# 國立交通大學

## 網路工程研究所

## 碩 士 論 文

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中 華 民 國 一百 年 十 月

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Master

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## 摘要

在無線感測網路中，感測器不只用蒐集資料，也同時扮演著儲存、計算和傳輸資料的角色．利用感測器將資料分散到無線感測網路中，我們稱之爲資料散播．過去已經有很多專門爲複數可移動的Sinks所設計的規約，但這些規約仍有問題存在，如：傳輸瓶頸、冗餘資料散播等．爲了解決這些問題，我們提出了利用可變動的階級角色進行資料散播的方法，我們使用clustering的技術和agent的機制去建構一個階級式的網路結構，這樣的結構可以幫助我們維護無線感測網路中的路由路徑及方便我們做資料散播，此外，我們還利用agent機制降低不必要的查詢訊息數量和電力的消耗；接著我們設計了新的選拔agent的演算法和cluser的維護機制去避免傳輸瓶頸的產生；最後，我們提出了可變動資料傳輸演算法來降低冗餘資料訊息的數量，讓資料傳輸更加的有效率．我們的實驗顯示出，透過我們的agent機制和新的資料傳輸演算法，我們可以更有效率的節省感測器的能源消耗並提升無線感測網路的存活時間．

關鍵字：資料散播，階級式角色，Clustering，Agent

# Adjustable Hierarchical Role-based Data Dissemination with Mobile Sinks in Wireless Sensor Networks

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## ABSTRACT

In wireless sensor networks, sensor nodes are capable of not only measuring real world phenomena, but also storing, processing, and transmitting these measuring data. Many protocols have been proposed for disseminating event data with multiple mobile sinks. However, most of them still bring some challenges such as bottleneck problem and redundant data delivery. In this paper, we propose the Adjustable Hierarchical Role-based Data Dissemination approach, named A-HRDD, with multiple mobile sinks for wireless sensor networks. In A-HRDD, we use clustering technique and agents mechanism to build a hierarchical structure that can help user's sinks to discover and maintain the routing paths for distributing data. The agents are use to avoid unnecessary query messages, and decrease energy consumption of broadcasting and number of flooding messages. We design a new agent selection algorithm and cluster maintenance scheme to decrease the loading and energy consumption of the agents and cluster heads. We also propose a query data delivery algorithm to transmit the event data more efficiently and decrease the number of redundant data messages. We evaluate and compare the communication cost and message complexity of A-HRDD with previous approaches. Our result show that A-HRDD is able to reduces the energy consumption of wireless sensor networks and achieve longer network lifetime.

**Keywords:** Data Dissemination, Hierarchical Role-based, Clustering, Agent

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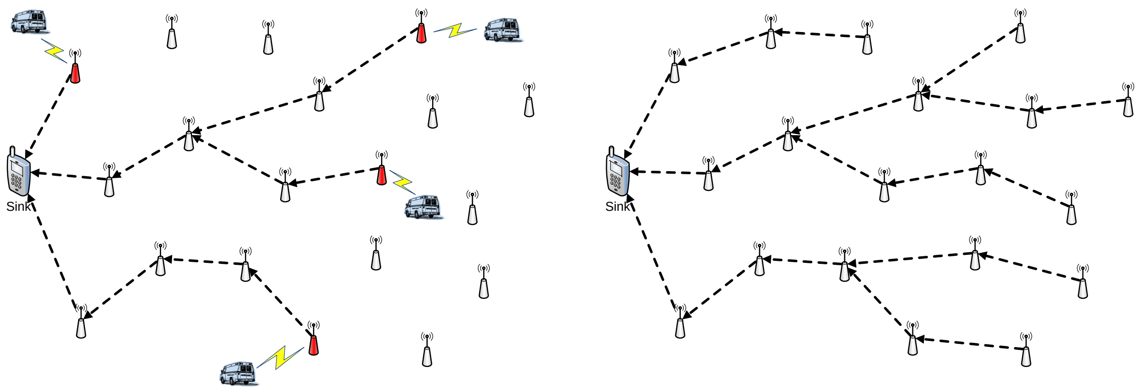
# Chapter 1

# INTRODUCTION

Wireless sensor networks (WSNs)[1], a network construct with hundreds or thousands of sensors that widely deployed in an area of interest. The sensor node which have capability of sensing and wireless communication can help us to monitor the phenomena, collect interest information, and forward the data to the control center. In the real world, the primary goal of WSN is to collect useful information such as military surveillance, disaster warning, habitat monitoring[2][3], and traffic tracking. The sensor node which collect data and generate data report is called source node. And the control center which issuing query messages and collect information from the source nodes is called a sink. The Data dissemination protocols are the means to distribute the queries and data among the sensor nodes that can separate to three different cases[4][5]: source nodes to sink, among neighboring sensors, and sink to sensors.

- **Source nodes to sink:** Each time when a source node detects an event or collects an information, it determine the sink's location, then generate and send the data report to the sink. The source node to sink has two kinds of mechanism: event driven, and time driven.
  - *Event driven mechanism* In event driven mechanism, source nodes generate and send data reports only at the time of event occurred. If there has no event in the sensing area, the source node works in silent monitoring mode (Figure 1.1(a)).
  - *Time driven mechanism* In time driven mechanism, all the source nodes continuously monitor the environments ,then periodically collect and report the values to the sink (Figure 1.1(b)).
- **Among neighboring sensors** In WSNs, sensor data dissemination often happens in the sensor nodes need to exchange data information with neighborhood, such like clustering




(a) Event driven (b) Time driven

Figure 1.1: Two Mechanisms of Source Nodes to Sink

technique [6][7][8][9][10]. The clustering technique use the node's information like node's ID, node's degree, residual energy...etc to calculate the weight of the node. The nodes with the highest weight among the neighboring nodes become the cluster head (CH) of the group. The CH will choose its members, and then collect and arrange the data from its members (Figure1.2).

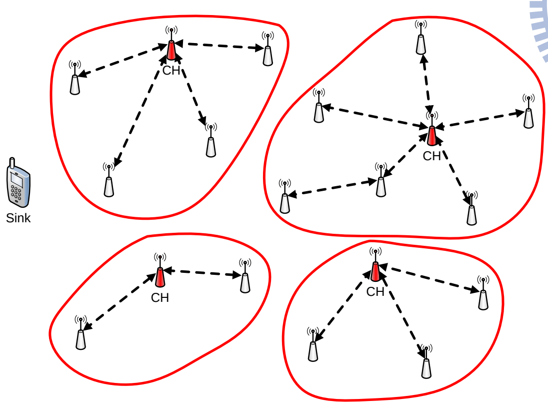



Figure 1.2: Among Neighboring Sensors

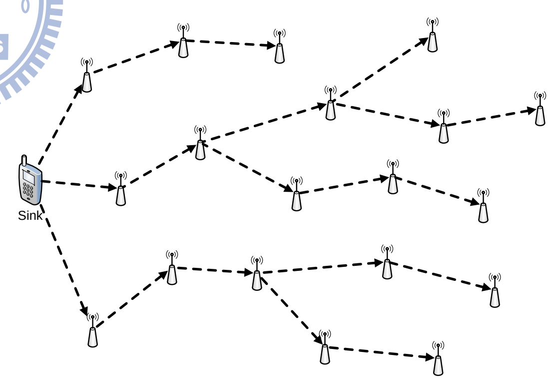



Figure 1.3: Sink to Sensors

- **Sink to sensors** Sink usually disseminate some messages to the other sensor nodes. The messages such as global information, control messages, and query messages. These messages can help us control and change the whole WSN or help us to obtain the desire information (Figure1.3).

Data dissemination protocols in WSNs have the following challenges:

1. Some research require all sensor nodes equipped with position devices, such as Global Positioning System (GPS) [11] to build their protocols. But these position devices also have high energy consumption and higher cost that does not apply to WSN.

2. In many case, a mobile sink is more feasible for deployment and security constraint than a static sink. The mobile sink also can improve the network lifetime of a WSN [12][13]. But It's hard to track the mobile sink's location for the other sensor nodes.

3. To maintain the routing information, sensor nodes have to periodically exchange information with their neighboring nodes. It will take a lot of costs and decrease the network lifetime in large-scale WSN.

Hierarchical Role-based Data Dissemination (HRDD) [14], which provide a hierarchical clustering structure and a role-based data dissemination scenario to solve these problems. But HRDD still have other problems: (a) HRDD create an agent mechanism and two level CHs to track the sink's location and disseminate data, but it means that the agents and CHs have to process more messages than other sensor nodes. These agents and CHs will fail much earlier than other sensor nodes and become the bottleneck of the WSN. (b) In HRDD, all the data have to deliver through the hierarchical structure. This will create many unnecessary, and redundant data delivery (Figure1.4) that increase the energy consumption [15] and decrease the network lifetime for the WSN. In this paper, we propose a Adjustable Hierarchical Role-based Data Dissemination (A-HRDD)

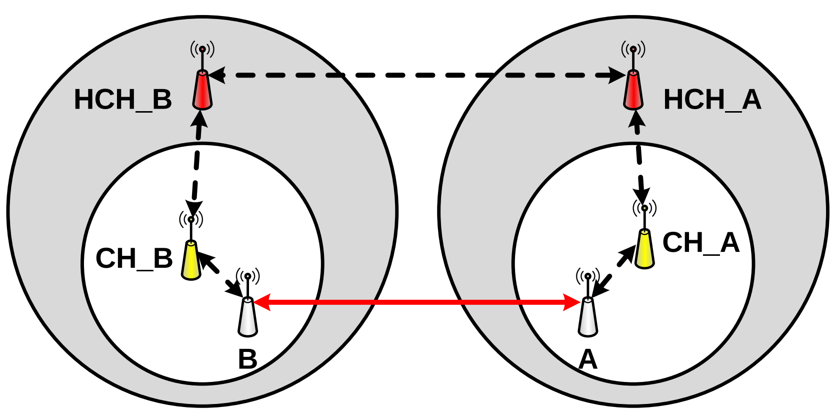



Figure 1.4: Redundant Data Delivery

approach which provide a more flexible and energy efficiency algorithm to traditional HRDD in

WSN. First, as same as HRDD, we exploit a clustering techniques to build a two-level hierarchical clusters that each mobile sink can easily maintain its data dissemination paths without the help of position devices. Then we set some nodes named indexing agents and gateway agents for efficient tracking, routing, and data dissemination. Different to HRDD, we re-design a load-balancing agents selection algorithm of indexing agents and gateway agents that can disperse the load of each agent. In query data delivery, we propose a efficiency data path selection algorithm to find a better path to deliver data that can decrease the redundant data delivery. Finally, to further increase the network lifetime of the WSN, we propose a cluster maintenance algorithm to change the CHs and agents when their energy lower than threshold. Figure1.5 is an example of the A-HRDD in WSN. The rest of the paper is organized as follows: Section 2 introduces several

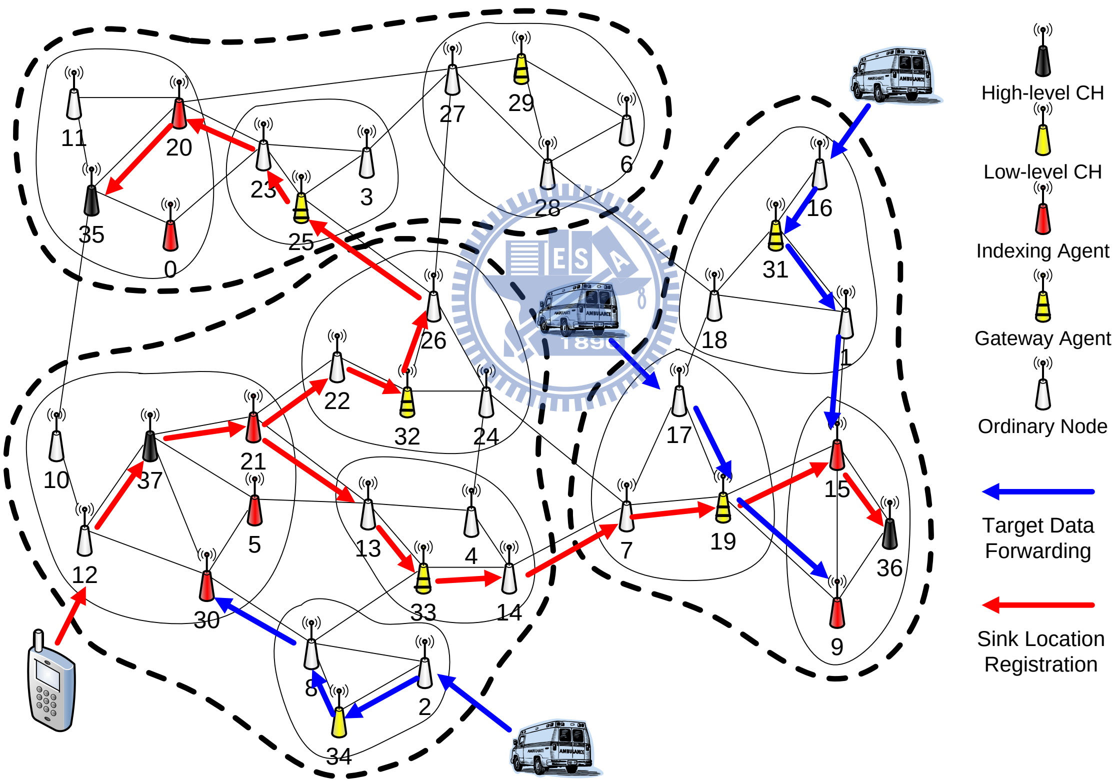


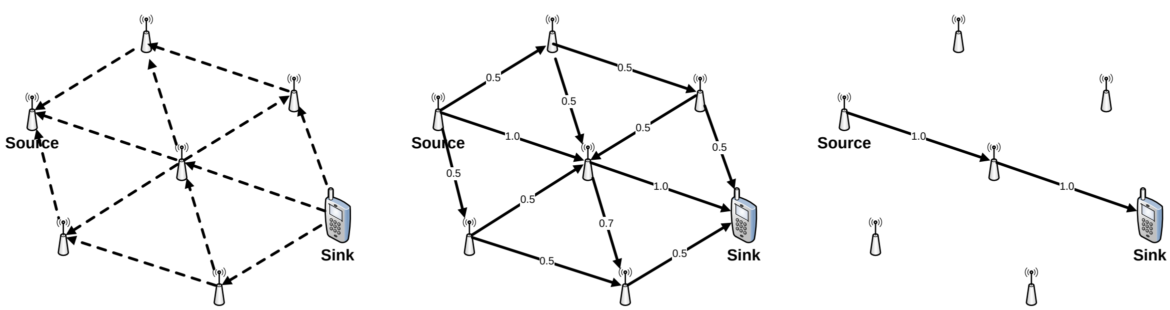

Figure 1.5: An example of the A-HRDD in WSN

related works. We describe A-HRDD in Section 3. Section 4 show the performance evaluation of A-HRDD. Finally, Section 5 draws the conclusions.

# Chapter 2

# RELATED WORK

In wireless sensor networks (WSNs), scalable and energy-efficient data dissemination play two important factors with mobile sinks. This is, because the global flooding and frequently location updating of mobile sinks are energy consuming. In this section, we give a brief literature survey of energy-efficient protocols for data dissemination on the WSNs with mobile sinks. The related works are divided into three categories: source-based approach [16][17][18], index-based approach [19][20], and hierarchical-based approach [14][21][22]. Directed Diffusion (DD) [16] is a data-centric routing protocol for named data which described by attribute-value pair. First, a sink broadcasts its interest for a certain types of data to source nodes in the area (Figure 2.1(a)). Then, the nodes set up the gradients which indicate the replies' path back to the sink (Figure 2.1(b)). Finally, the match data are forwarded back to the sink through the reinforced path (Figure 2.1(c)). In DD, sinks still have to refresh its location and interest when they receive data. However, the sink periodically propagates and flooding messages may result in network congestion. Two-Tier Data




(a) Interest propagation (b) Initial gradients set up (c) Data delivery along reinforced path

Figure 2.1: Directed Diffusion (DD)

Dissemination (TTDD) [18] provide a scalable and efficient data delivery with multiple mobile

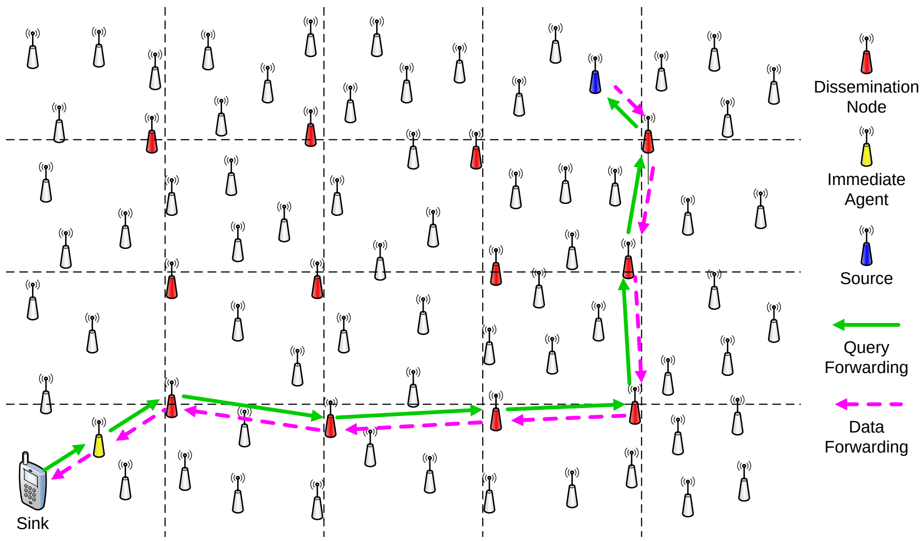



Figure 2.2: Two-Tier Data Dissemination (TTDD)

sinks, as shown in Figure 2.2. Each data source proactively builds a grid structure in TTDD. Mobile sinks' query flooding is confined within a local grid cell only. Queries are forwarded upstream to data sources along grid branches, pulling sensing data downstream toward each sink. However, in TTDD, each node should acquire the location information by GPS devices, and also, grid construction for each source node and local query flooding may consume much energy. Scalable Energy-Efficient Asynchronous Dissemination (SEAD) [17], one of the registration-based

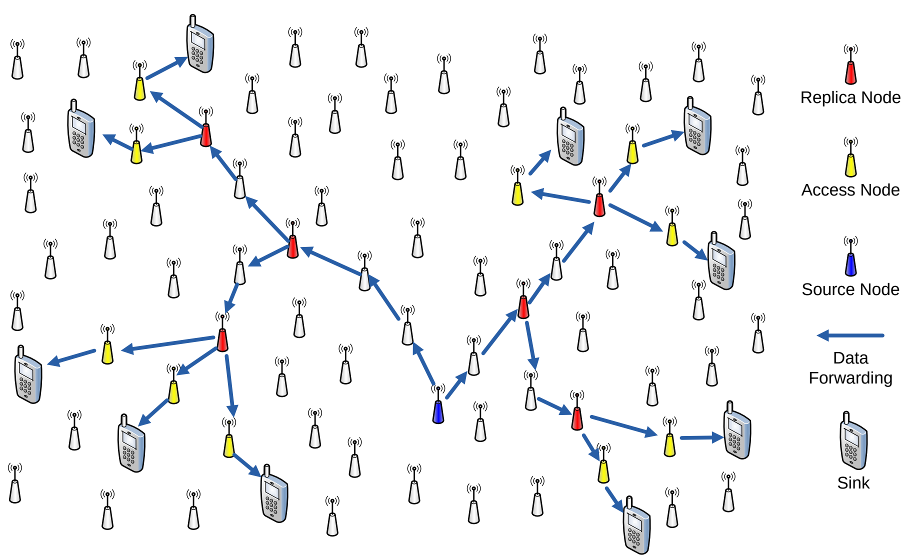



Figure 2.3: Scalable Energy-efficient Asynchronous Dissemination (SEAD)

protocol, constructs a minimum Steiner tree for each data source and designates some nodes on the tree as the access points, as shown in Figure 2.3. Each mobile sink sends the register message to the closest access point, and the access point receiving the registration should forward data to registered mobile sinks. When the sink move out of the coverage range of the corresponding access point, it should dynamically register itself to alternative access point and adjust the tree adaptively. However, like TTDD, the SEAD also acquires GPS devices and has to construct separate dissemination trees for multiple sources. In Data-Centric Storage (DCS) [19] scheme,

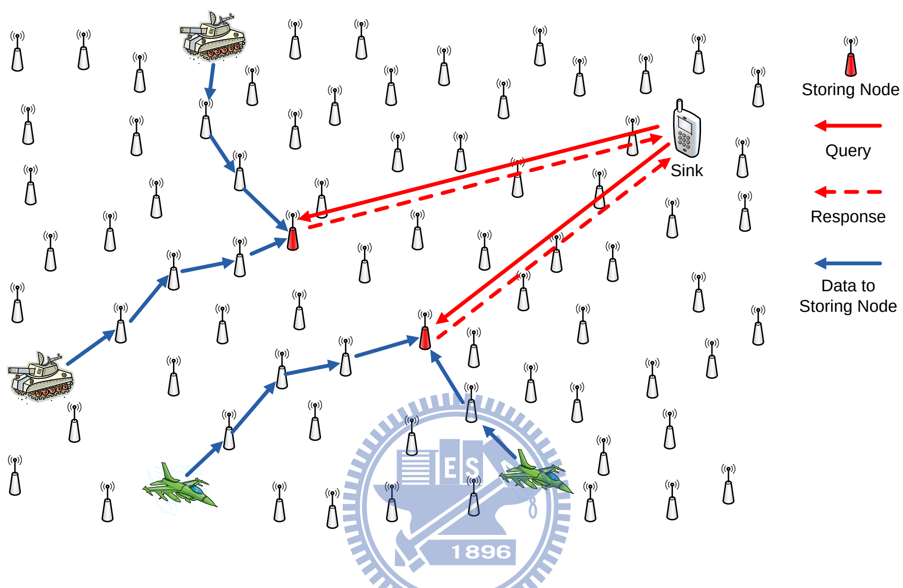



Figure 2.4: Data-Centric Storage (DCS)

each event to be detected are named , and these events data are stored at nodes within network instead of an external storage. In Figure 2.4, the storage nodes of an event is calculate by applying a hash function with the event's name, the events with same name will hash to same location. Hence, they lack flexibility and may introduce lots of unnecessary data transfer. Railroad [20] builds a virtual infrastructure which called a rail. The rail is placed in the middle area of the sensing field, as shown in Figure 2.5. When a source nodes detects an event, it stores the data and forwards a notification to the nearest neighbor toward Rail. When a sink node issues a query, the query is forwarded to the sources in three phases. First, the nodes on the forwarding path transfer the query to the nearest node on Rail. Then, the query is forwarded along Rail until it reaches the entered point. Finally, if there is a station with relevant data, the node generates a query notification message and forwards it to the source node. After the reception of a query notification, the source node sends the data messages directly to the sink. However, Railroad presents a rather high path-stretch which is almost twice the optimal path. This is direct consequence of the query path length. In Figure 2.6, shows the Hierarchical Data Dissemination

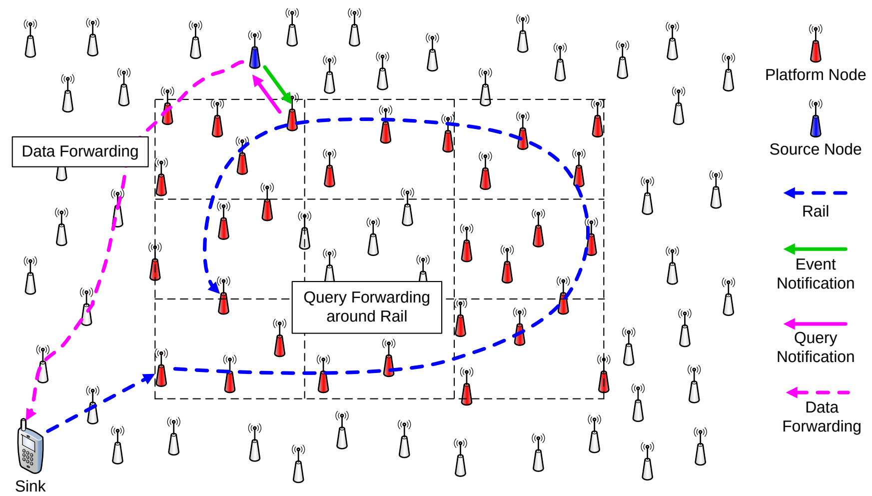



Figure 2.5: Railroad

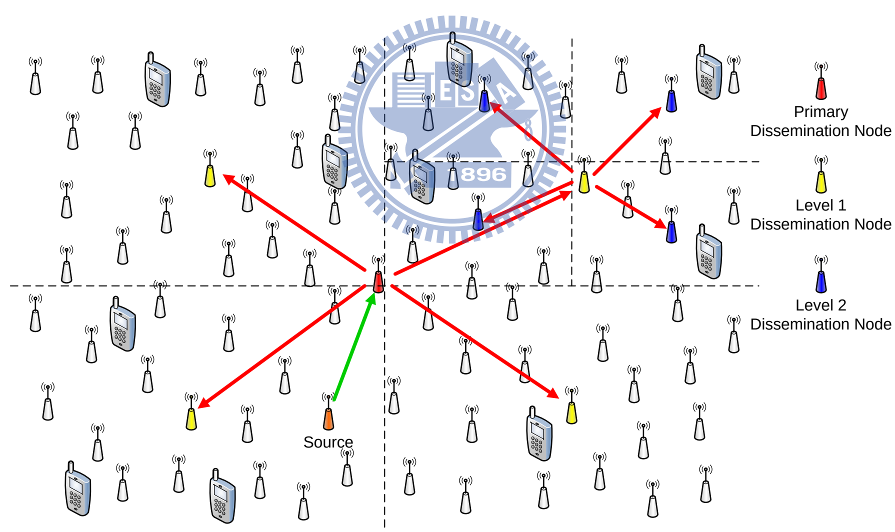



Figure 2.6: Hierarchical Data Dissemination Scheme (HDDS)

Scheme (HDDS) [21], source nodes routes data towards sinks using a hierarchically of selected dissemination nodes. Because dissemination nodes have limit resources, whenever a dissemination node is overloaded, it insert another level of dissemination nodes to reduce its loading. The data messages forwarded through these dissemination nodes to the sink. HDDS follows a data transmission policy that forwards data to the forwarding agent directly. Thus, data may take a shorter path, and total energy consumption and delay can be reduced. However, in TTDD, SEAD, DCS, Railroad, and HDDS, each sensor node should acquire the location information for data dissemination by such as GPS devices. TTDD, SEAD, and HDDS use location information to construct specific structure for transfer event. Railroad and DCS select certain nodes for queries and data reports with location information. Once the location information doesn't work well in these schemes, source can not build a routing structure to send event data. Also, the GPS devices which used to acquire location information may consume much energy. Hierarchical Cluster-based Data Dissemination (HCDD) [22], a hierarchical cluster-based structure to discover and maintain the routing paths for distributing data to the mobile sinks, as shown in Figure 2.7. HCDD build a k-level cluster structure without location information. Each node only exchanges the information with its neighboring nodes. The high-level CH called Routing Agent in HCDD. When a sink query an event, it register at one of the Routing Agents, which is responsible for the management of the sink information. Then, the CHs and Routing Agents cooperate to find the path from source nodes to the sink by the inter-cluster and intra-cluster routing. However, the broadcasting of the sink registration in HCDD increase energy consumption and number of messages. Hierarchical Role-based Data Dissemination (HRDD) [14], as shown in Figure 2.8, a

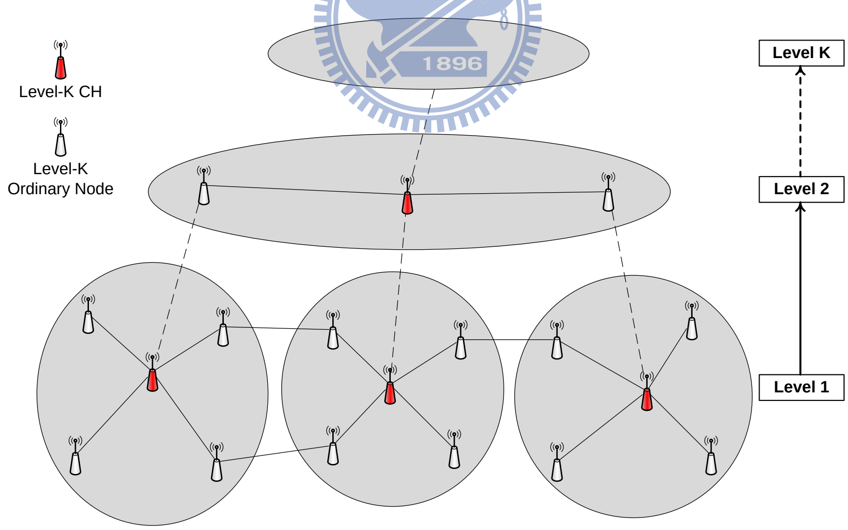



Figure 2.7: Hierarchical Cluster-based Data Dissemination (HCDD)

hierarchical cluster-based structure with agent mechanism. Similar to HCDD, HRDD build a k-level cluster without location information. HRDD assign two roles called indexing agent and gateway agent. Indexing agents which are like rendezvous area for source data reports and sink queries could avoid unnecessarily transferring the query messages. The gateway agents could decrease energy consumption and number of flooding messages when broadcasting. But even HRDD decrease the cost of sink registration, it still have some problems. First, the loading of the agents and CHs are much higher than other nodes. This will make these nodes become the bottleneck of the WSN. Second, there are too many redundant data delivery from source to sinks that increase the energy consumption and number of messages in HRDD. Table 2.1 and 2.2 compares the existing approaches describe in section 2 according to these different criteria we have just presented.

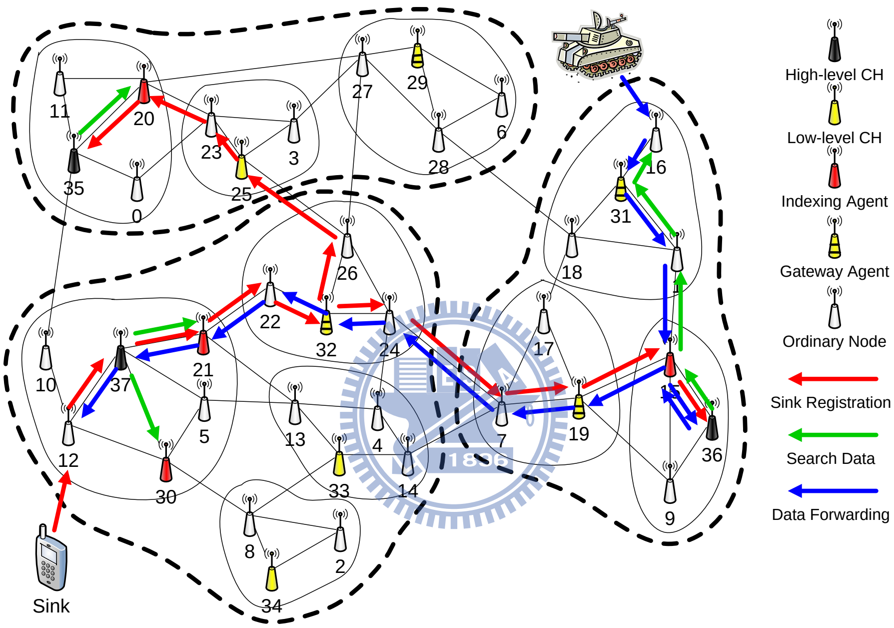



Figure 2.8: Hierarchical Role-based Data Dissemination (HRDD)

In this paper, we propose the Adjustable Hierarchical Role-based Data Dissemination (A-HRDD) approach. In A-HRDD, we design a new load balancing agent selection algorithm to separate and reduce the loading of each agent. Then, we propose a flexible data delivery algorithm to find a shorter path from sources to the sink which decreases the energy consumption for data forwarding. Finally, we design a cluster maintenance scenario to increase the network lifetime for the WSN. The objectives of our work are to (1) build an energy-efficient data dissemination for WSN without acquiring the GPS devices, (2) construct a flexible and load balancing cluster structure with agents to avoid the bottleneck of WSNs, (3) provide a short and dynamic routing path between the data sources and the mobile sinks.

| Protocol | How to send query | Equip GPS device | Exist Rendezvous area |
|---|---|---|---|
| DD | Flooding | no | no |
| TTDD | Grid structure | yes | no |
| SEAD | D-tree structure | yes | no |
| DCS | GPSR | yes | yes |
| Railroad | Rail structure | yes | yes |
| HDDS | Hierarchical structure | yes | no |
| HCDD | Hierarchical structure | no | no |
| HRDD | Hierarchical structure | no | yes |
| A-HRDD | Hierarchical structure | no | yes |

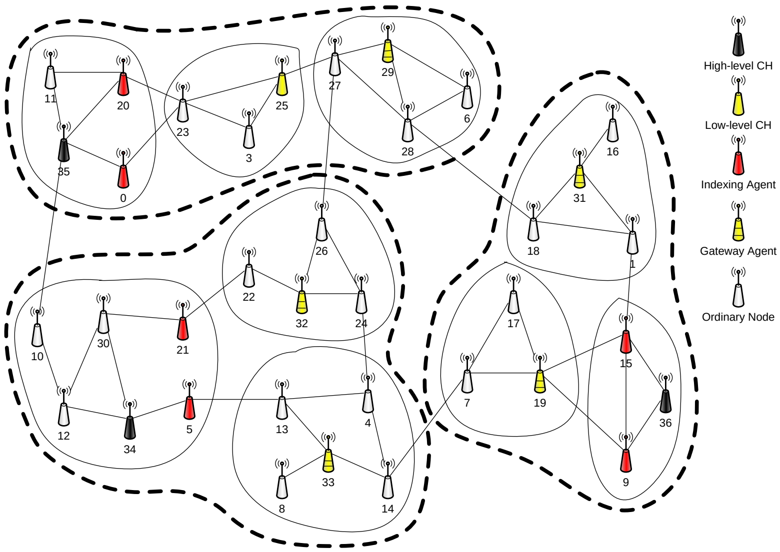
Table 2.1: Data Dissemination Protocols

# Chapter 3

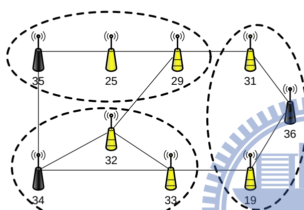
# ADJUSTABLE HIERARCHICAL ROLE-BASED DATA DISSEMINATION

## 3.1 Overview of the A-HRDD

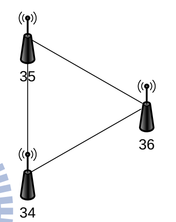
In this section, we will describe our adjustable hierarchical role-based data dissemination scheme in detail. In traditional wireless sensor networks, we usually use flooding technique to communicate and disseminate data. But the flooding overhead will rapidly increase when the network scale grow up. Here we use clustering technique [6][7][8][9][10] to build hierarchical structure, shown as Figure 3.1, to reduce communication overhead and data redundancy. Each sensor nodes organize itself in low-level clusters by cluster election process, and then the low-level clusters organize itself in high-level clusters. In HRDD, it reduces the sink's registration and query messages by using indexing agents and gateway agents mechanism for HCDD. The indexing agents, which are border nodes of high-level clusters, store the event messages of neighboring low-level clusters. The gateway agents, which are border low-level clusters of the high-level clusters, allocate the broadcast path to other high-level clusters. Indexing agents and gateway agents reduce the registration and query message, but there has a problem for this mechanism. The goal of HRDD's agent selection algorithm is choosing the fewest nodes to reduce the message. But this make a lot of query and data messages have to pass the indexing agents and gateway agents, it cause them failed quickly and become the bottleneck of the network lifetime in WSN. So we here re-design a load balance agents selection algorithm for choosing indexing agents and gateway agents to solve this problem. Figure 3.2 shows the different.




(a) Oringinal Topology



(b) Low-level Topo.



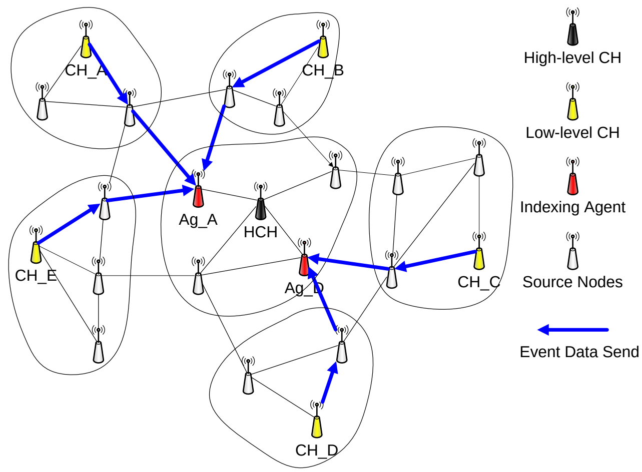
(c) High-level Topo.

Figure 3.1: Example of Adjustable Hierarchical Role-based Data Dissemination (A-HRDD)

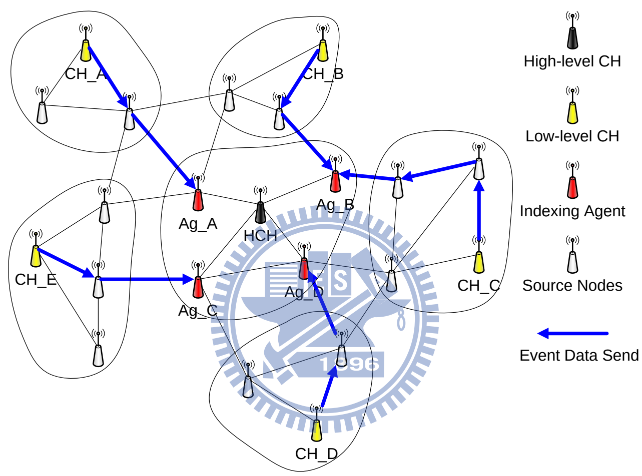
We also find when query data delivery, the HRDD will create redundant data messages. The redundant data messages create more loaded at indexing agents and high-level cluster head. So we design a data dissemination algorithm to deliver data messages more efficiently. Finally, we propose a cluster maintenance mechanism for re-choosing cluster heads and agents when they have low energy alert. In Section 3.2, we will discuss how we build hierarchical structure. In Section 3.3, we will show the agents selection algorithm. Section 3.4 introduces how the mobile sink registers its location and the event detection mechanism. To efficiently query and deliver data shows in Section 3.5. Finally, Section 3.6 introduces the cluster maintenance scheme.

## 3.2 Cluster Construction

There are a number of clustering techniques been proposed. But most of them like, Linked Cluster Algorithm (LCA) [7] , Distributed Clustering Algorithm (DCA) [8], Weighted Clustering



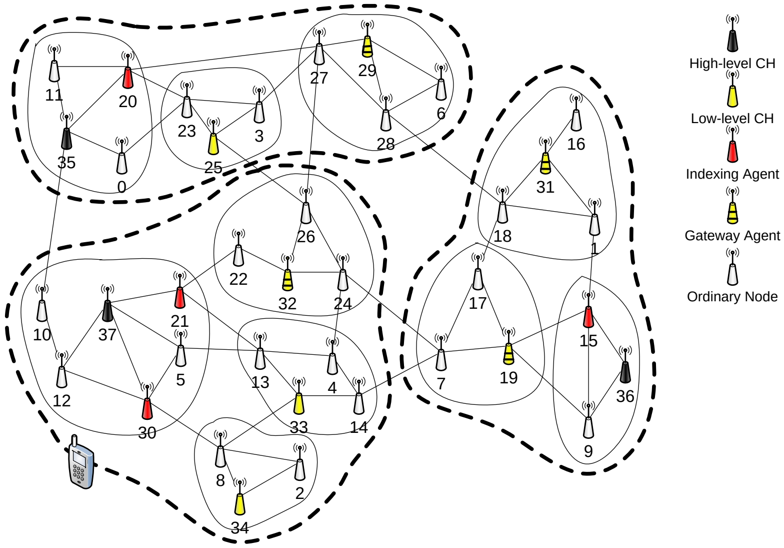

(a) Indexing Agents in HRDD



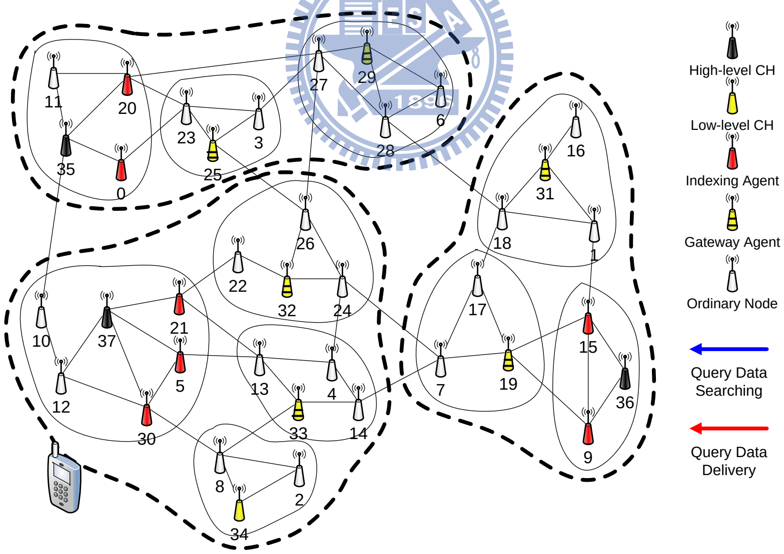

(b) Indexing Agents in A-HRDD

Figure 3.2: Different Agents Selection between HRDD and A-HRDD

Algorithm (WCA) [9], and Voting-based Clustering Algorithm (VCA) [10] are generate one-hop clusters. Its not suitable for large-scale WSN. The Max-Min D-Cluster Algorithm [6] propose a method that generate D hops clusters for WSN. It generates clusters based on node-ids without any location information. The Max-Min D-Cluster Algorithm consists a load balanced and distributed CHs election algorithm, it guarantee that no node is far than D-hops away from its CH. In our work, we group the sensor nodes into D-hops clusters by Max-Min D-Cluster Algorithm. The algorithm has four stages to build clusters. First stages each sensor node delivers the largest node ID which collect from their neighbor nodes for D rounds. Second stages similar to first stages but deliver and collect the smallest one. In the third stages, each nodes use the information collect from first and second stage to elect its CH. The four stages, all the non-CH nodes send the messages to announce its own CH and join into the cluster. These clusters we call them low-level clusters. Finally, we run the Max-Min D-Cluster Algorithm again with the low-level clusters to get the high-level clusters.




(a) Examp of HRDD agents selection




(b) Example of A-HRDD agents selection

Figure 3.3: Difference between A-HRDD and HRDD agents selection

## 3.3 Agent Selection

In HRDD's Agent Selection Algorithm, it select nodes with most different neighboring clusters to be the indexing agents and low-level clusters with most different neighboring high-level-clusters to be the gateway agents shown as Figure3.3. In Figure 3.3(a), high-level CH 37's indexing agent candidate are node 5, 21, and 30, in HRDD's Agent Selection Algorithm, it will select node 21 to be the indexing agent for cluster 32 and 33 and node 30 for cluster 34. For this situation, all the query messages send to high-level cluster 34, and all the data messages from the low-level cluster 32 and 33 have to send to indexing agent 21. This will make node 21 overloaded and run out of energy quickly. For the gateway agents selection it has the same problem. So in our algorithm, we propose a load balance Agent Selection Algorithm for indexing agents and gateway agents. The

| High-level CH 37 | |
|---|---|
| **Agent Candidate** | **Neighboring Clusters** |
| 5 | { 33 } |
| 21 | { 32, 33 } |
| 30 | { 34 } |

Figure 3.4: High-level CH 37's Indexing Agent Candidate table

Agent Selection Algorithm consists of the following two phase: **Phase I:** Agent candidate table set up

- The high-level CHs collect local information from its cluster members and low-level clusters, and then set up the relationship between agent candidates and neighboring clusters to build the agent candidate tables. In Figure 3.4, the indexing agent candidates of high-level CH 37 are node 5, 21, and 30. Their neighboring low-level clusters are, respectively, cluster 33, cluster 32, 33, and cluster 34. According to the agent candidate table, high-level CH 37 selects the agents at next phase.

**Phase II:** Agents selection

- There are five steps for agents selection. In Figure 3.5, it shows the example of agents selection for indexing agents in high-level CH 37. **Step 1:** Transform the agent table into

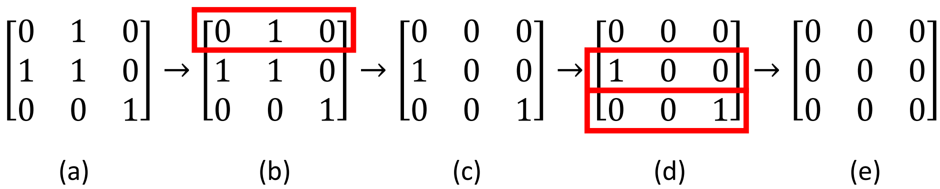



Figure 3.5: Agent selection for high-level CH 37's Indexing Agents

an array

- The high-level transform the agent candidate table into an array which agent candidates are column and neighboring clusters are row of array.
- If agent candidates is next to one of the neighboring clusters, the high-level CH sets 1 to array. Others, sets 0 to array (Figure 3.5(a)).

**Step 2:** Agent selection

- The high-level CH counts number of 1 in every row first.
- Then, the high-level CH selects a row with the minimum number of 1 and record it (Figure 3.5(b)).

**Step 3:** Converse nonimplication operation

- After record the row select in step 2, the high-level CH use this row to do Converse nonimplication operation for the entire rows of array. Then sets all 0 for record row to array (Figure 3.5(c)).

**Step 4:** Repeat agent selection

- After Converse nonimplication operation, high-level CH repeats the step 2 to the step 3 (Figure 3.5(d)).

**Step 5:** Final agent decision

- If high-level CH find that all elements of array is set 0, it finish the Agent Selection phase (Figure 3.5(e)).

- The indexing agents of high-level CH 37 are node 5, 21, and 30. Different to HRDD, it balances loading for each indexing agents shown as Figure 3.3(b). The gateway agent selection is the same as above.

When the Agents Selection Algorithm is finished, the high-level send the ROLE messages to the nodes or clusters which are selected to be agents. When nodes receive the Indexing Agents ROLE message, they will start to collect the event information from the low-level clusters which they are responsible for. The other nodes which get the Gateway Agents ROLE message will wait for registration messages and forward them to the neighboring high-level clusters.

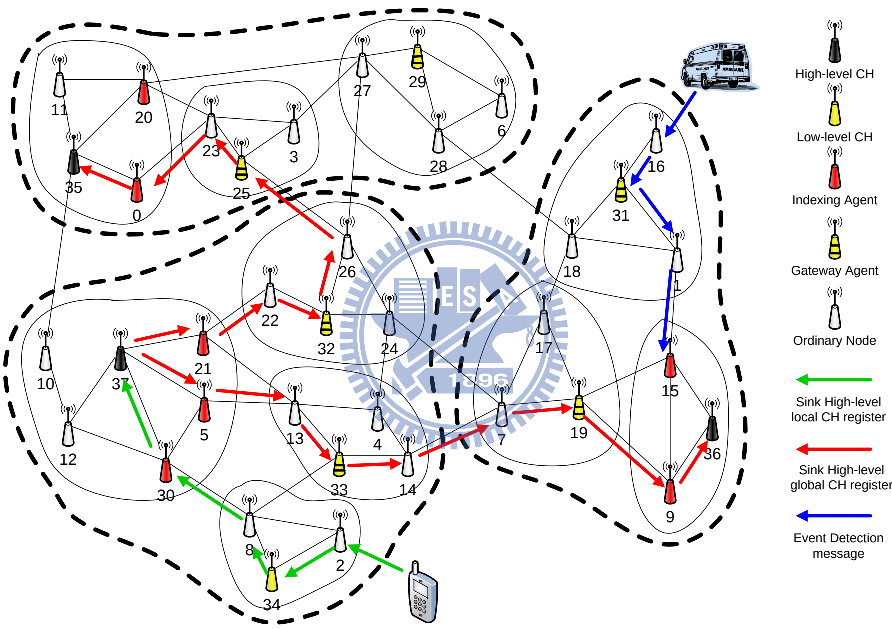



Figure 3.6: Sink Registration and Data Detection

## 3.4 Sink Registration and Event Detection

The sink registration and event detection here are as same as HRDD shown as Figure3.6. Sink registration divide into two phases: high-level local CH registration and high-level global CH registration. In high-level local CH registration phase, when a sink issue a query, it register to its low-level local CH first. Then the low-level local CH forwards the registration messages to the high-level local CH to finish the phase. After the first phase, the high-level local CH forwards the registration messages to all other high-level clusters through the gateway agents. The high-level

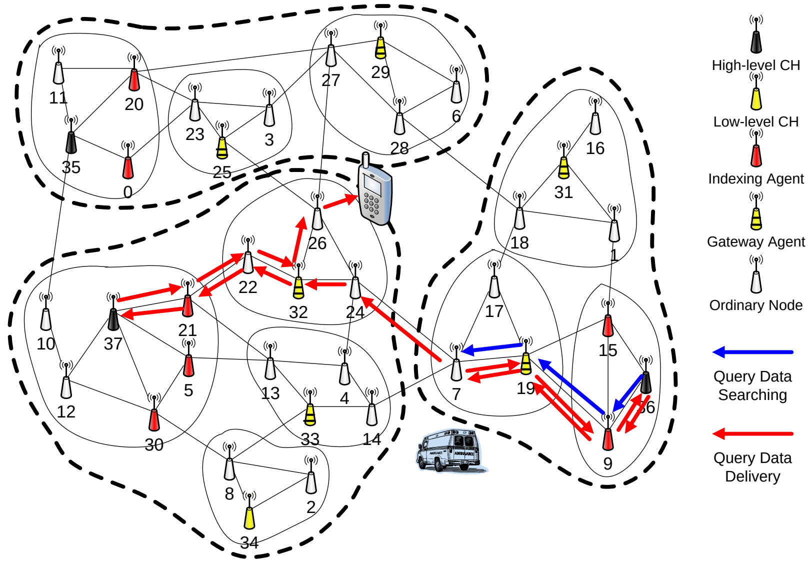
CHs which receive the registration messages can easily forward the data back by reverse path. In event detection, when a source detects an event, the sensing data are sent towards the local CH. After that, local CH inform its indexing agents which local CH belongs to with an event message (The event message include such as CH's ID and event type). When a sink want to query the detailed sensing data of event, it sends a query message to indexing agents. The indexing agents transmit the request to the local CHs which have the match event and send responses to the querying sink.

## 3.5 Query Data Forwarding

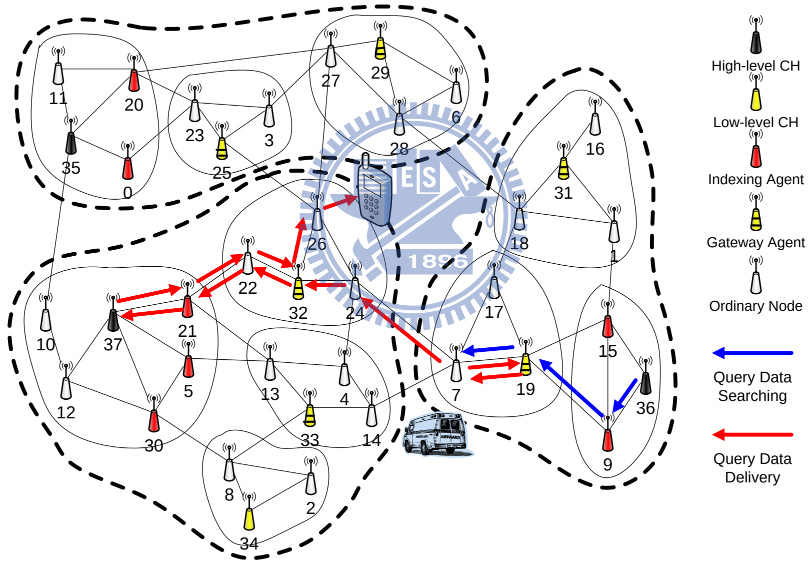
In Section 3.1, we mention that HRDD have redundant query data delivery between high-level CH and its indexing agents shown as Figure 3.7(a). Here we propose a Query Data Delivery Algorithm to solve the problem. After the sink registration, each high-level CH starts to proceeds query data forwarding. The query data forwarding is also divided into two stages, query data searching and query data delivery. In the query data searching phase, high-level CH send the query message to its indexing agents. Then indexing agents forward the query messages to the low-level CHs which have relevant data. Different to HRDD, the query messages now contain the information of sink's location and the gateway agents correspond to sink. These two information can help us reduce the redundant data delivery when query data delivery phase. When the low-level CH receives the query message, it start the query data delivery phase. There are four steps for data delivery:

**Step 1:** Event's low-level local CH data delivery

- First, the low-level CH check the gateway agent information of the query message. If the gateway agent is the low-level CH itself or it is the low-level CH's neighboring cluster, the CH forwards the data to the gateway agent directly. If not, the low-level CH forward the data back to its indexing agent (Figure3.7).




(a) Query Data Delivery without Step 1

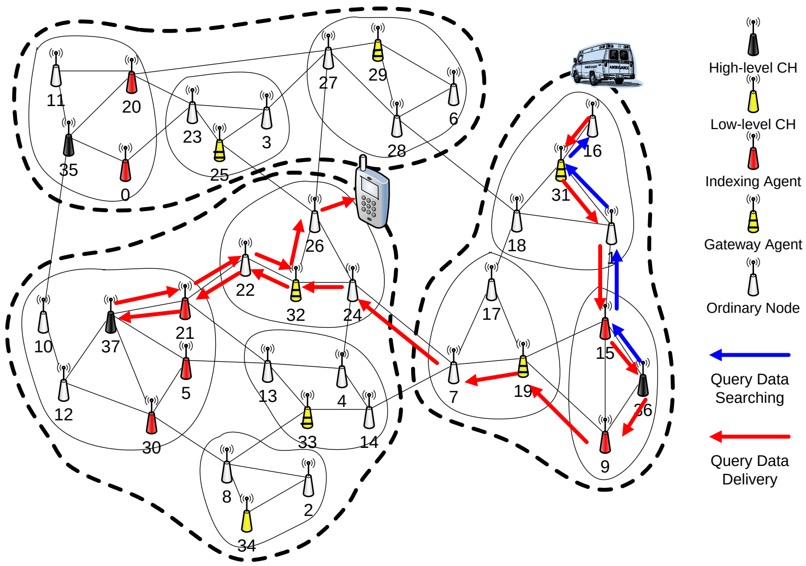



(b) Query Data Delivery with Step 1

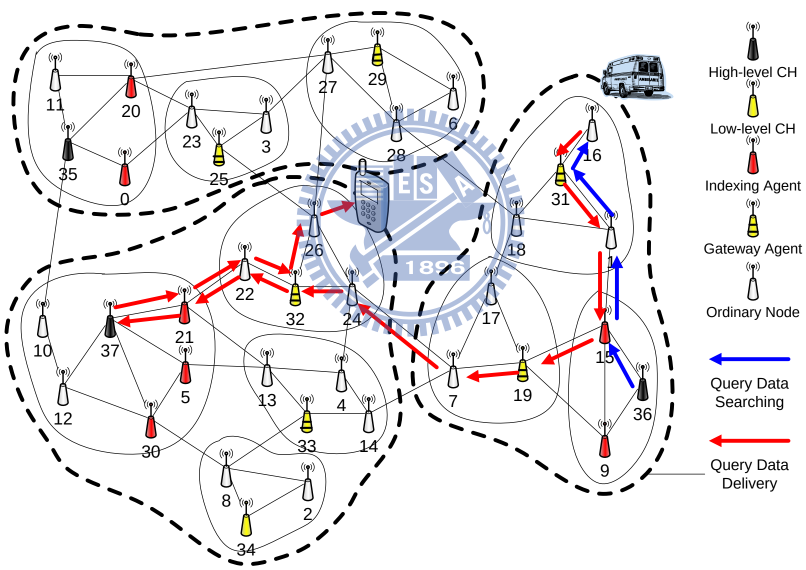
Figure 3.7: Event's low-level local CH data delivery

**Step 2:** Indexing agents data delivery

- When indexing agent receive the query data, as same as the low-level CH, it compare the gateway agent information with its neighboring clusters. If match, deliver the data to the gateway agent. If not, forward the data back to the high-level CH (Figure3.8).




(a) Query Data Delivery without Step 2

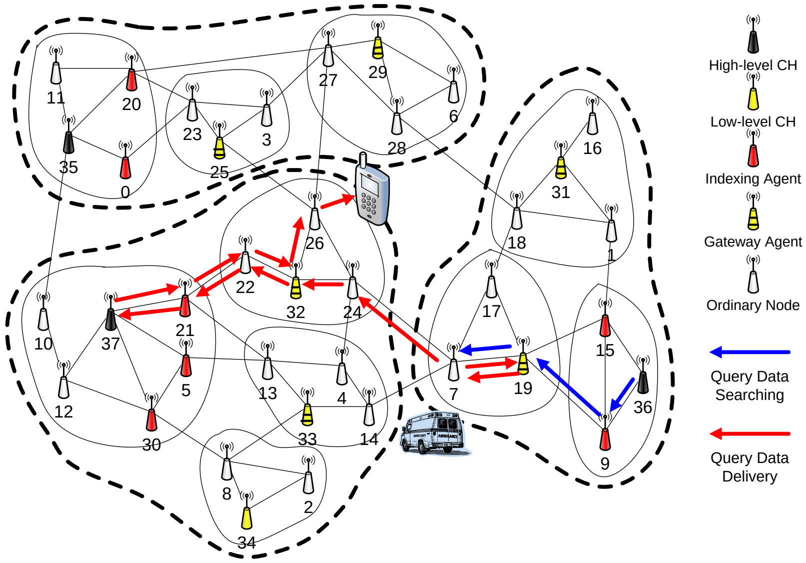



(b) Query Data Delivery with Step 2

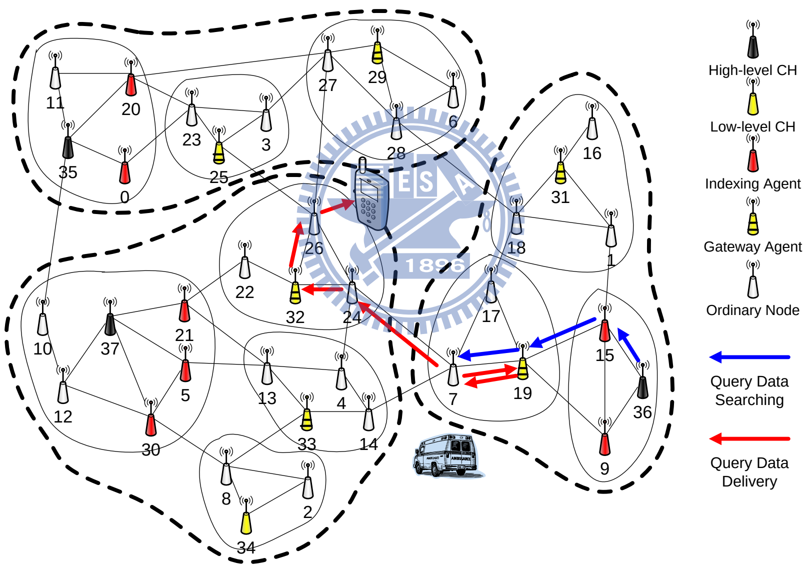
Figure 3.8: Indexing agents data delivery

**Step 3:** Other low-level CH data delivery

- Each time the low-level CH receive the query data disseminate from other high-level clusters, it check the sink is in its own cluster or in neighboring clusters by sink's location information. If so, forwarding the data directly. Otherwise, send the query data through the reverse path of sink registration phase (Figuire3.9).




(a) Query Data Delivery without Step 3




(b) Query Data Delivery with Step 3

Figure 3.9: Other low-level CH data delivery

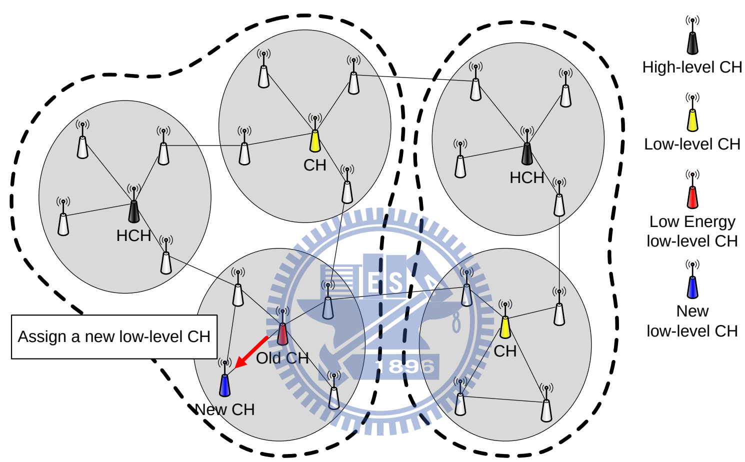
**Step 4:** High-level local CH data delivery

- When high-level CH receive the query data, it forward the data back through the reverse path of sink registration phase.

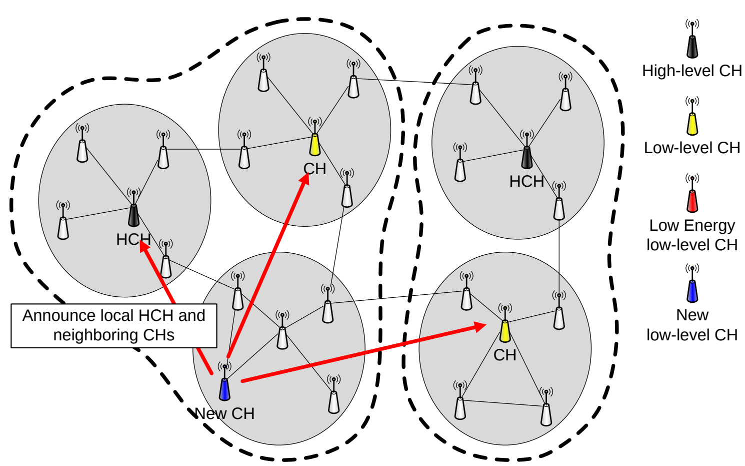
Step 1 and Step 2 are used to reduce the redundant query data delivery inside the event's local clusters and Step 3 is for sink's local clusters. However, if query data delivery without Query Data Delivery Algorithm, the indexing agents and high-level CH will be overloaded and crash quickly because of too many redundant data delivery. The Query Data Delivery Algorithm help us safe the energy for high-level CHs and indexing agents.

## 3.6 Cluster Maintenance

In both A-HRDD and HRDD, high-level CHs, indexing agents, and gateway agents have more loading then other nodes that cause these nodes fail much earlier and become the bottleneck of the network. So, here we propose a cluster maintenance mechanism which change the role of the node with low energy to raise the network lifetime. This mechanism has two part, one for low-level clusters maintenance, the other for high-level clusters. **Part I:** Low-level clusters maintenance




(a) Search for New CH




(b) Announce Local HCH and Neighboring CHs

Figure 3.10: Change Low-Level CH

- Figure 3.10 shows that when a low-level CH's energy lower than threshold, it will choose a cluster member which has the most energy become the new CH and notify all the other cluster members. Finally, send the CH change message to all the neighboring clusters and high-level local CH.

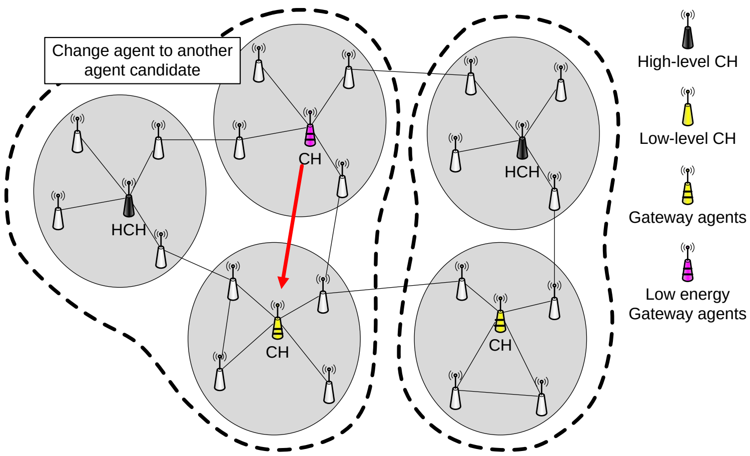


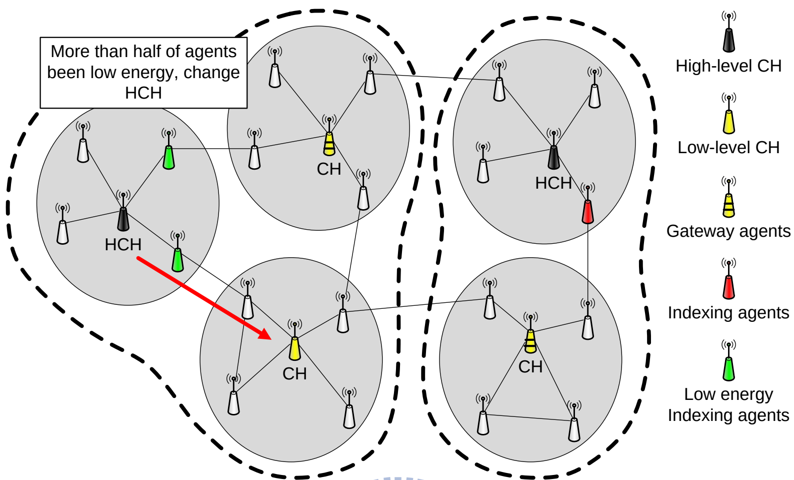

Figure 3.11: Example of Changing Gateway Agent

**Part II:** High-level clusters maintenance

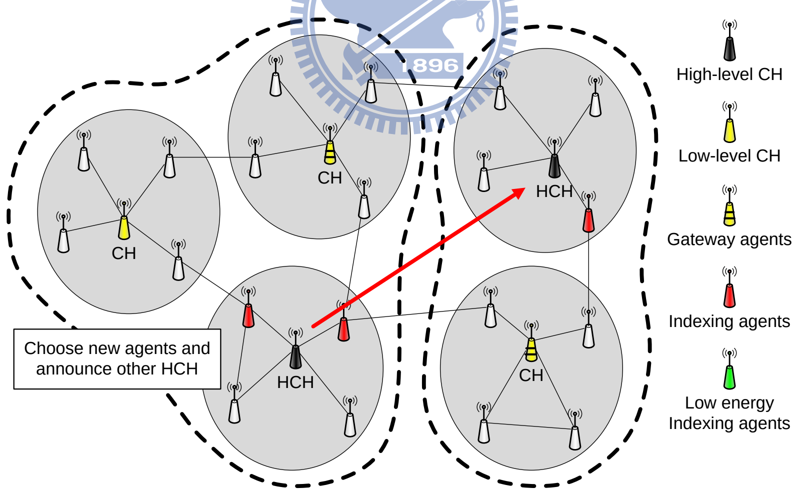
- The high-level clusters maintenance can separate in two stages: Changing Agents and Changing high-level CH.

- In Changing Agents stage, when high-level CH receive the low energy alert from its indexing or gateway agents, It search if there has any available agent node from the agent candidate table as shown in Figure 3.11. If so, the node becomes the new agent. If not, keep the old one.

- In Changing high-level CH stage, as shown in Figure 3.12. If the high-level CH energy lower than threshold or there are more than half of indexing agents have low energy, the high-level CH start the changing high-level CH process. First, the high-level CH chooses the neighboring low-level CH with the highest energy to be the new high-level CH. Then the new high-level CH send notifies to all the other high-level CHs and all the low-level CHs which belong to it.




(a) Search for New HCH




(b) Choose New Agents and Announce Other HCHs

Figure 3.12: Change High-Level CH

# Chapter 4

# PERFORMANCE EVALUATION

In this section, we evaluate the performance of A-HRDD through simulations. In Section 4.1, we introduce the simulation environments and metrics. We evaluate the impact of different environment factors and control parameters on the performance of A-HRDD in Section 4.2 to 4.4 with the performance of HRDD and HCDD. The result shows the A-HRDD has better efficiency in delivering data from sources to multiple mobile sinks.

## 4.1 Simulation Environment and Metrics

We developed a simulator based on NS-2 to compare the performance of A-HRDD to HRDD and HCDD. We deploy 3 mobile sinks and 100 sensor nodes in $2000 \times 2000\ m^2$ field. The maximum number of wireless hops between a node and its CH was set to 2. Sinks' mobility follows the NS-2 random-motion module and the event frequency of each sensor node was set to 10%. Each sink generate queries at every 50 seconds. Each query packet and data packet have 48 bytes. The energy spent for transmission and reception of a $l$ bits packet [23] shown as below:

$$E = \begin{cases} l \times (50 \times 10^{-9} + 0.0013 \times 10^{-4}) & , E_{Tr}\ (J) \quad (4.1) \\ l \times (50 \times 10^{-9}) & , E_{Rc}\ (J) \quad (4.2) \end{cases}$$

The Equation 4.1 describe how much energy cost when transmit a $l$ bits packets, and Equation 4.2 show the energy cost when receive a $l$ bits packets. Table 4.1 lists the parameters in the simulation. This metrics used to evaluate the performance of A-HRDD for registration messages, query data messages, and network lifetime. The registration message is the amount of packets transmitted in sink registration phase and the query data messages is the amount of packets

| Parameter | Value |
|---|---|
| Field size | $2000 \times 2000 m^2$ |
| Number of nodes | 50, 100, 150, 200, 250 |
| Number of sinks | 2, 3, 4, 5, 6 |
| Event frequency of nodes per minute | 5%, 10%, 15%, 20%, 25% |
| Speed of sink | 5-10$m/sec$ |
| Query packet size | 48 *bytes* |
| Data packet size | 48 *bytes* |
| Initial Energy | $2J$ |
| Query generation period | 50.0 *sec* |
| Simulation time for counting messages | 10000.0 *sec* |

Table 4.1: Simulation Parameters

in query data forwarding phase. Network lifetime, which is defined as the duration from the beginning of simulation to the time of one of sensor nodes runs out its energy.

## 4.2 Impact of Number of Nodes

We first study the impact of number of nodes on A-HRDD's performance. In this experiment, the number of sensor nodes is varied from 50, 100, 150, 200, to 250. In general, the more nodes are, the number of high-level CHs becomes more. More high-level CHs may increase the registration messages and query data messages greatly. Figure 4.1 shows the registration messages within the time of range of different numbers of sensor nodes between A-HRDD, HRDD, and HCDD. In the Sink Registration phase, since the usage of the gateway agents could decrease number of flooding messages, so the registration packet s in A-HRDD and HRDD are both less than in HCDD. But because of Agents Selection Algorithm in A-HRDD, we choose more gateway agents than HRDD for load balancing. The registration packets were also little more than HRDD. Figure 4.2 shows the query data messages of different numbers of sensor nodes between A-HRDD, HRDD, and HCDD. In Query Data Forwarding phase, both A-HRDD and HRDD use the indexing agents to decrease the query messages in query data searching phase. But in query data delivery phase, A-

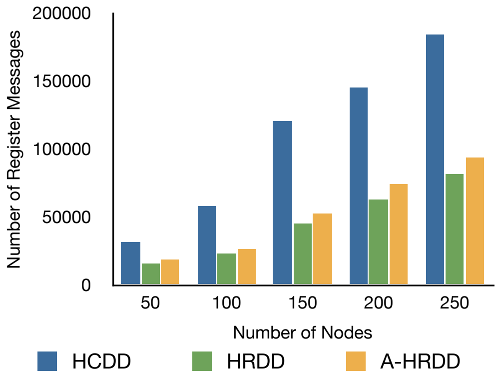



Figure 4.1: Register messages for different number of nodes

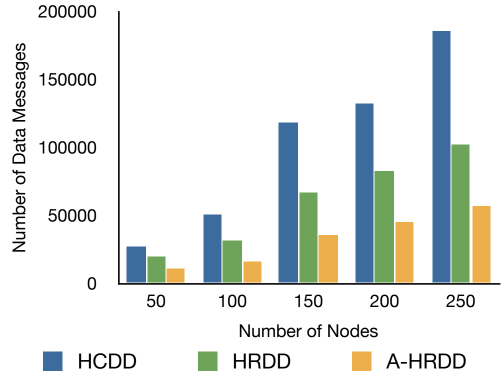



Figure 4.2: Data messages for different number of nodes

HRDD reduce the redundant data messages that happened in HRDD. The HRDD will increase the redundant data delivery packets while the number of high-level CHs increases. But in A-HRDD, we can reduce these redundant data messages. Figure 4.3 show the network lifetime between

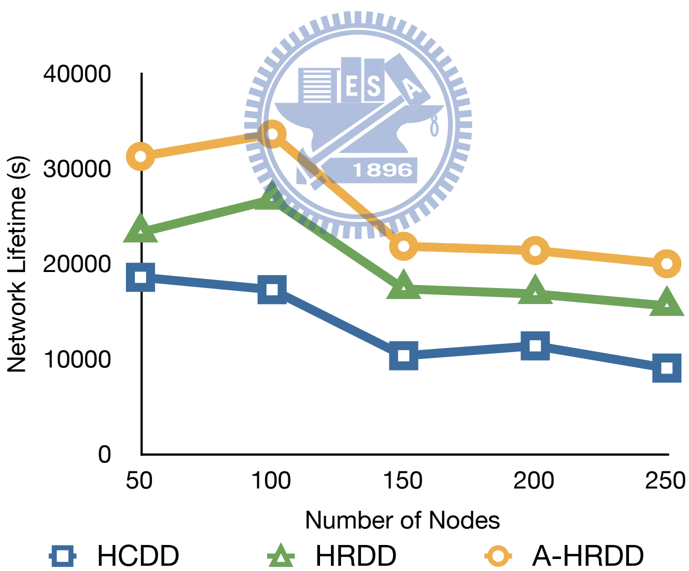



Figure 4.3: Network lifetime for different number of nodes

A-HRDD, HRDD, and HCDD. Even the registration messages, the A-HRDD is little more than HRDD. But A-HRDD reduces more redundant messages than HRDD, and A-HRDD also have Cluster Maintenance mechanism to solve the bottleneck problem of CHs and agents. This result influence the network lifetime directly. Since A-HRDD have fewer total messages and better load balancing mechanism to HRDD, and HCDD, A-HRDD has better performance of longer network lifetime.

## 4.3 Impact of Number of Sinks

In this section, we study the impact of number of sinks on A-HRDD's performance. The number of sinks varies from 2, 3, 4, 5, to 6. Figure 4.4 shows the registration messages within the time of range at different number of sinks. Since the number of sinks increase, the registration messages also increases in A-HRDD, HRDD, and HCDD. Figure 4.5 shows the query data messages at different number of sinks. Though the event frequency is changeless, the data messages in A-HRDD, HRDD, and HCDD are slightly increasing with increase of sinks. Figure 4.6 shows the network lifetime with the increase sinks. Because the registration messages are more than query data messages when number of sinks increase. The network lifetime between A-HRDD and HRDD are more closely when number of sinks increase.

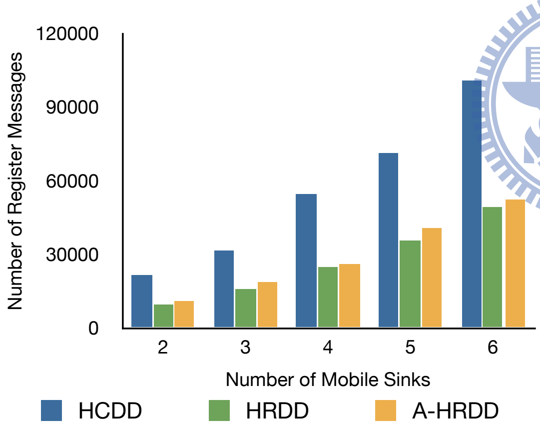



Figure 4.4: Register messages for different number of sinks

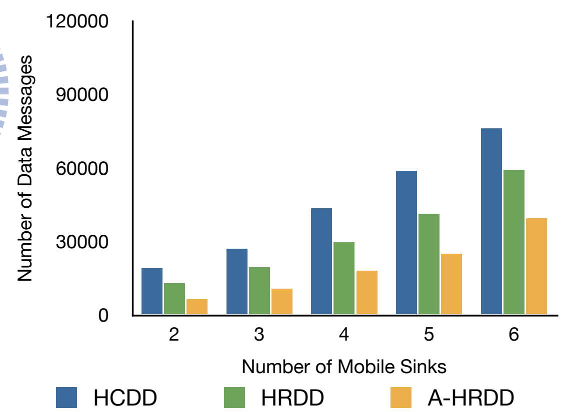



Figure 4.5: Data messages for different number of sinks

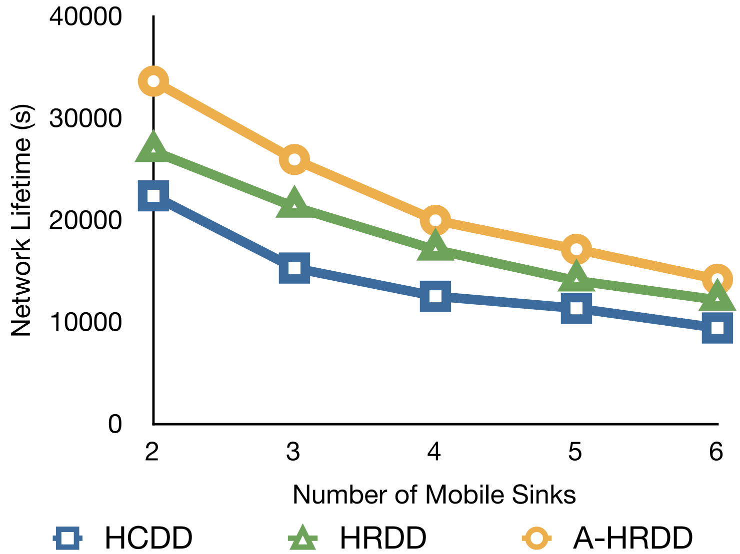



Figure 4.6: Network lifetime for different number of sinks

## 4.4 Impact of Event Frequency

In this section, we study the impact of event frequency on A-HRDD's performance. The event frequency varies from 5% 10%, 15%, 20%, to 25% per minute. Figure 4.7 shows the registration messages within the time at different event frequency. Because the number of sinks is changeless, the number of registration messages are almost the same with different event frequency. Figure 4.8 shows the query messages. When event frequency increase, more data that will be queried and delivered to sinks. It means that will produce more redundant data deliveries in HRDD. In A-HRDD, the total data messages increase much slightly than HRDD when event frequency increase. Figure 4.9 shows the network lifetime with different event frequency. The higher event frequency cause the more redundant data delivery. The A-HRDD has much better performance with the higher event frequency.

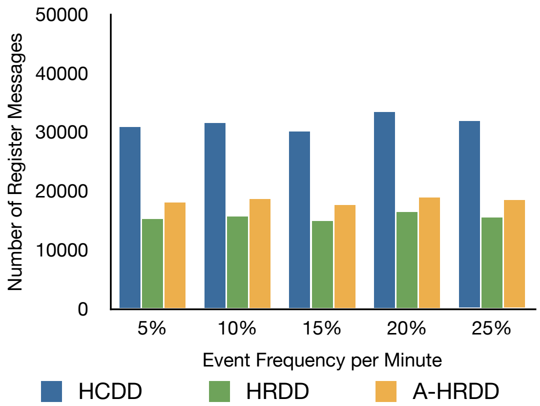



Figure 4.7: Register messages for different event frequency

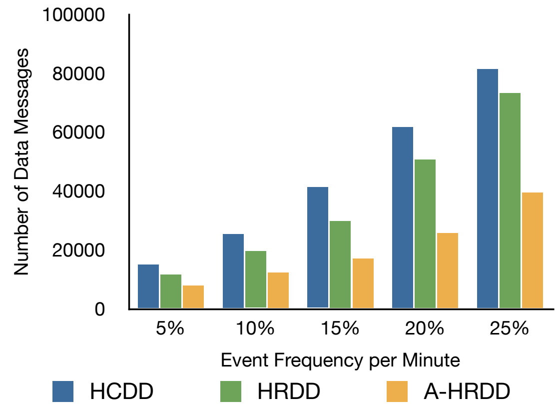



Figure 4.8: Data messages for different event frequency

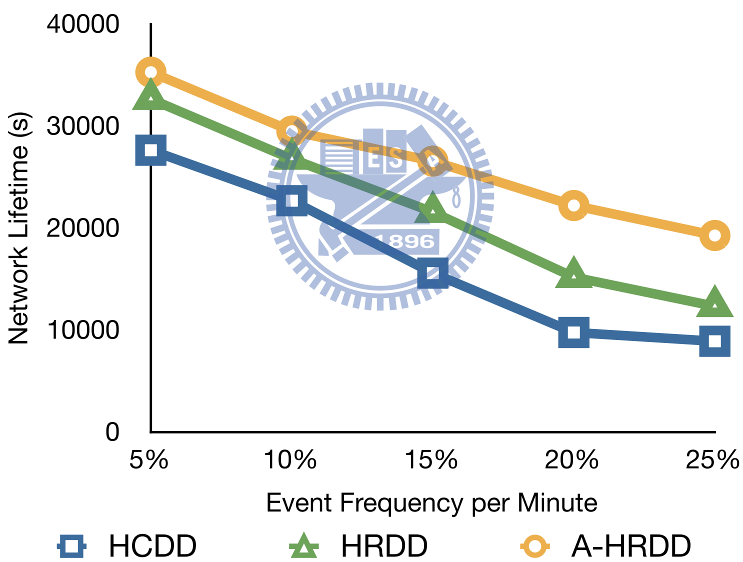



Figure 4.9: Network lifetime for different event frequency

## 4.5 Impact of Speed of Mobile Sinks

In this section, we study the impact of speed of mobile sinks on A-HRDD's performance. The sink's speed varies from 2, 4, 6, 8, and 10 (m/s). Figure 4.10 shows the registration messages within the time at different speed of mobile sinks. When the speed of sink increase, the sink change its location more fast. This means each sink need to update its location more frequently, and the register message will increase, too. Figure 4.11 shows the query data messages. Because the query times and event frequency are changeless, the data messages are almost the same with different speed of sinks. Figure 4.12 shows the network lifetime with different event frequency. The higher speed creates more register message for location update. The A-HRDD still has better performance when sink's speed increase.

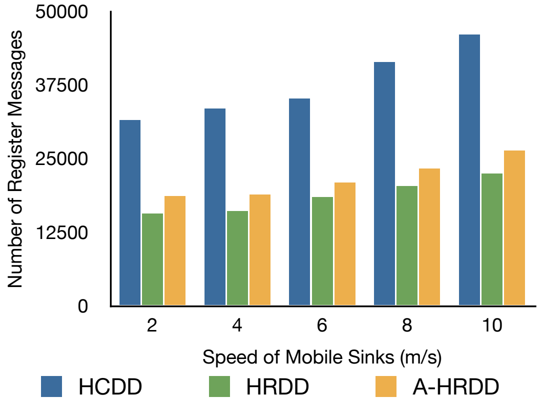



Figure 4.10: Register messages for different sink's speed

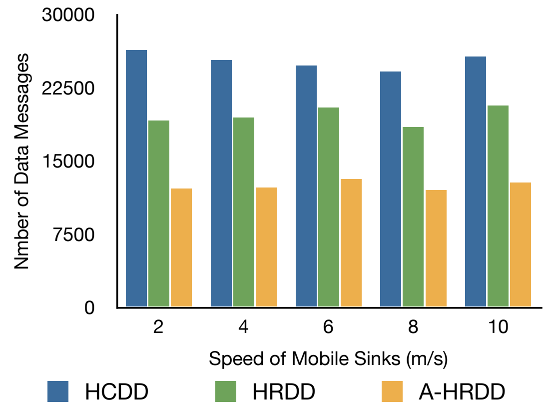



Figure 4.11: Data messages for different sink's speed

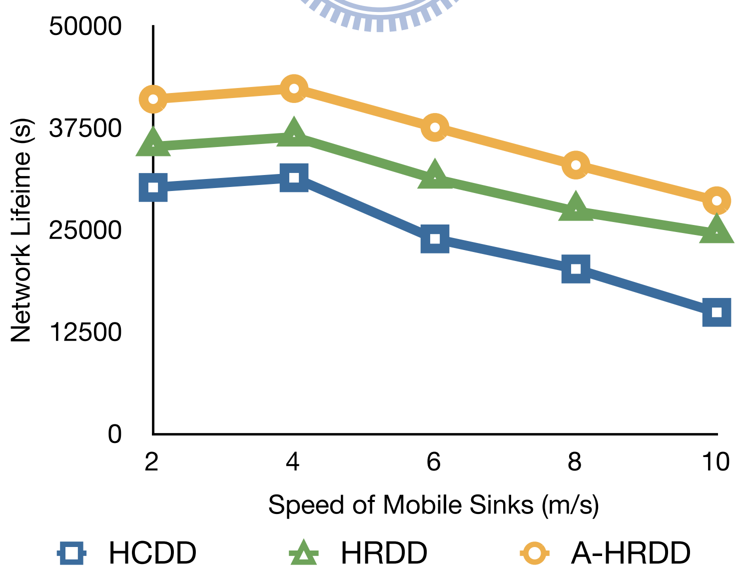



Figure 4.12: Network lifetime for different sink's speed

# Chapter 5

# CONCLUSION

In this paper we proposed a Adjustable Hierarchical Role-based Data Dissemination (A-HRDD) scheme for data dissemination with multiple mobile sinks in WSNs. The new load balancing agent selection algorithm in A-HRDD solve the agents overloading problem in HRDD. Then we introduced a data delivery algorithm which decreasing the redundant data messages that help us save more energy in WSNs. Finally, A-HRDD's cluster maintenance mechanism solve the bottleneck problem with CHs and agents. Simulation result shows that A-HRDD is more efficient than prior works in conserving the battery energy.

# Bibliography

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," *IEEE Communication Magazine*, vol. 40, pp. 102–114, 2002.

[2] A. Cerpa, J. Elson, D. Estrin, L. Girod, M. Hamilton, and J. Zhao, "Habitat monitoring: Application driver for wireless communications technology," *ACM SIGCOMM Computer Communication Review*, 2001.

[3] R. Szewczyk, A. Mainwarning, J. Polastre, J. Anderson, and D. Culle, "An analysis of a large scale habitat monitoring application," *Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems*, 2004.

[4] A. Boukerche, R. W. N. Pazzi, and R. B. Araujo, "A fast and reliable protocol for wireless sensor networks in critical conditions monitoring applications," *Proceedings of the 7th ACM International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, 2004.

[5] M. D. V. Machado, O. Goussevskaia, R. A. F. Mini, C. G. Rezende, A. A. F. Loureiro, G. R. Mateus, and J. M. S. Nogueria, "Data dissemination in autonomic wireless sensor networks," *IEEE Journal on Selected Areas in Communications*, vol. 23, pp. 2305–2319, 2005.

[6] A. D. Amis, R. Prakash, T. H. Vuong, and D. T. Huynh, "Max-min d-cluster formation in wireless ad hoc networks," *Proceedings of the 19th IEEE INFOCOM Conference*, 2000.

[7] D. J. Baker and A. Ephremides, "The architectural organization of a mobile radio network via distributed algorithm," *IEEE Transaction on Communications*, vol. 29, pp. 1694–1701, 1981.

[8] S. Basagni, "Distributed clustering algorithm for ad hoc networks," *Proceedings of the 4th International Symposium on Parallel Architectures, Algorithm and Networks*, 1999.

[9] M. Chatterjee, S. K. Das, and D. Turgut, "An on-demandweighter clustering algorithm (wca) for ad hoc networks," *Proceedings of the IEEE global Telecommunications Conference*, 2000.

[10] M. Qin and R. Zimmermann, "An energy-efficient voting-based clustering algorithm for sensor netwoks," *Proceeding of the 6th International Conference on Software Engineering*, 2005.

[11] B. H. Wellenhof, H. Lichtenegger, and J. Collins, *Global Position System: Theory and Practice*. ISBN 3211825916, Springer-Verlag, 1994.

[12] W. Wang, V. Srinivasan, and K. C. Chua, "Using mobile relays to prolong the lifetime of wireless sensor networks," *Proceeding of the 11th Annual International Conference on Mobile Computing and Networking*, 2005.

[13] Z. M. Wang, S. Basagni, E. Melachrinoudis, and C. Petrioli, "Exploiting sink mobility for maximizing sensor network lifetime," *Proceeding of the 38th Annual Hawaii International Conference on System Sciences*, 2005.

[14] G.-H. Ye, L.-Y. Yeh, and J.-L. Huang, "Hierarchical role-based data dissemination for large-scale wireless sensor networks with mobile sinks," *Proceeding of the 6th International Workshop on Mobile Peer-to-Peer Computing*, 2010.

[15] J. N. Al-Karaki and A. E. Kamal, "Routing techniques in wireless sensor networks: A survey," *IEEE Journal of Wireless Communications*, vol. 11, pp. 6–28, 2004.

[16] C. Intanagonwiwat, R. Govindan, D. Estrin, and J. Heidemann, "Directed diffusion for wireless sensor networking," *IEEE/ACM Transactions Networking*, vol. 11, pp. 2–16, 2003.

[17] H. S. Kim, T. F. Abdelzaher, and W. H. Kwon, "Minimum-energy asynchronous dissemination to mobile sinks in wireless sensor networks," *Proceeding of the 1st International Conference on Embedded Networked Sensor Systems*, 2003.

[18] F. Ye, H. Luo, J. Cheng, S. Lu, and L. Zhang, "A two-tier data dissemination model for large-scale wireless sensor networks," *Proceeding of the 8th Annual International Conference on Mobile Computing and Networking*, 2002.

[19] S. Shenker, S. Ratnasamy, B. Karp, R. Govindan, and D. Estrin, "Data-centric storage in sensornets," *ACM SIGCOMM Computer Communication Review*, 2003.

[20] J.-H. Shin, J. Kim, K. Park, and D. Park, “Railroad: Virtual infrastructure for data dissemination in wireless sensor networks,” *Proceeding of the 2nd ACM International Workshop on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks*, 2005.

[21] A. Visvanathan, J.-H. Youn, and J. Deogun, “Hierarchical data dissemination scheme for large-scale sensor networks,” *Proceeding of the IEEE International Conference on Communications*, 2005.

[22] C.-J. Lin, P.-L. Chou., and C.-F. Chou, “Hcdd: Hierarchical cluster-based data dissemination in wireless sensor networks with mobile sink,” *Proceeding of the 2006 International Conference on Wireless Communications and Mobile Computing*, 2006.

[23] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-efficient communication protocol for wireless microsensor networks,” *Proceeding of the 33rd Annual Hawaii International Conference on System Sciences*, 2000.