontrolled way

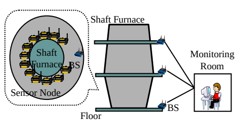


Wireless sensor networks (2)

- In periodical data gathering, sleep scheduling is good to save energy consumption
- In some classes of applications,
  - A sensor node needs to change its sensing interval to monitor the region more frequently when it detects unusual conditions and phenomena.
  - The number of sensor nodes which monitor and report the phenomena should be regulated in accordance with its criticality and importance.

Shaft furnace in steel plant

- Deployment of temperature and CO gas sensors
  - Temperature changes slowly or stays long period
  - CO gas may suddenly appear, move fast, and dissipate
- Three intervals of monitoring are required
  - Monitoring temperature and CO gas in stable conditions
  - Monitoring temperature more frequently when changes are detected
  - Monitoring CO gas more frequently than temperature when CO gas is detected



Research target

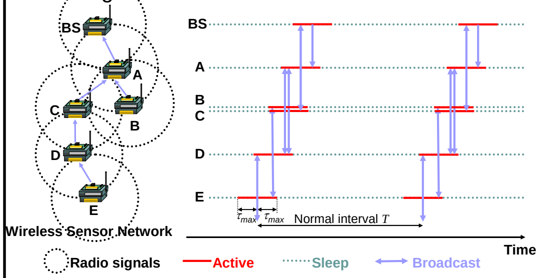
- Proposal of a data gathering scheme adaptive to sensing requirements
- To accomplish self-organizing control:
  - Adaptive sensing task engagement
    → Response threshold model
  - Energy efficient transmission and sleep scheduling
    → Pulse-coupled oscillator model

Sensing state

- All sensor nodes have k_{max} sensing devices
  - Ex) temperature, CO gas
- Sensor node i has two sensing state for each sensor k
  - Normal state
    - Monitoring at a normal interval of T sec.
  - Frequent state
    - Monitoring at a new interval of T_k sec. ($T_k < T$)
    - To relay sensor data from sensor node i to a BS (base station), sensor nodes on the path from sensor node i to the BS also change their operation interval to T_k sec.

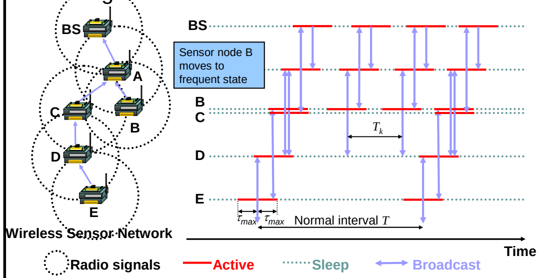
Basic behavior in normal state

- Timing of broadcast emission



Basic behavior in frequent state

- Timing of broadcast emission



Decision of sensing state (1)

- To decide a sensing state in self-organizing manner, we use response threshold model
  - Mathematical model of division of labor and task allocation in social insects
- Demand of sensing target k at sensor node i

$$\frac{ds_{i,k}}{dt} = \delta_{i,k}(t) - \alpha \frac{m_{i,k}(t)}{n_{i,k}(t)}$$

$m_{i,k}$: the number of neighbor nodes in frequent state
$n_{i,k}$: total number of neighbor nodes
$\delta_{i,k}$: rate of temperature change / CO gas value itself

If the number of workers is insufficient, the demand increases

Decision of sensing state (2)

- Probability of state transition

P(normal state → frequent state) = $\frac{s_{i,k}^2(t)}{s_{i,k}^2(t) + \theta_{i,k}^2(t)}$

P(frequent state → normal state) = $p_{i,k}(t)$

- Adjustment of threshold θ_i

$$\frac{d\theta_i}{dt} = \begin{cases} -\xi & \text{if } i \text{ performs frequent sensing} \\ +\varphi & \text{otherwise} \end{cases}$$

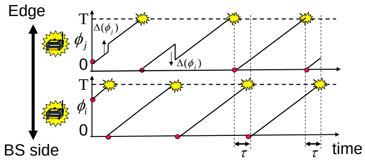
This threshold adjustment makes specialists having a small threshold and keep sensing the target frequently.

Maintenance of broadcast timing (1)

- To autonomously generate and maintain timing of message propagation, we use pulse-coupled oscillator model
  - Mathematical model of synchronization observed in a group of flashing fireflies

Maintenance of broadcast timing (2)

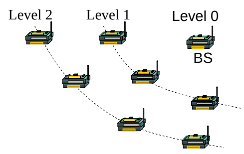
- Sensor node behavior
  - Sensor node has phase $\phi \in [0,T]$
  - When the phase reaches T, the sensor node i broadcasts a message and the phase jumps back to 0
  - Neighboring sensor node closer to edge of WSN are stimulated and advance their phase by an amount $\Delta(\phi)$



By exchanging messages and using appropriate Δ, message propagation keeping a fixed phase difference τ is accomplished regardless of initial condition [2]

Control parameters

- Sensor node i has:
  - Phase ϕ_i
  - Offset τ_i
  - Level value l_i
    - Number of hops from BS
  - Sensing state vector X_i
  - Relay flag vector F_i
    - Used to notify downstream nodes of the existence of upstream nodes in frequent state
  - Parameters of response threshold model
  - Sensor data D_i

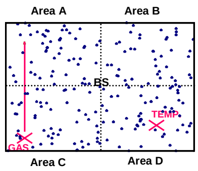


Sensor node behavior

- Sensor node behaves in accordance with its phase and relay flag vector
- Sensor node periodically acts as follow:
  - Wake up
  - Receive broadcast messages from upstream node
  - Receive broadcast messages from same-hop node
  - Monitor and broadcast a message
  - Receive broadcast messages from downstream node
  - Sleep
- Details are in the paper

Simulation experiments

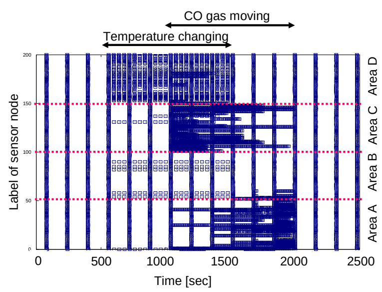
- Simulation settings
  - 200 nodes are randomly distributed in 100x100 m^2 region
  - Range of radio signals is fixed at 20 m
  - Energy model is based on MICAz
  - Data gathering intervals
    - Normal state: 160 sec.
    - Temperature frequently state: 40 sec.
    - CO gas frequently state: 10 sec.

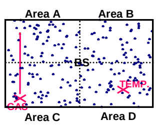


Wireless sensor network

- Simulation scenario
  - From 500 to 1500 seconds, temperature increases in Area D
  - From 1000 to 2000 seconds, CO gas leaks in Area C and moves to Area A at 0.08m/sec.

Timing of message emissions





Wireless sensor network

Energy consumption / duty cycle

- Adaptive intervals at 10/40/160 sec. (Proposal)
  - Total energy consumption: 57.6 mJ/node
  - Duty cycle: 0.03/node
- Fixed intervals at 10 sec.
  - Total energy consumption: 632 mJ/node
  - Duty cycle: 0.2 /node

Demonstration

- Simulator
  - Red node: active
  - Gray node: sleeping
  - Pink region: temperature is changing
  - Blue region: CO gas is exist
- Data gathering intervals
  - Normal state: 32 sec.
  - Temperature frequently state: 8 sec.
  - CO gas frequently state: 4 sec.
- Simulation scenario
  - Temperature increases and stays in an area
  - CO gas leaks, moves, and disappears

JAVA simulator

Conclusion and future work

- Proposal of a data gathering scheme for industrial environment monitoring
  - Adaptive sensing task engagement using response threshold model
  - Energy efficient transmission and sleep scheduling using pulse-coupled oscillator model
- Preliminary simulation experiments
  - Autonomous and energy-efficient data gathering
- Future work
  - In-depth evaluation of the sensing adaptability
  - Implementation of our scheme

Thank you