# Dynamic Protocol Switching Scheme for Data Query in Wireless Sensor Networks

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**Abstract**
The dynamic routing layer based data query system is introduced to handle data query with different route selection mechanism. The route selection is done with reference to the data query and network density factors. A centralized authority manages the route selection operation. In this case all the query values are redirected to the centralized authority. The central authority initiates the route selection and query distribution operations. The centralized dynamic query selection mechanism makes delay and computation overhead for data query processing with high node density environment.
The proposed system is designed to handle the data query operations with dynamic routing layer mechanism in a decentralized manner. The sensor nodes select the routing protocol with reference to the data query and network density information. The self-adaptive data query system is also enhanced to handle join query and event query values.

## 1. Introduction

The data query processing systems such as TinyDB and Cougar [8] are promising for data acquisitional applications of wireless sensor networks. With these systems, a user injects SQL-style queries into the network through a PC. The networked sensor nodes then work together to process the queries and send results back to the PC. The performances of these sensor query systems are greatly affected by routing protocols, because routing protocols response for the query dissemination and result gathering. On the other hand, the performance of routing protocol is closely
related to application and network condition [3]. For example, when sensor nodes are location aware, GEAR is more energy efficient to disseminate query than Directed Diffusion. However, current available data query systems only use one routing protocol to deal with all kinds of query processing, such as TinyDB and Cougar, where they all assume a fixed tree-based topology.

There are some query processing operators in data query system [2]. For data collection, such as "select node_ID, temperature from sensors", the data is not aggregated in TinyDB and Cougar, and all data must be transmitted to base station. While for data aggregation, such as "select average (light) from sensors", data can be perfectly aggregated. Because data collection and data aggregation are commonly used operations, in this paper, these queries are used to demonstrate that the adaptive routing service is an effective way to improve the performance of data query system.
In our previous work, we compared MintRoute and HEED routing protocols according to different operations and network densities. Simulations and analyses show that for data aggregation HEED is 40- 60% more energy efficient than MintRoute when network dense D > 0.0025 nodes/m2. However, in the case of data collection, MintRoute is 30-50% more energy efficient than HEED. With the sensor node density decreasing, the performance of HEED and MintRoute trends to be similar.
In this paper, we implement a dynamic routing layer using MintRoute and HEED protocols for data query. It automatically conducts protocol switching according to query and network density.

## 2. Related Works

### 2.1. Hierarchical routing protocols

Tree-based and cluster-based routing protocols are extensively used in query system of sensor networks [4]. This section gives an overview of tree-based and cluster-based routing protocols.
(1) Tree-based routing protocols
Tree-based routing protocols are aimed to construct the best rout from a node to base station. A parent node is selected based on two parameters, one is the number of hops from the node to base station, and the other is one of

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the follows: parent's residual energy, link quality, or routing path length to base station.
A. Woo proposed MintRoute [1] protocol, which is the most popular tree-based routing protocol. It is integrated into TinyOS [7] and is considered by many to be the "de-facto standard" sensor network routing protocol. MintRoute uses a sink-based periodic beacon, called a route advertisement, to construct and maintain a tree. Route advertisements are originated at the sink and are forwarded by every node that receives them in order to cover the entire network. A node determines its parent by selecting a neighbor which has the minimum number of hops to the base station. If two or more neighbors have the same minimum number of hops, it selects a node with the best link quality as its parent.

(2) Cluster-based routing protocols
Clustering technique is effective in achieving scalability and load balance. Many clustering protocols have been proposed for sensor networks, like LEACH, TEEN, HEED [5-6], AEEC [9], and so on.
O.Younis proposed HEED (hybrid energy-efficient distributed clustering) protocol [5-6], in which cluster head selection is based on two parameters: The primary parameter (node residual energy) is used to select an initial set of cluster heads, and the secondary parameter is used to break ties. A tie occurs when two nodes within range from each other announce their willingness to become cluster heads. The secondary parameter can be set to an estimate of the intra-cluster communication "cost," which is a function of cluster density or neighbor proximity. After clustering process, a routing tree is constructed among cluster heads. If inter-cluster heads communication range is R, to ensure a member node to be able to communicate with its cluster head via a single hop, the cluster radius must be set as R/2. HEED is a distributed clustering protocol and can achieve uniform cluster head distribution.

### 2.2. Matching routing protocols to applications

The performance of routing protocol is greatly affected by applications and network conditions. Some people attempted to explore adjust routing protocols according to applications.
S. Madden proposed semantic routing trees (SRT) to optimize query processing. Traditionally, in sensor networks, routing tree construction is done by having nodes pick a parent with the most reliable connection to the root (highest link quality) [1], The selection of parent in SRT includes some considerations of semantic properties. An SRT is an index over constant attribute A that can be used to locate nodes that have data relevant to query. Each node stores the range of A values for each of its children. When a query q with a predicate over A arrives at a node n, n checks to see if any child's A value overlaps the query range of A in q. If so, it prepares to receive results and forward the query.
Y. He described a framework to build programmable routing services for sensor networks. This framework includes a parameter space that identifies both common and different properties among routing services. With the parameter space, different routing services can be obtained with small programming effort. A programmable routing architecture is proposed to maintain this parameter space and support energy-efficient service. In the work, he developed a dynamic routing service. However he did not tell when the routing service needs to be changed.
Filter-based architecture in sensor networks [3] specifies a software structure that contains a list of filter handlers, each of which is executed when its attributes match incoming packets. This architecture provides a flexible way to add application-specific code into sensor nodes in the form of filters. But the filter architecture only considers diffusion algorithms (there have three diffusion algorithms: two-phase pull diffusion, push diffusion, and one-phase pull diffusion).

## 3. Dynamic Routing Layer

### 3.1. Dynamic routing layer design

We have implemented the dynamic routing protocol system on NS2, Figure. 1 describes the software architecture of a sensor node. The adaptive routing services module supports routing services and control dynamic switching of routing protocols.
In this architecture, the Energy Manager is used to keep track of a node's energy. It provides a common interface for the application layer and physical layer to access the energy resource [10].
When physical layer receives packets from MAC layer, it sets the transmit power based on an approximation of distance to receiver, removes the appropriate amount of energy for sending the packet through the interface provided by the Energy Manager, and sends the packet to Channel. On the other hand, when a packet comes from Channel, it removes the amount of energy for receiving a packet and forwards the packet to MAC layer.
The MAC is running carrier-sense multiple access (CSMA) algorithm. The scheduling is a hybrid of depth-based scheduler and TDMA. The depth based scheduler is adopted for parent nodes, and TDMA is for siblings.
The routing layer can dynamically switch between two routing protocols: HEED and MintRoute. The application layer is data query, currently consisting of acquisition and aggregate operators. The required energy is removed by the application layer as the node performs computation of data aggregation and sampling.

Fig.2 describes the dynamic routing layer. In HEED, member nodes communicate with their cluster heads over single hop, and cluster heads communicate with base station over multi-hop. HEED adopts MintRoute to construct a routing tree between cluster heads. In our design, HEED and MintRoute share tree construction algorithm and routing table. The module of Routing Protocol Control is to control the Clustering module and Tree Construction module start and stop.

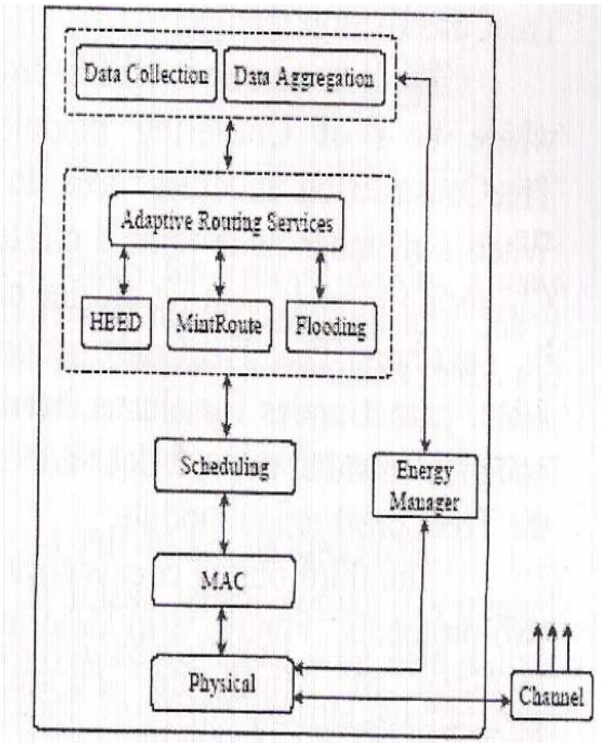



Fig 1. The Architecture of Sensor Node

Using the module design, we can get three kinds of routing protocols:

The First one is MintRoute protocol. It can be obtained by stopping the Clustering module and starting the TreeConstruction module.

The Second one is HEED protocol, where both of Clustering module and TreeConstruction modules need to start. When a member node joins a cluster, the Clustering module sets its cluster head as its next-hop. The TreeConstruction only select parent nodes for cluster heads. If a node is a member node, it does not execute the TreeConstruction module.

The third one is coexistence of the two-protocols. Figure.3(a) describes the topology of MintRoute. Figure.3(b) describes the topology of HEED clustering. Figure.3 (c) describes the topology of coexistence of HEED and MintRoute. The Routing Protocol Control module starts both Clustering and TreeConstruction modules. In the routing table, every node has two fields for routing selection: head field and parent field. When a node joins a cluster, Clustering module marks the head field who is its cluster head; The TreeConstruction constructs a tree for all nodes and marks the parent field who is its parent. Cluster heads use the information in parent field to forward data to base station. Every member node has two choices for nexthop: one is its parent node in the tree, and the other is its cluster head. We use this kind of routing to deal with multi-query coexistence. For example, there coexist two kinds of queries- One is data collection, and the other is data aggregation. Routing service chooses nexthop in the tree to forward data for data collection, and chooses next-hop in the cluster topology to routing data for data aggregation.

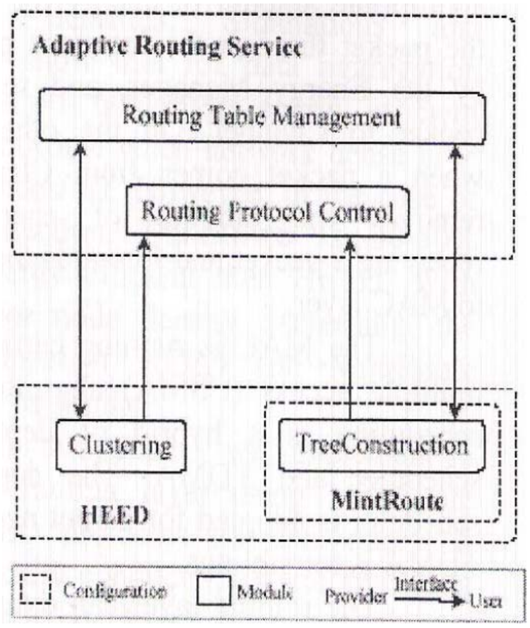
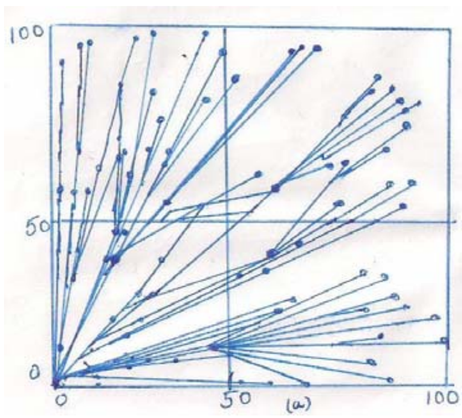
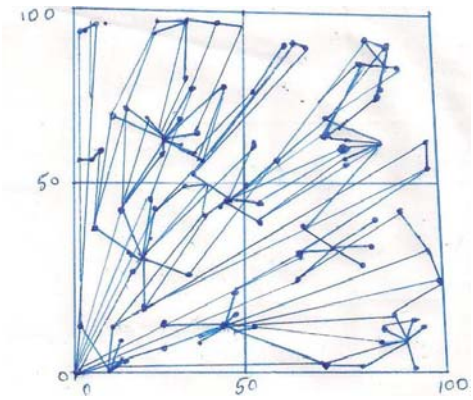



Figure 2. Module design of HEED and MintRoute




( a )

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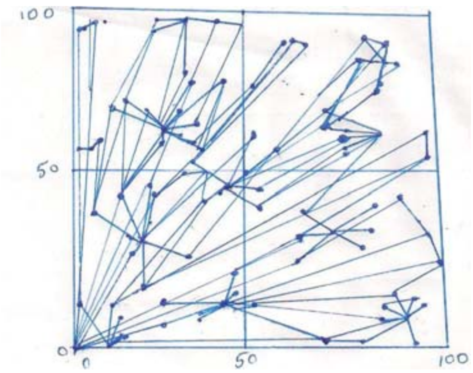


( c )

a) The Topology of Mint Route ;

b) The Topology of HEED clustering, where cluster radius is 25m;

(c) The topology of HEED and MintRoute coexistence.

## 3,2. The algorithm of dynamic routing protocol

We have implemented a dynamic routing protocol which switches between HEED and MintRoute. The dynamic protocol includes three parts: base station selects routing protocol, sensor node executes the selection, and base station collects network density information.

(1) Procedural at base station

a) Upon receiving a query from user, if base station does not have network density information, it sends a query to collect density information.

b) Base station selects routing protocol according to query category and network density. There are two cases:

Firstly, single query at a time, for data aggregation and dense network (D>0.0025nodes/m2), base station chooses HEED as routing protocol. Otherwise, it chooses MintRoute.

Secondly, multi-queries coexistence, if all queries are data aggregation, base station chooses HEED as routing protocol. If all queries are data collection, it chooses MintRoute as routing protocol. If queries are mixture of data collection and data aggregation, HEED and MintRoute hybrid protocols are used.

c) Base station attaches the routing protocol information on query and sends it out using flooding algorithm.

(2) Procedural at node

Node receives a query and decodes it. If it contains routing switching information, the node executes routing switching which is described.

If data collection and data aggregation coexist, data flow of aggregation follows cluster topology, and data flow of collection follows tree topology.

(3)Procedural of obtaining density information

a) A Node receives a query for network density.

b) Every leaf node sends its parent the information of its coordinate,

c) After a parent node receives all messages from its children, it computes the coverage range of its sub-tree and the number of nodes in the tree, and then sends the information to the next-hop. As shown in Figure. 4, node C calculates the number of nodes in its sub-tree, which is 3, the x-coordinate range is from 5 to 10, and the y coordinate range is from 3 to 7.

d) When base station receives all messages from its children, average node density can be calculated according to the network coordinate range and number of nodes. As shown in Figure. 4, at node A, the density can be calculated as

D = 4/[(10-l)*(12-3)] = 0.05 nodes/m2.

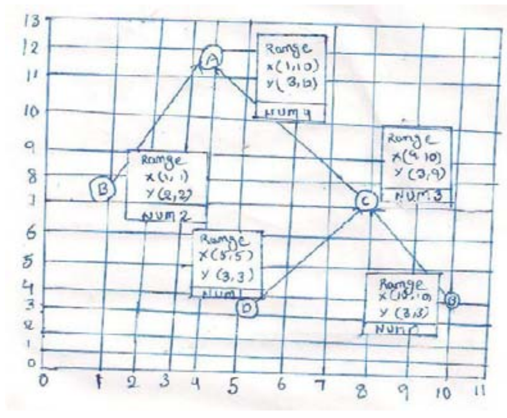

Fig. 4 Query for Network density, arrows indicate

flow of density information. X and Y represents the sub trees X coordinate range, Y coordinate range, respectively. Num represents the Number of nodes in sub tree.

## 4. Problem Definition

Wireless sensor network is treated as a distributed database. The data values are fetched from the distributed database nodes. TinyDB and Cougar tools are used to manage the distributed database operation over the WSN. The query values are supplied from a PC and data values are fetched from the nodes. TinyDB and Cougar tools uses the tree based routing structure for data transmission. MintRoute and HEED routing protocols are in used in WSN. MintRoute protocol selects the route using hierarchical tree. The HEED routing protocol uses the cluster mechanism. Dynamic routing protocol uses the MintRoute and HEED protocols The query value is issued by the nodes to the central authority. The network density and query semantics are used for the route selection. The centralized authority finalizes the route. The dynamic routing selection mechanism faces the following problems. They are Static routing method, Response time is high, Network traffic is high and Dynamic routing protocol uses centralized authority for route selection.

## 5. Protocol Switching Scheme

The dynamic routing protocol is converted into decentralized manner. Route selection decisions are made by the node itself The query processing scheme is improved to perform join query values and event query values. The query structure is optimized. The system is developed as two applications. They are sensor node and query node. The sensor node application manages data capture and data distribution operations. The query node handles the query submission and network management activities. The sensor node performs the data capture and data transmission tasks. Data capture module fetches environment information. Data distribution module send response to the query values. Query responses are transferred using radio frequency. The query node is the external system under the wireless sensor network environment. The query node application is divided into three modules. Query management, network monitor and protocol selection modules are used in the system. The query management module handles the query submission, query analysis and response receive operations. The sensor nodes and their traffic conditions are monitored under network monitor module. The protocol selection module is used to select the data transmission scheme for the query. The HEED and MintRoute protocols are used for the system. The system uses the integrated protocol for join query values

## 6. Conclusion

This work describes that properly selecting routing protocol based on query can improve the performance of query processing. We have designed a dynamic routing layer for sensor networks. Base station decides which routing protocol should be selected according to the query category and network density. Two routing protocols, HEED and MintRoute, are loaded into each node. The dynamic routing layer can automatically switch between HEED and MintRoute. Simulations show that dynamic routing layer is more energy efficient than both HEED and MintRoute. Decentralized decision-making is supported by the system. Central authority is not required. Query system is improved in the proposed protocol switch scheme. The system reduces the Network traffic in considerable manner. In the future development the protocol switching scheme can be improved with data caching scheme and privacy preservation mechanisms.

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