TRƯỜNG ĐẠI HỌC BÁCH KHOA HÀ NỘI
VIỆN ĐIỆN TỬ VIỄN THÔNG

Giới thiệu một số kết quả nghiên cứu về mạng cảm biến không dây (Wireles Sensor Networks)

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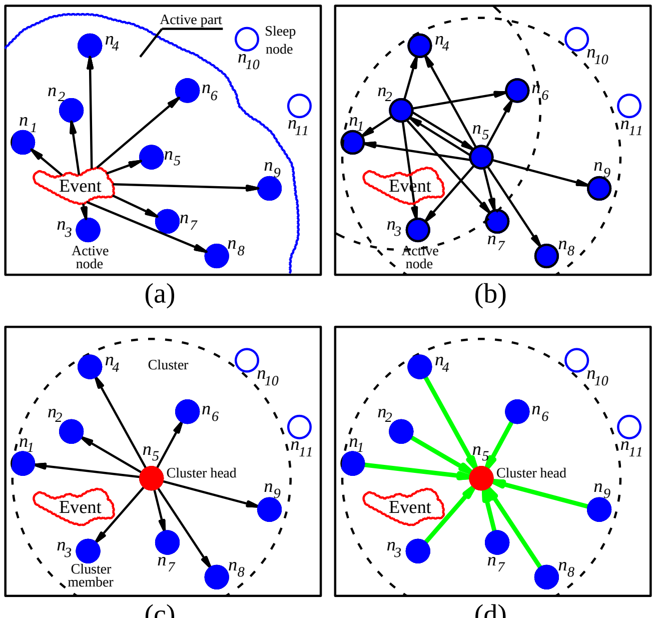
Adaptive Routing Protocol with Energy-Efficiency and Event-Clustering for WSNs (ARPEES)

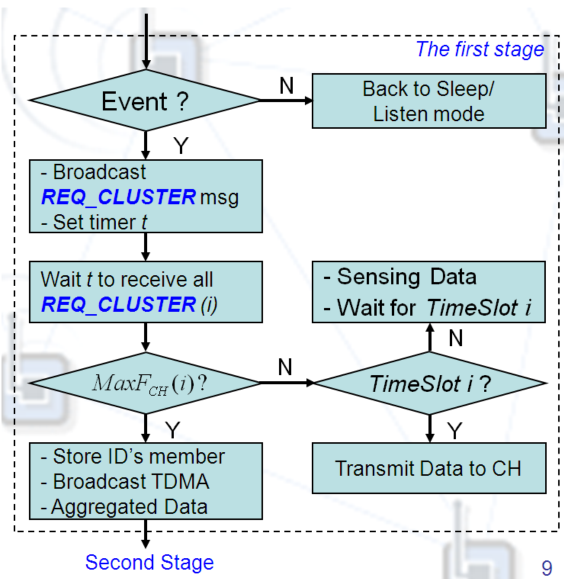
Introduction

- ARPEES
  - Adaptive Routing Protocol with Energy-Efficiency and Event-Clustering for WSNs
- Event-clustering algorithm
  - Clusters was formed dynamically base on the occurrence of events
    - Reduce the global data to be transmitted and localized most traffic to within each individual cluster
    - Reduce contention in the network
- Goals
  - Spread energy required for gathering and aggregating data, and relaying the data to different sensor nodes
  - Prolong network lifetime

Protocol Operation

- The first stage: Selecting cluster head algorithm
  - Cluster head is selected based on its residual energy
  - Rotating cluster head among available nodes





(a) Nodes in a part of network become active when detected the event

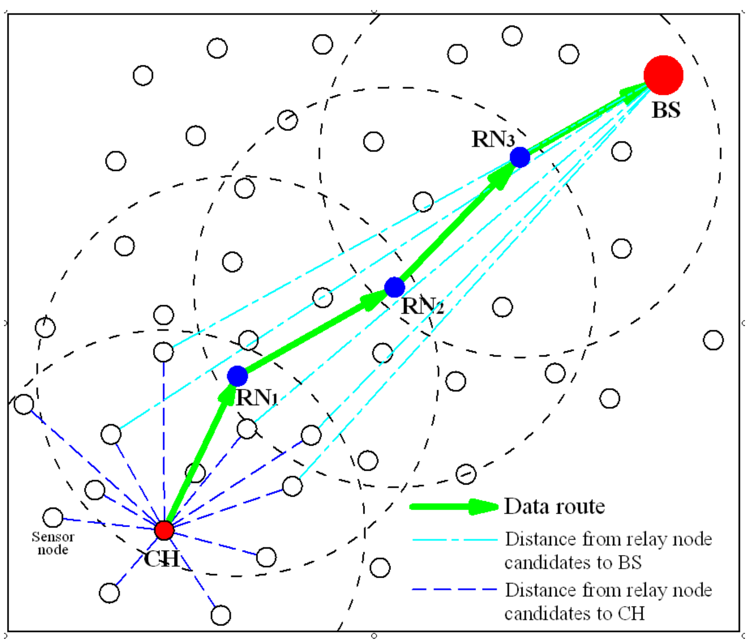
(b) Active nodes exchange *REQ_CLUSTER* message

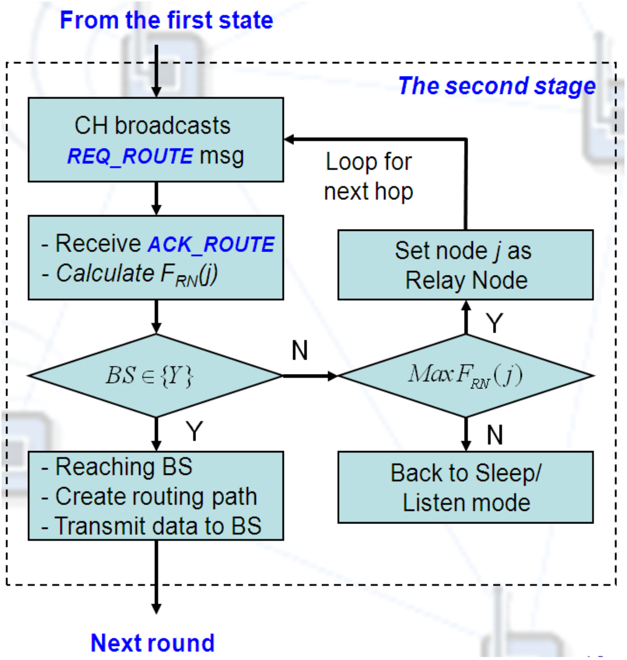
(c) Node n_5 becomes cluster head with maximum solution of $F_{CH}(n_5)$ function and broadcasts TDMA schedule

(d) Cluster members transmit their sensed data to the cluster head in their assigned time slot

Protocol Operation

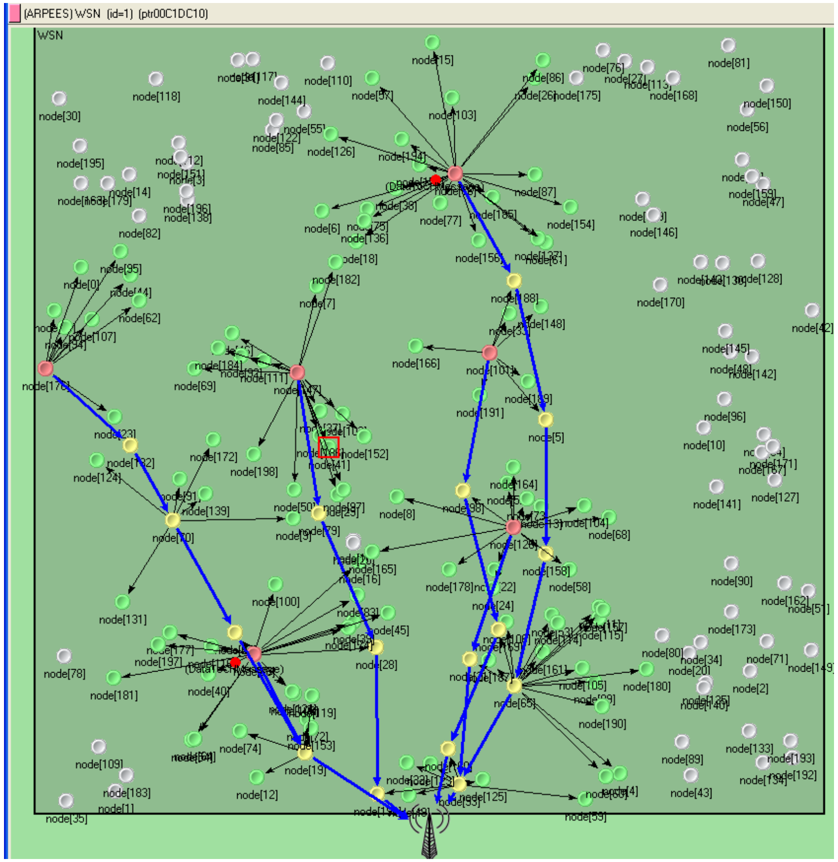
- The second stage: Selecting relay node algorithm
  - Energy aware relay node selection
  - Construct optimal relaying route



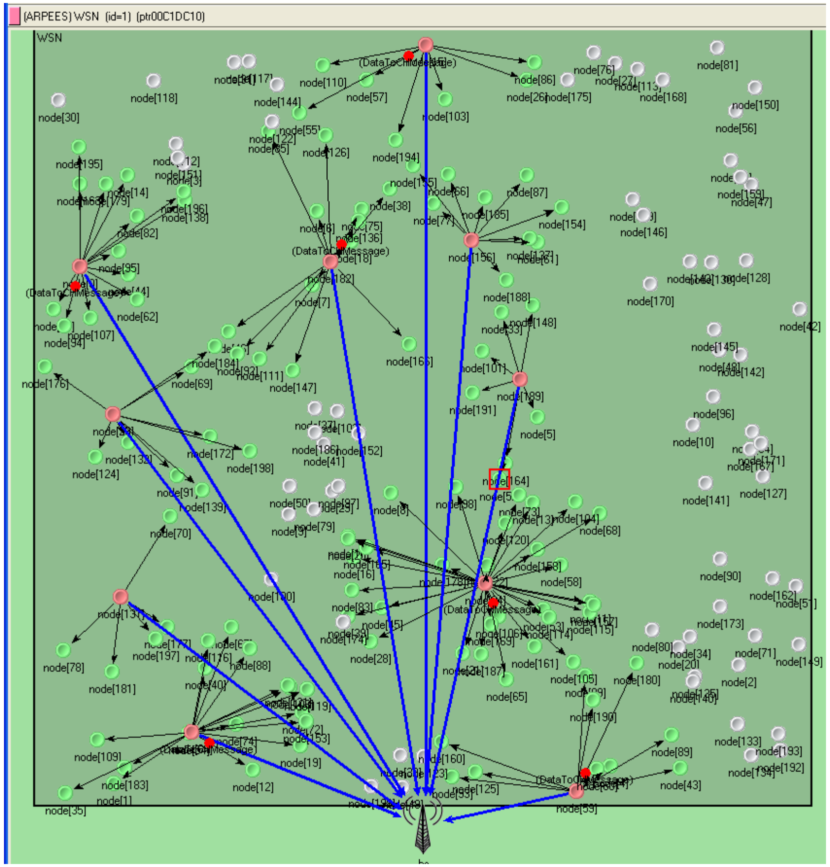


Protocol Operation

- Snapshot



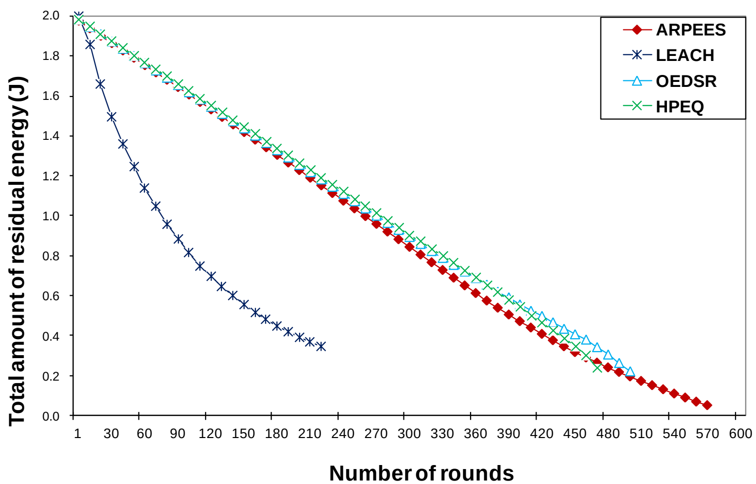
ARPEES

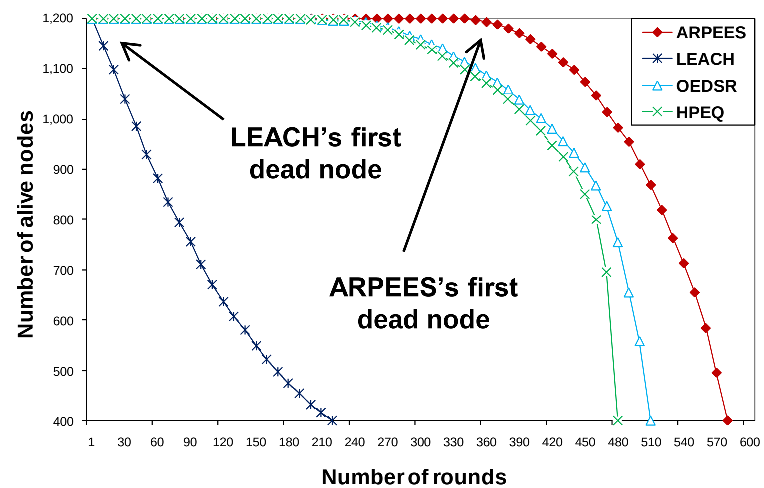


LEACH

Result Analysis

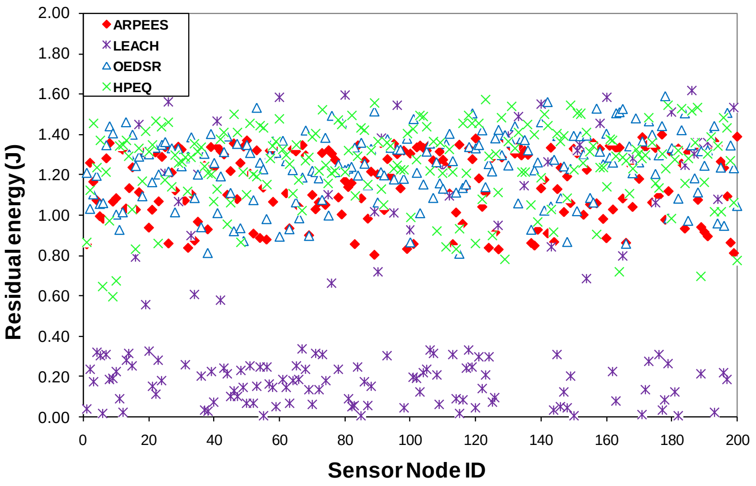
- Comparators
  - Single-hop routing (LEACH)
  - Clustering, multi-hop routing (OEDSR and HPEQ)
- Network lifetime, living node, first dead
  - ARPEES extends 13%, 20% and 50% to compare with HPEQ, OEDSR, and LEACH
  - ARPEES has more number of alive nodes than the comparators
  - 350 rounds before the first node dead. LEACH, OEDSR, HPEQ: 7, 200, and189 respectively



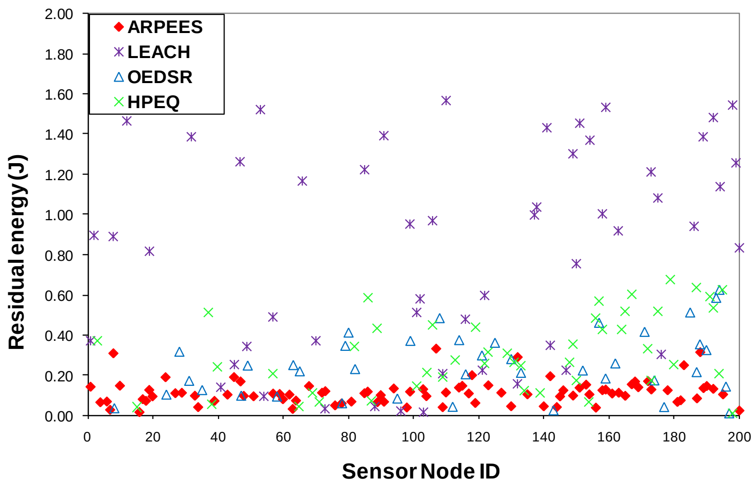


Result Analysis

- Load balance
  - ARPEES achieves load balance by scattering required energy to different nodes



After 200 rounds

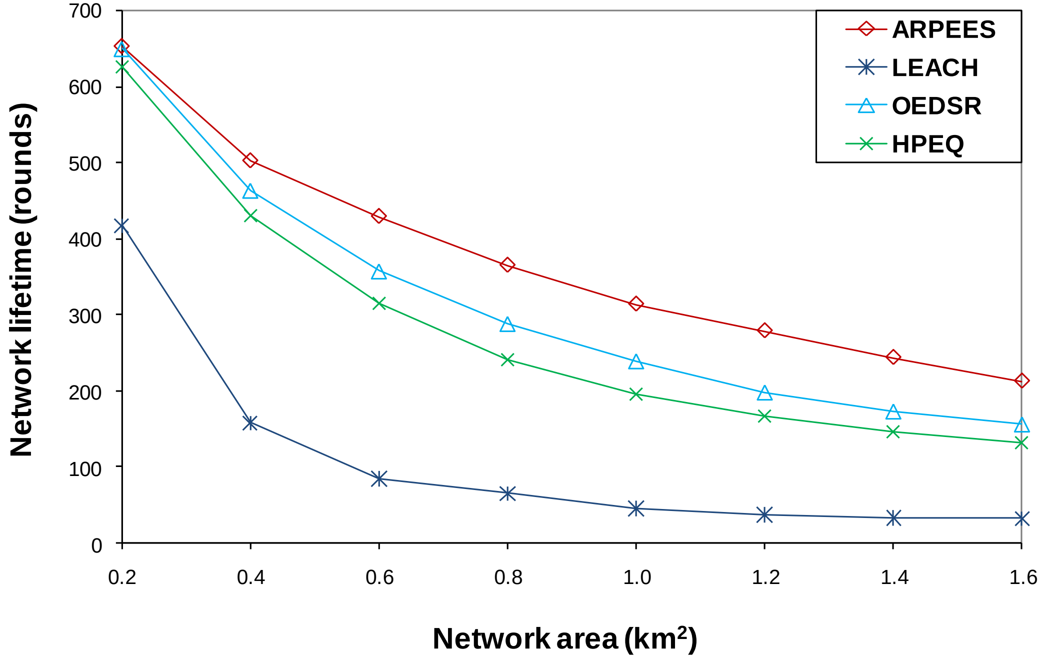


After end of simulation

The residual energy of 200 randomly selected sensor nodes in a 500m × 500m area of 1200 sensor nodes

Result Analysis

- Performance in larger application
  - 1,500 nodes dispersed in a square field: from 0.2 up to 1.6 km^2
  - ARPEES operates much longer than the others, especially as network area increases



The network lifetime versus network area with 1500 sensor nodes

Conclusion

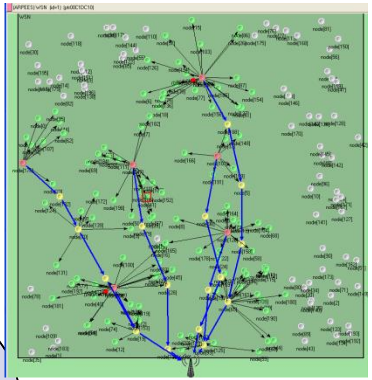
- Results
  - Reduce the energy consumption of each node
  - Distribute data load or balance energy to different nodes
  - Prolong the whole network lifetime, especially as the network size becomes large

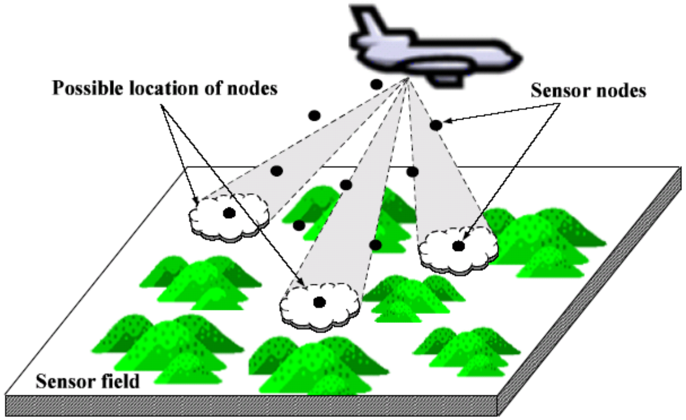
- Major Publications
  - V. Tran Quang and T. Miyoshi, " Adaptive Routing Protocol with Energy Efficiency and Event Clustering for Wireless Sensor Networks," *IEICE/IEEE Transactions on Communications*, Vol. E91-B, No. 9, pp. 2795-2805, September 2008.
  - V. Tran Quang and T. Miyoshi, "ARPEES: Adaptive Routing Protocol with Energy-Efficiency and Event-Clustering for Wireless Sensor Networks," *4th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI 2007)*, Pohang, Korea, pp. 95-100, November 2007.

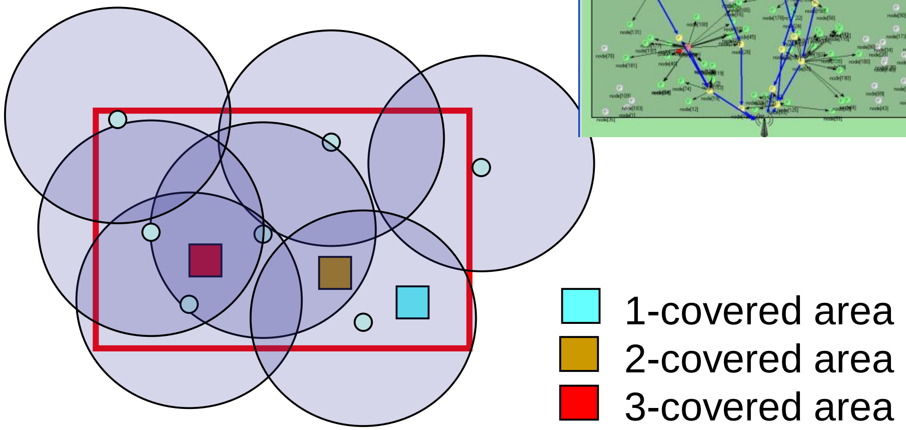
Energy Balance on Adaptive Routing Protocol Considering the Sensing Coverage Problem for WSNs (CoARPEES)

Introduction

- Combination of MSCR algorithm and ARPEES routing
  - Maximum Sensing Coverage Region Algorithm (MSCR)
  - Sensor network deployment
    - Sensor nodes are mostly deployed at random
    - High density → redundancy → Waste energy
    - Increase overhead and collision





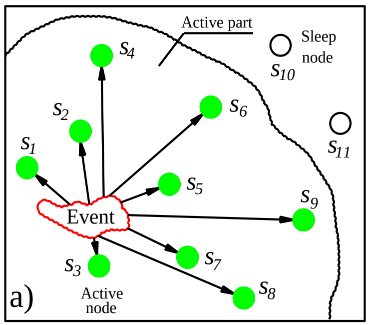


Overlap sensing areas

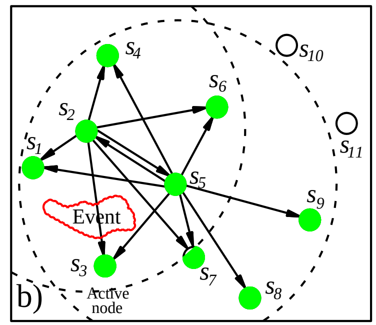
MSCR Algorithm

- **Design Goal**
  - Selecting a small number of delegated sensor nodes by identifying redundant nodes
  - Assigning redundant nodes to an off-duty operation
  - Make sure all events occurred in monitoring area can be accurately and timely detected
- **Proposed Algorithm**
  - Maximum Sensing Coverage Region Algorithm (MSCR)
  - MSCR Algorithm can be state as: given a set *S* of *m* sensors deployed in an area *A* and a natural number *k*, MSCR is an algorithm to discover a minimum subset $S' \subseteq S$ such that:
    - (1) guarantees the area *A* is *k*-covered
    - (2) achieves maximum sensing region
- **Cực đại vùng giám sát bằng tối thiểu thiết bị cảm biến**

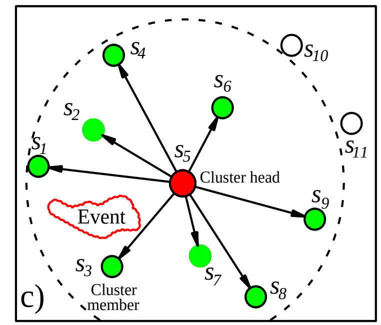
CoARPEES Operation



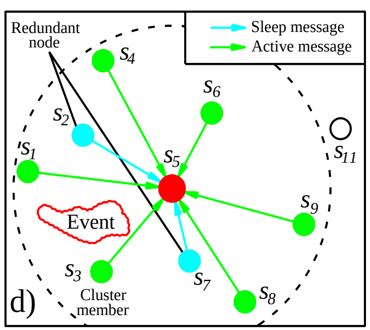
Nodes become active when detecting the event



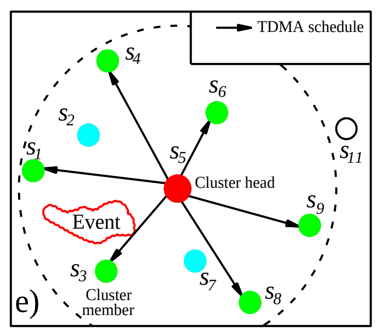
Active nodes exchange needed information



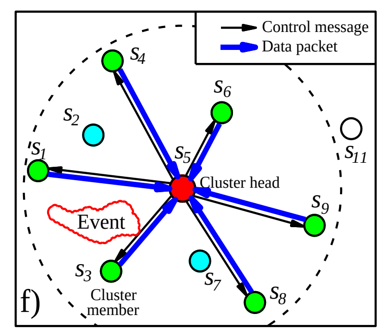
One node selected as a cluster head



Nodes check redundancy, send their status to cluster head



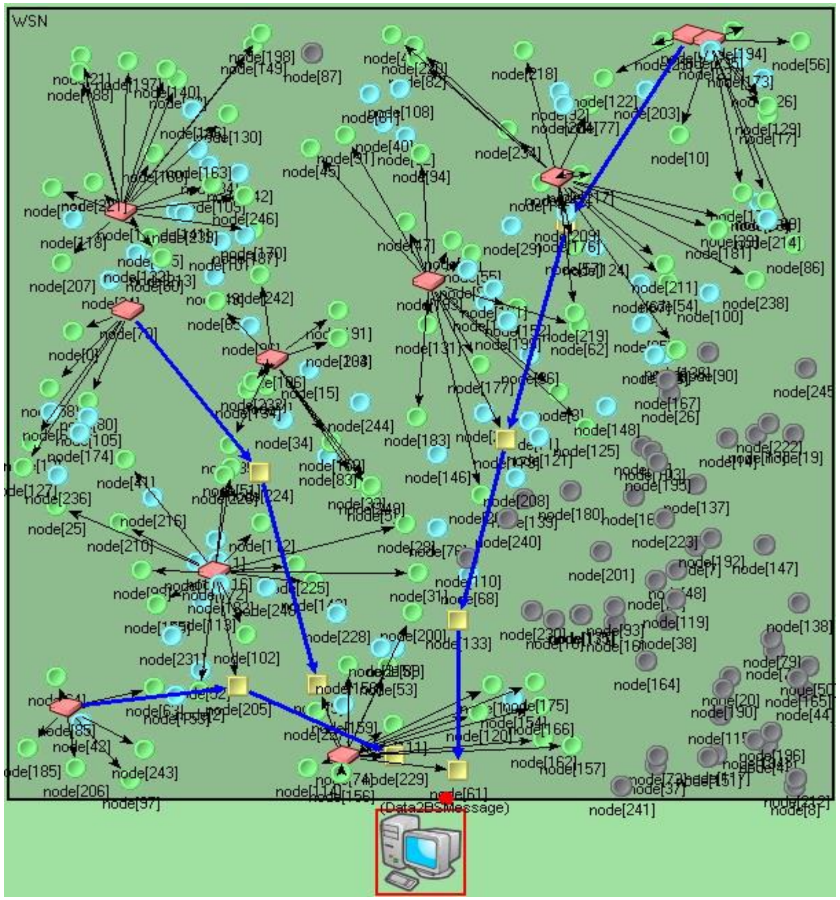
Cluster head sends TDMA schedule to active members



Active members send data to cluster head in their assigned time slot

Result Analysis

- Snapshot

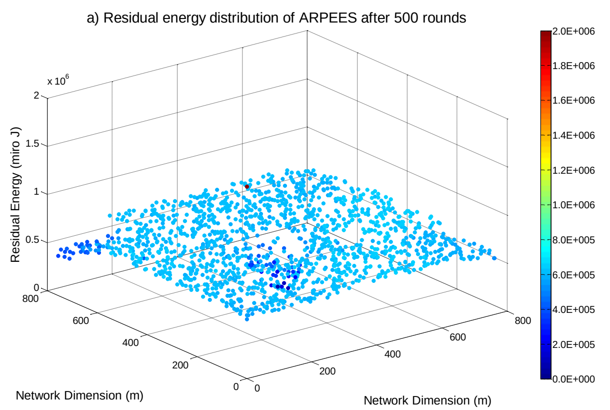


Active node

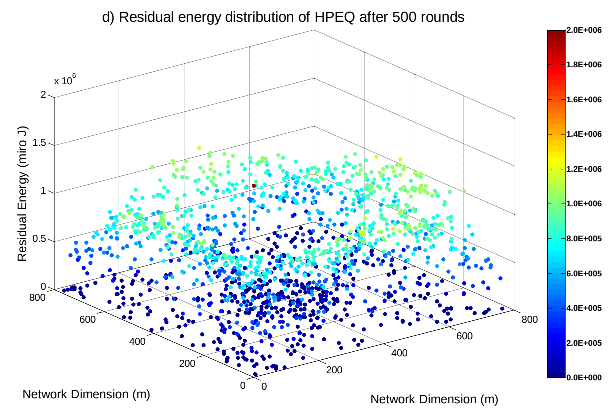
Redundant node

Result Analysis

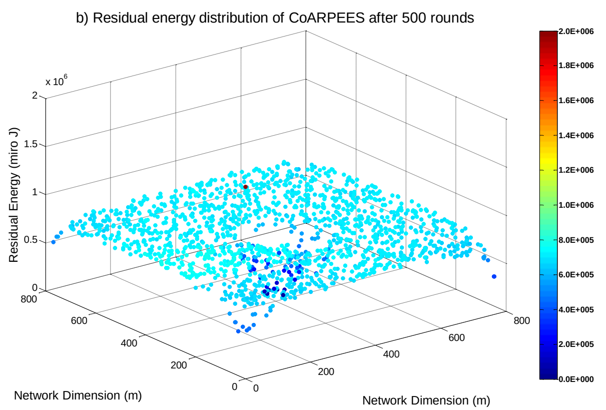
- Energy balance



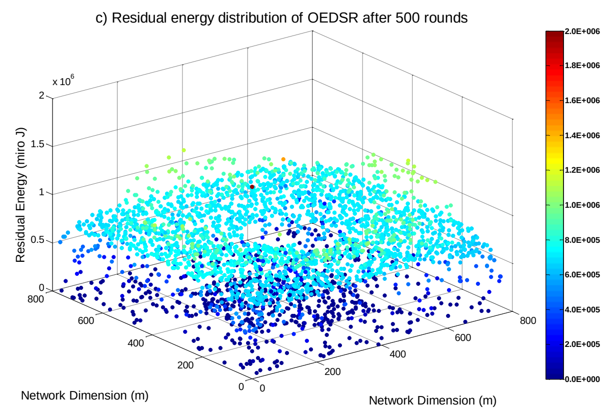
ARPEES



HPEQ



CoARPEES (*k*=2)



OEDSR

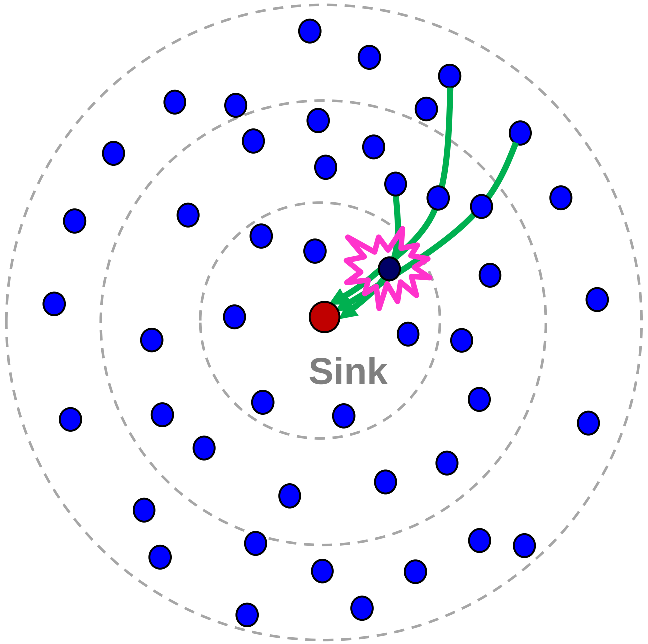
Conclusion

- CoARPEES
  - Reduces total energy consumption in the whole system
  - Achieve energy balance → increase network lifetime
  - Energy hole problem
- Major Publications
  - V.Tran Quang, T. Miyoshi, A novel gossip-based sensing coverage algorithm for dense wireless sensor networks, *Computer Networks* 53 (2009), pp. 2275-2287, September 2009.
  - V. Tran Quang and T. Miyoshi, "An Algorithm for Sensing Coverage Problem in Wireless Sensor Networks," *2008 IEEE Sarnoff Symposium*, Princeton, New Jersey, USA, Paper No. S3.5, April 2008.
  - V. Tran Quang and T. Miyoshi, "Energy Balance on Adaptive Routing Protocol Considering the Sensing Coverage Problem for Wireless Sensor Networks," *2nd International Conference on Communications and Electronics (HUT-ICCE 2008),* Hoi An, Vietnam, pp. 86-91, June 2008. ***(IEEE Student Best Paper Award)****.*
  - V. Tran Quang and T. Miyoshi, "Energy Balance on Multi-hop Relay Routing Protocol for Large Scale Wireless Sensor Networks," *IEICE Technical Report*, Vol. 108, No. 134, NS2008-40, pp. 83-88, July 2008, Japan.

A Transmission Range Adjustment Algorithm to Avoid Energy Holes in WSNs (ARPEES-DTA)

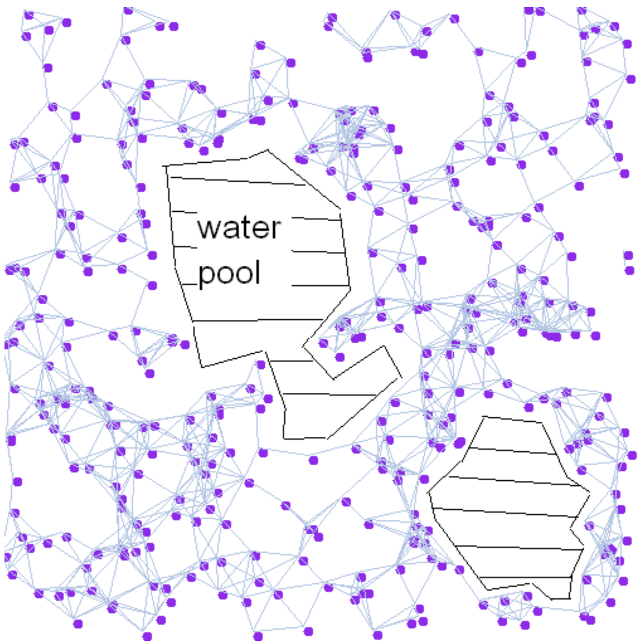
An Energy Hole Formation

- Traffic Distribution
  - Multi-hop routing to deliver data
  - Self-generated traffic and,
  - Relayed traffic for far away sensors
- Energy Hole
  - Nodes closer to sink consume energy quickly
  - Leaving a hole near the sink
  - Partitioning the whole network
  - Reduce the effective network lifetime
    - Remaining nodes still have a plenty of energy
- When does it appear ?
  - Homogeneous sensor nodes
  - Regardless of the routing strategy and MAC protocols [1]

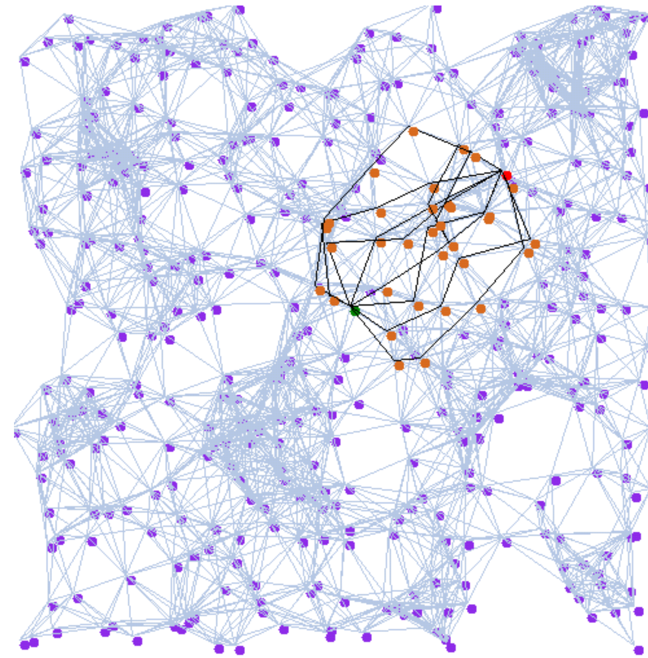


Other Types of Energy Holes

Figure source : Shu2008 [2]



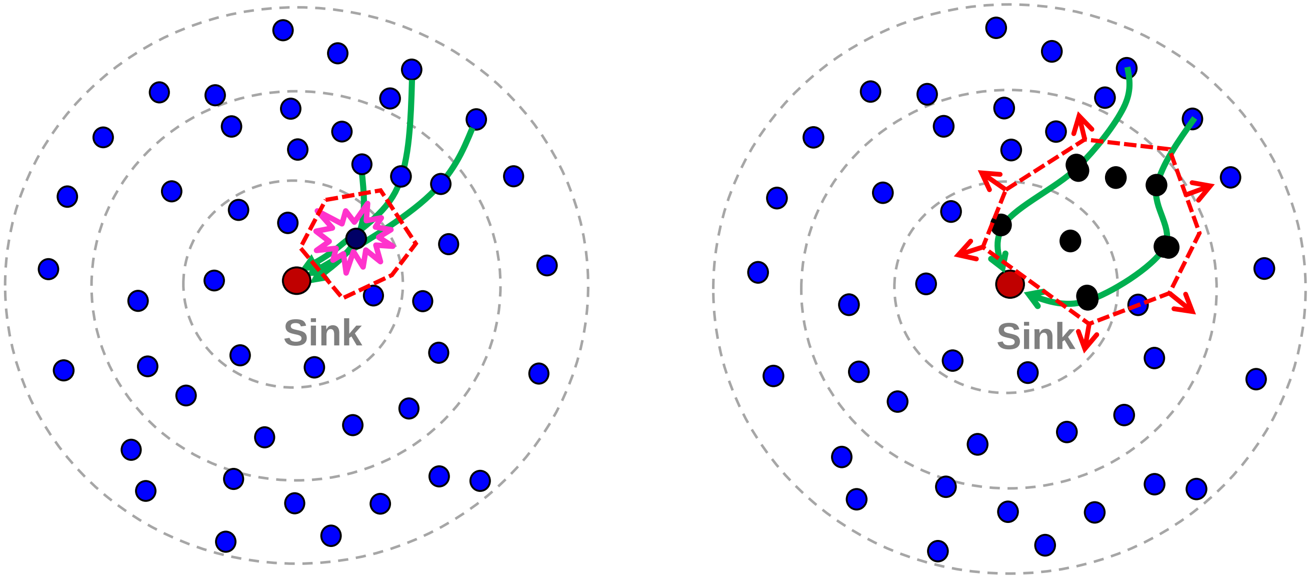
Energy hole caused by nature terrain



Energy hole appear in "Hot spot" area

Spreading of Energy Hole

- Normal routing protocols try to “by-pass” energy holes
  - Boundary nodes carry a heavy load and die soon
  - This process spreads the hole out



Energy Hole Analysis

- Considering traffic load
  - Average traffic load per sensor node in each annular is calculated as:

$$Load_i = \frac{\rho\pi(md)^2 b - \rho\pi((i-1)d)^2 b}{\rho\pi(id)^2 - \rho\pi((i-1)d)^2} = \frac{m^2-(i-1)^2}{2i-1} b,\ i = 1, 2, \ldots, m$$

  - Residual energy of the sensor node in each annulus a_i is calculated as:

$$\begin{aligned} E_{res}(a_i) &= E_{ini} - E_{Rx}(load_i, d) - E_{Tx}(load_i, d) \\ &= E_{ini} - \delta_1 b \varepsilon_{elec} - \delta_2 b(\varepsilon_{elec} + \varepsilon_{fs} d^{\alpha}). \end{aligned}$$

$$\delta_1 = \frac{m^2-(i-1)^2}{2i-1}$$

$$\delta_2 = \frac{m^2-(i-1)^2}{2i-1}$$

  - **Remark**
    - There is a considerable difference between the per node traffic load in different annuli: unbalanced traffic distribution
    - Energy consumption rate depends on **transmission range** and load

Basic Idea

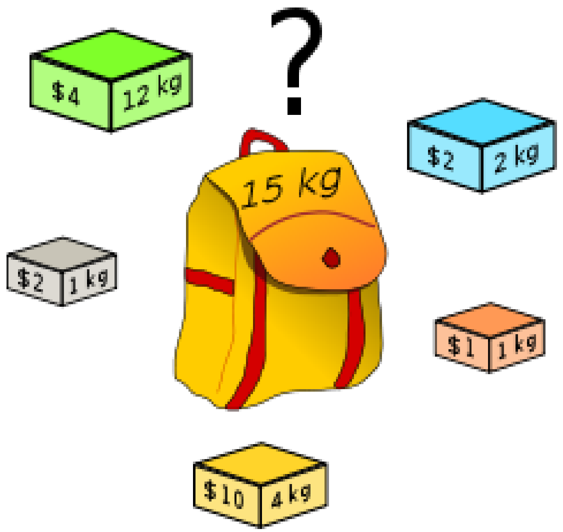
- Objective
  - Maximize overall network lifetime
- How to do ?
  - Modeling lifetime of a sensor as a function of residual energy level and traffic load
  - Adjust transmission range level to equalize the energy dissipation rate
  - Make sure all sensor nodes exhaust their energy at the same time
    - → energy holes do not appear
- Our Proposed Method
  - Find a Dynamic Transmission-Range Adjustment (DTA) algorithm that:
    - determines what transmission level the sensor nodes in each annulus should use to transmit their data so as
    - to distribute the traffic load optimally
    - to maximize the network lifetime

Knapsack Problem

- Classical Knapsack Problem (0-1 KP)
  - Well-known and well-studied decision problem in 1960s–1990s
  - The decision problem belongs to NP-complete class

A thief breaks into a store and wants to fill his knapsack with as much value in goods as possible.

Given the list of *n* items, the i^{th} item is profit p_i dollars and weights w_i pounds, but he can carry at most *C* pounds in his knapsack.



Source: wiki

Question:
Which items should he take to maximum his profit?

Knapsack Problem

- Multi-Choice Knapsack Problem (0-1 MCKP)
  - If the items are subdivided into *k* classes denoted n_i, and exactly one item must be taken from each class, we get the **0-1 MCKP** [6]

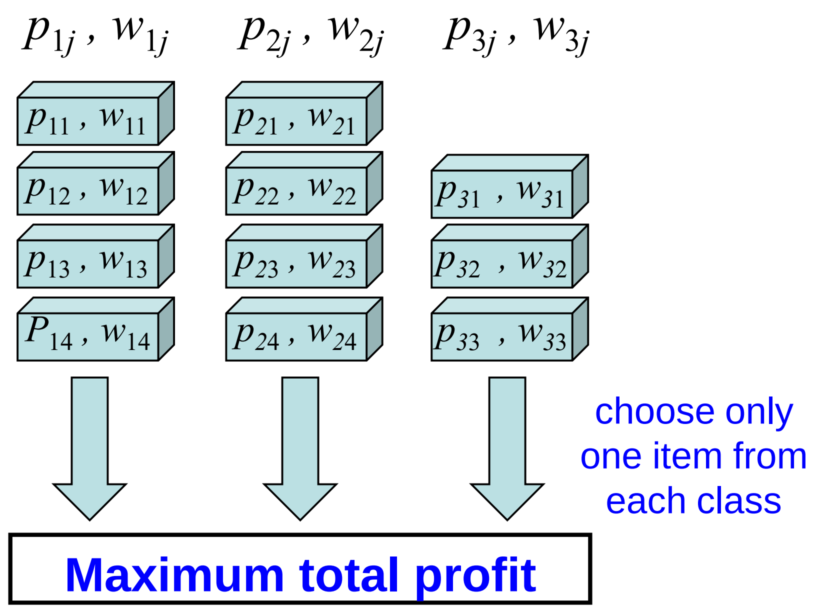
$$\text{maximize} \qquad z = \sum_{i=1}^{m} \sum_{j=1}^{n_i} p_{ij} x_{ij}$$

$$\text{subject to} \qquad \sum_{i=1}^{m} \sum_{j=1}^{n_i} w_{ij} x_{ij} \le c,$$

$$\sum_{j=1}^{n_i} x_{ij} = 1, i = 1, \ldots, m,$$

$$x_{ij} = 0 \text{ or } 1,\ i = 1, \ldots, m,\quad j = 1, \ldots, n_i.$$

$$x_{ij} = \begin{cases} 1 & \text{if item } j \text{ of class } n_i \text{ is selected;} \\ 0 & \text{otherwise.} \end{cases}$$



What to do next?

Mapping the DTA to the 0-1 MCKP

Using dynamic programming to solve for optimal solution

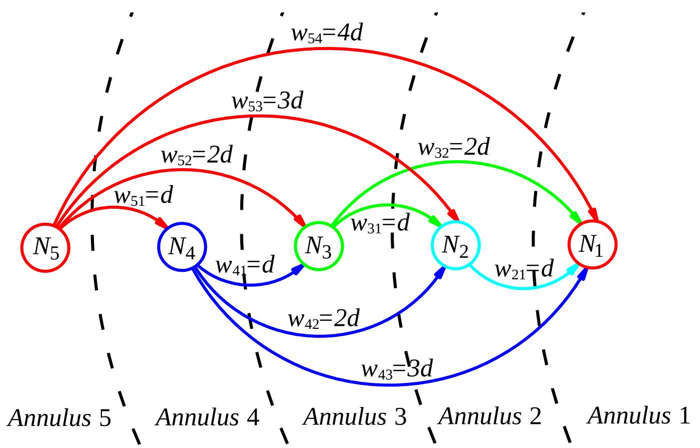
Mapping DTA to 0-1 MCKP

- The DTA problem can be formulated as a 0-1 MCKP

w_{ij} = transmission level j of sensor i

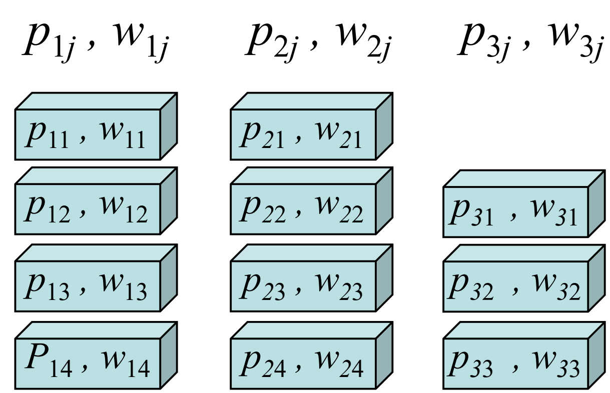
p_{ij} : residual energy of sensor i if using transmission level j

$$\boxed{p_{ij} = e_i^{curent} - e_{ij}^{req} = e_i^{curent} - f(data_i, w_{ij})}$$



choosing at most one item from each annular

Maximum overall network lifetime



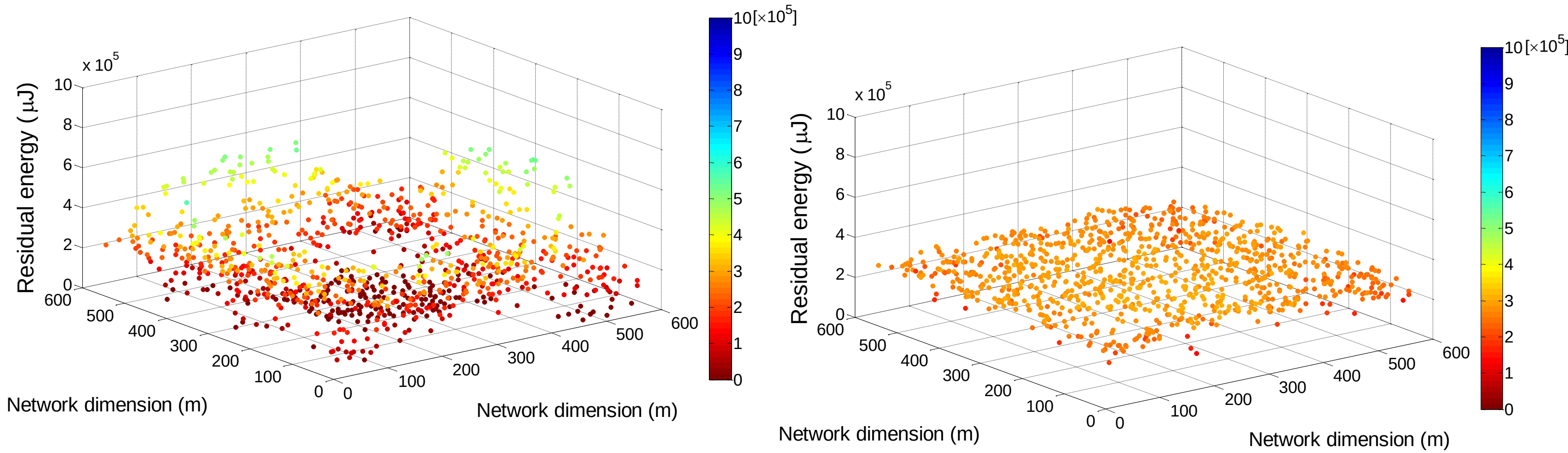
choosing only one item from each class

Maximum total profit

Simulation Results

- Energy Balance

ARPEES ARPEES-DTA



Residual energy distribution of 1000 sensor nodes after 800 rounds.

Conclusion

- Main Points
  - The profit from the optimal solution of the **DTA** ensure that sensor nodes consume their energy smoothly
  - Achieve energy balance → all nodes exhaust their energy at the same time → avoid energy holes
- Major Publications
  - V. Tran-Quang, P. Nguyen Huu, and T. Miyoshi, "A Transmission Range Optimization Algorithm to Avoid Energy Holes in Wireless Sensor Networks," IEICE Transactions on Communications, Vol. E94-B, No. 11, pp. 3026-3036, November 2011.
  - P. Nguyen Huu, V. Tran-Quang, and T. Miyoshi, " Low-Complexity and Energy-Efficient Algorithms on Image Compression for Wireless Sensor Networks," *IEICE Transactions on Communications*, Vol. E93-B, No.12, pp. 3438-3447, December 2010.
  - V. Tran-Quang, P. Nguyen Huu, and T. Miyoshi, " Adaptive Transmission Range Assignment Algorithm for In-routing Image Compression on Wireless Sensor Networks," *3rd International Conference on Communications and Electronics* (ICCE 2010), Nha Trang, Vietnam, pp. 18-23, August 2010.
  - P. Nguyen Huu, V. Tran-Quang and T. Miyoshi, " Image Compression Algorithm Considering Energy Balance on Wireless Sensor Networks," *8th IEEE International Conference on Industrial Informatics* (INDIN 2010), Osaka, Japan, pp. 1005-1010, July 2010.
  - V. Tran-Quang and T. Miyoshi, " A Transmission Range Adjustment ALgorithm to Avoid Energy Holes in Wireless Sensor Networks," *8th Asia-Pacific Symposium on Information and Telecommunication Technologies* (APSITT 2010), Kuching, Malaysia, Paper No. A-5-4, June 2010.

A Collaborative Target Tracking Algorithm Considering Energy Constraint in WSNs

Outline

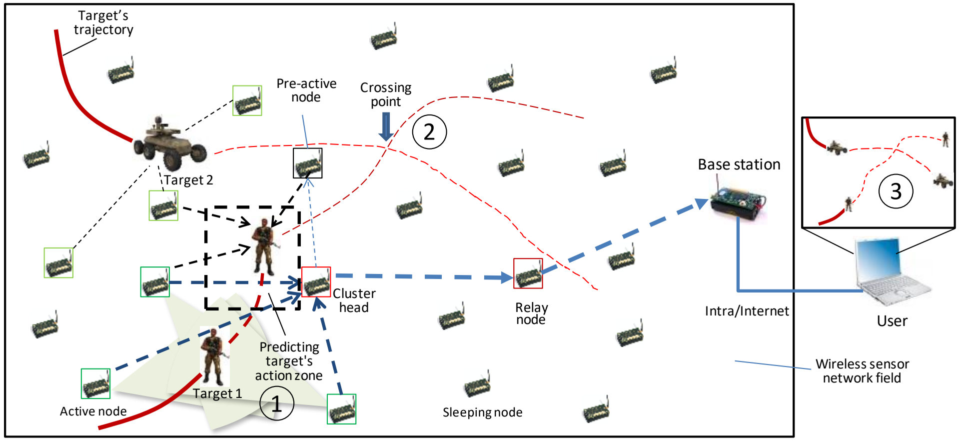
- Introduction
  - Challenge
  - Objective and the basic idea
- Proposed Method
  - Formulating the Problem
  - Extended Kalman Filter
  - Collaborative target tracking
- Simulation Results
  - Simulation setup
  - Performance evaluation
- Conclusion and Future Work

Introduction

- Target tracking using wireless sensor network
  - Target tracking sensor network refers to a wireless sensor network designed to monitor and track mobile targets in the covered area.
  - To obtain a record of the trajectory of moving targets
- Challenges
  - Scalable coordination
    - Ad-hoc deployment
    - Size of the network, the number of targets
  - Tracking accuracy
    - Deal with uncertain behavior of targets
    - Reduce probability of missing a target
    - Robust against node failure
  - Energy constraint
    - Minimize communication
    - Balance energy consumption

Basic Idea

- Prediction (Extended Kalman Filter)
  - Using the EKF to **estimate trajectory** of a dynamic target
  - **Assigning suitable sensor nodes** to track approaching target
- Goals
  - Reduce energy consumption by **managing behavior of sensor nodes**
  - Increase quality of tracking through **target prediction** and **node pre-activation** techniques
  - Prolong **network lifetime**



Extended Kalman Filter

- What is a Kalman Filter and What Can It Do?
  - A Kalman filter is an ***optimal estimator – i.e infers parameters of interest from*** indirect, inaccurate and uncertain observations.
  - It is ***recursive processing*** so that new measurements can be processed as they arrive. (batch processing where all data must be present).
  - Convenient form for ***online real time processing***.
- Optimal in what sense?
  - If all noise is Gaussian, the Kalman filter minimizes the mean square error of the estimated parameters.
- Extended Kalman Filter (EKF)
  - A variation of Kalman Filter for nonlinear model

Formulating the Problem

- Target Model – State Definition
  - A dynamic target *j* that moves according to an i.i.d over time
  - Using the discrete-time white noise acceleration model described by the evolution of **target state sequence vector** $\mathbf{x}(k) = [x(k)\ \ \dot{x}(k)\ \ y(k)\ \ \dot{y}(k)]^{\mathrm{T}}$

$$\mathbf{x}_j(k+1) = \mathbf{A}_j(k)\mathbf{x}_j(k) + \mathbf{w}_j(k)$$

  - $\mathbf{A}_j(k)$: state-transition matrix, $\mathbf{w}_j(k)$: process noise (Gaussian), k: discrete time step
- Sensor Nodes and Measurement Model
  - Homogeneous, stationary, random distributed, and location awareness
  - Capability to measure the target in sensing range using
    - such as an acoustic signal that is emitted from the target
  - Noisy target measurement model with the true target state at time *k* is described by **noisy target measurement vector**

$$\mathbf{z}_j(k) = \mathbf{h}_j[k, \mathbf{x}_j(k)] + \mathbf{v}_j(k)$$

  - $\mathbf{h}_j[k, \mathbf{x}_j(k)]$: measurement function, $\mathbf{v}_j(k)$: measurement noise (Gaussian)

State Estimation of EKF

- 0. Known Input
  - Estimate of state target $\hat{\mathbf{x}}_j(k\,|\,k)$, and given measurements $\mathbf{z}_j(k+1)$
- 1. State Prediction:

$$\hat{\mathbf{x}}_j(k+1\,|\,k) = \mathbf{A}_j(k)\hat{\mathbf{x}}_j(k\,|\,k)$$

- 2. Measurement Prediction:

$$\hat{\mathbf{z}}_j(k+1\,|\,k) = \mathbf{h}_j[k+1, \hat{\mathbf{x}}_j(k+1\,|\,k)]$$

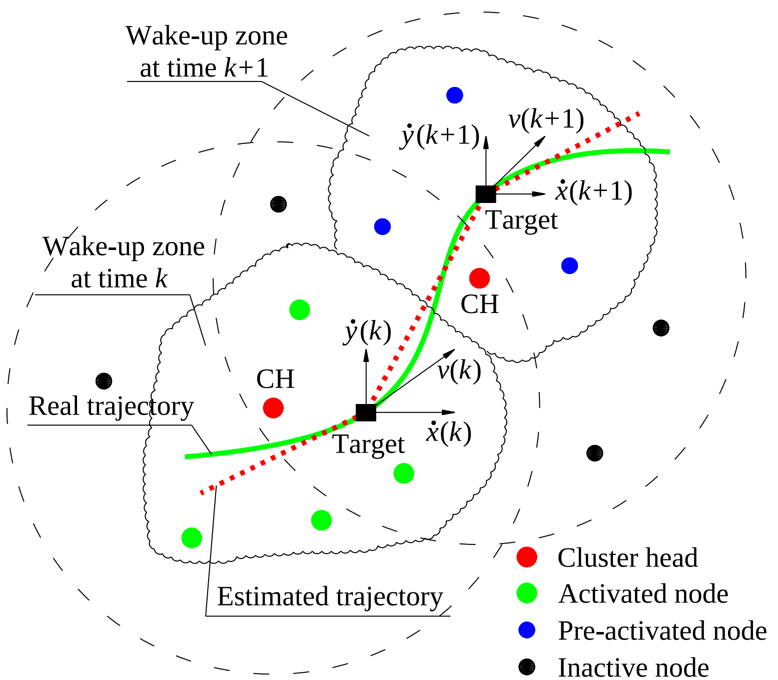
- 3. Measurement Residual:

$$\mathbf{r}_j(k+1) = \mathbf{z}_j(k+1) - \hat{\mathbf{z}}_j(k+1\,|\,k)$$

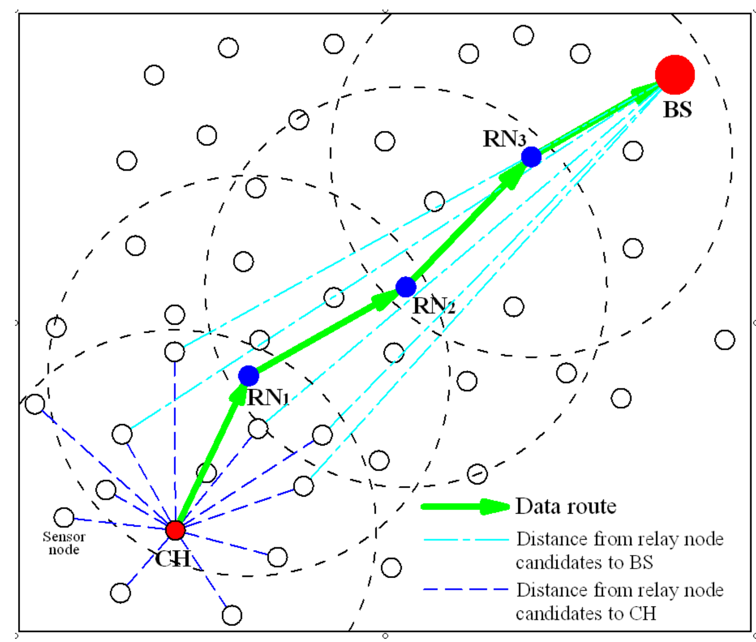
- 4. Updated State Estimate:

$$\hat{\mathbf{x}}_j(k+1\,|\,k+1) = \hat{\mathbf{x}}_j(k+1\,|\,k) + \mathbf{K}_j(k+1)\mathbf{r}_j(k+1)$$

Collaborative Target Tracking



An example of collaborative target tracking and dynamic wake-up zone determination using EKF.



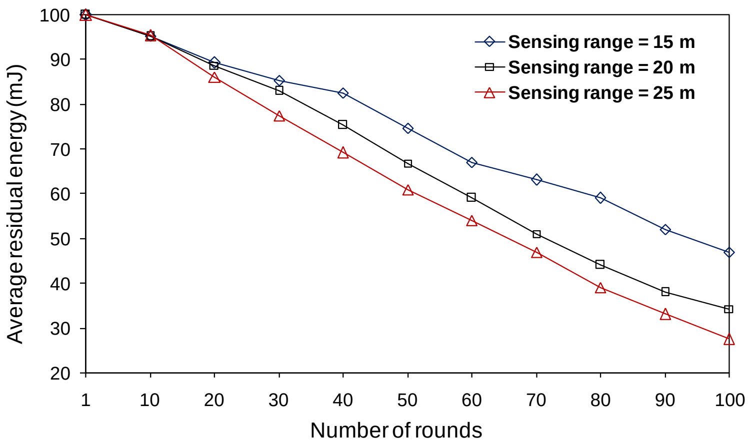
Report tracking information to base station using multi-hop relaying technique (ARPEES routing protocol).

Simulation Setup

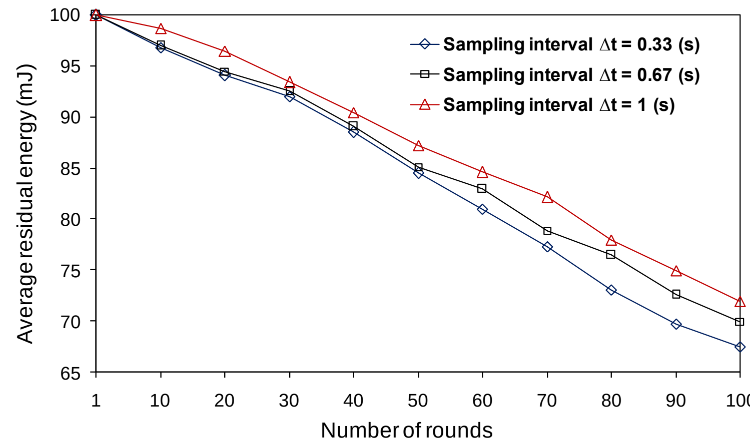
- Simulator
  - OMNet++, C++
- Network
  - Network field: 640 (m) x 540 (m)
  - Number of sensor nodes: 800
  - Energy of sensor node: 0.1 (J)
  - Sensing range: 5, 20, and 30 (m)
- Target
  - Number of target: 2
  - Movement pattern : pre-decided trajectory model
  - Average target speed: 10 (m/s)

Performance Evaluation (1)

- Energy Consumption
  - Varying sensing range (wake-up zone) and sampling interval
    - Smaller wake-up zone or smaller sampling interval between two tracking process results in higher residual energy level of sensor nodes.
    - Tracking accuracy ?



(a)

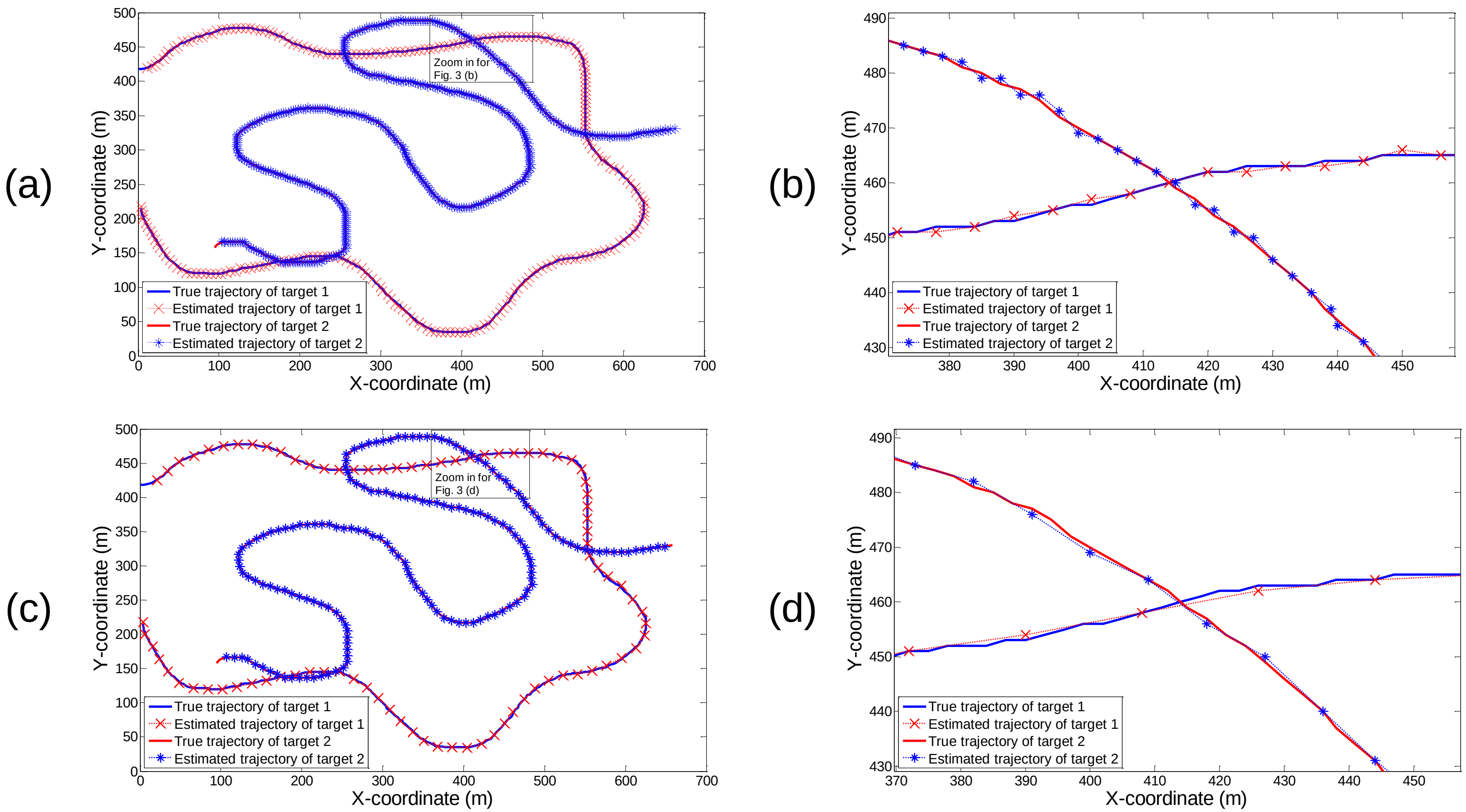


(b)

Average residual energy of sensor nodes as a function of network lifetime with (a) different sensing range, (b) different sampling interval.

Performance Evaluation (2)

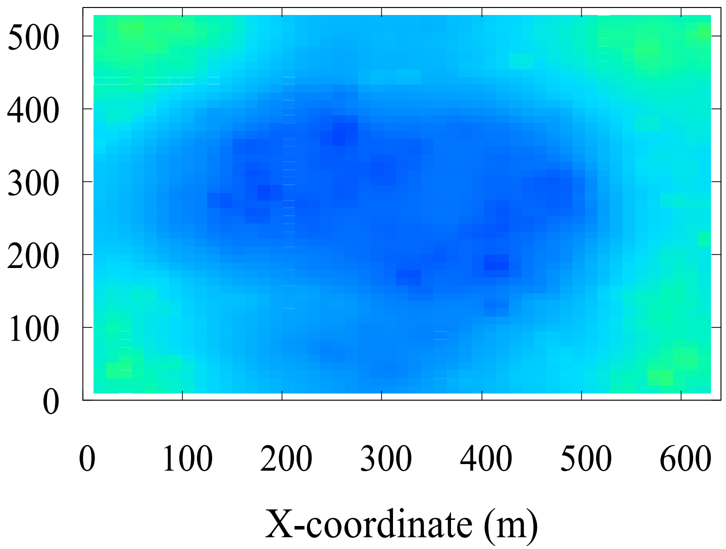
- Tracking Accuracy



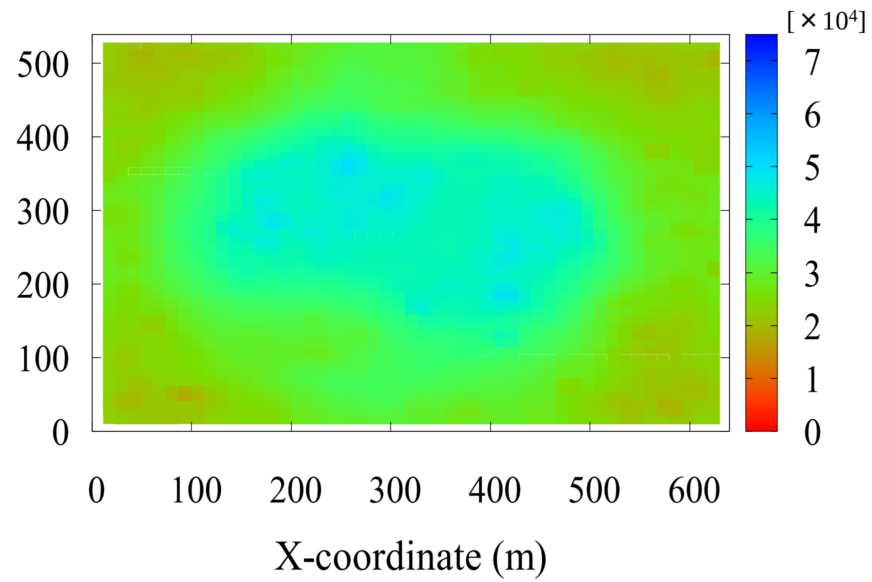
The true trajectory of two targets and their estimated location with sampling interval Δt=0.33 (s) (Figs. (a) and (b)) and Δt=1 (s) (Figs. (c) and (d)).

Performance Evaluation (3)

- Energy Balance
  - Distribution map of residual energy



(a) using wake-up zone prediction



(b) without wake-up zone prediction