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# Research on Query Gain Routing Algorithm and Application in Wireless Sensor Networks

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**Abstract:** It is necessary to reduce the consumption of network node energy and the network load for solving the query design for routing algorithm in wireless sensor network, thus this article presents query gain routing algorithms and load balancing mechanism. This algorithm selects routing node by querying the routing information of gain matrix according to the successful record of historical query. The load balancing mechanism queries the energy information, which records node in the routing process and transfers load to balance the energy consumption of each node in the query path. This algorithm is able to effectively aware routing load to reduce the network energy consumption and avoid the data collision. The experimental result shows that compared with other query routing strategy, the query gain routing can increase the success rate of query under the condition of reducing the node energy consumption, but the load balancing mechanism can reduce the energy consumption of query gain routing further and prolong the network life cycle more effectively.

**Keywords:** Routing Algorithms; Load; Gain; Energy

## 1. Introduction

Wireless sensor network is a kind of wireless communication network which has been constructed by a large of arranged sensor nodes with data-aware, data storage and communication capabilities over a surveillance area in Ad hoc mode, then monitor the object of the physical world up close in real-time by various kinds of sensor. As the perception nerve endings of the internet of things, wireless sensor network is applied widely in the many fields: national defense military, environmental monitoring, agricultural production, health care, anti-terrorism and disaster relief etc [1-4]. Since sensor produce a variety of observational data continuously, wireless sensor networks can be regarded as a special database, user can issue a query to obtain the required information through the wireless sensor network. Although the application scenarios of wireless sensor network and hardware deployment are not the same, their ultimate goal is for obtaining, processing and transmitting the perceptive data. Therefore, the wireless sensor network is a data-centric network which is also has the characteristics like numerous nodes, short communication distance, limited energy etc [5-7]. For the query routing algorithms of wireless sensor network design, it must to be tried to reduce the energy consumption of network node. Additionally, since some of the key nodes may use up the energy prematurely due to the heavy load, it will cause the network to be divided into several isolated regions. Therefore, it is necessary to combine the energy information from nodes

during the process of the query routing, so that it can balance the energy consumption, thereby extending the network life cycle [8].

In the Rumor routing algorithm, which BRAGINSKY D presents, source node transmits the data randomly in the network, then keeps a copy in the intermediate node which the data pass by and user query also transmits randomly in the network. Once the transmissions path of both intersects, the user query will get the result. The simplest strategy to implement Rumor routing algorithm is: the source node transmits data along the horizontal direction and keeps a copy in the passing path, user query transmits along the vertical direction, and thus it ensures the path of both can intersect. Rumor routing algorithm is better than flooding algorithm in query efficiency and data transmission rate indicators [9]. LIU Xin proposed a kind of data storage and query routing algorithms that based on comb - pin model [10]. The algorithm is an expansion of Rumor routing algorithm; this idea is similar to using a comb to find the needle in the haystack [11]. Data (like needle) transmits a certain distance along the vertical direction and keeps a copy in the passing path; user query (like comb) transmits along the vertical direction; then transmits along the horizontal direction with multiple paths at regular distance in the same time, this distance can ensure that the transmission path of query requirement intersects data storage path. This process can also be reversed, that is the query requirement transmits a certain distance in a vertical direction, user query transmits along the horizontal direction with multiple paths, it

depends on the relation between the rate of data generation and query occurrence [13-15]. Huhua proposed a kind of routing algorithm based on tree clustering, through clustering sensor nodes of the sensor network to form a super node, reducing access to the sensor nodes and improve query efficiency . XIN Li proposed a kind of distributed indexing algorithm to handle the multi-dimension range query in the sensor networks [16].

## 2. Query Routing Algorithm

### 2.1. Network Model

Assume all the nodes in wireless sensor networks randomly distributed in a two-dimensional plane, and each node has the same transmission radius, you can use the unit disk graph(UDG) to model network topology, and all connections are bidirectional.

Define1 use an undirected graph with  $G(V, E)$  to represent a wireless sensor network,  $E \in V \times V$  represents the sensor node set of Euclidean plane;  $E \in N \times N$  represents the set of corresponding nodes edges. Assume that all nodes have the same communication range  $r$ , the distance between any two nodes of  $s_u$  and  $s_v$  is given from the function of  $(u, v)$  :

$$\delta(u, v) = \sqrt{\overset{\delta: N \times N \rightarrow r: \delta(u, v)}{(u_x - v_x)^2 + (u_y - v_y)^2}} \quad (1)$$

If and only if the distance  $\delta(u, v)$  between any two nodes of  $s_u$  and  $s_v$  is less than  $r$ ,  $s_u$  and  $s_v$  become neighboring nodes, and  $s_u$  and  $s_v$  exists a link between each other.

The energy consumption of wireless sensor networks use the formula LEACH model gave, it consist of packet to send, receive, and event perception these three parts, and make use the formula LEACH model gave can calculate the residual energy of nodes.

Consider  $s_u$  and  $s_v$  on the two minimum hop distance  $h$ , there are thresholds of  $u(h)$  and  $v(h)$ , to meet  $u(h) \leq \delta(u, v) \leq v(h)$ . Among them, the threshold size depends on node density  $P$  of wireless sensor network, and for any  $h > 0$  exists:

$$\lim_{p \rightarrow \infty} (v(h) - u(h)) = r \quad (2)$$

Definition 2 given source node  $s_v$  and the destination node  $s_u$ , the sensor model is defined as

$$r(u, v) = \frac{\lambda}{\delta(u, v)^i + \varepsilon} \quad (3)$$

In the above formula,  $\lambda$  represents the wireless signal amplitude  $\lambda > 0$ ;  $k$  is the sensor parameters;  $\varepsilon$  is a pre-

defined parameters used to process the same situation for the source node and the destination node position,  $\varepsilon > 0$ . Sensor node sends a data packet use the following six-tuple to represent: (SenderID, SeqNo, state, hops, DestID, data). SenderID is a identifier to create the sensor nodes of data package; SeqNo represent the serial number of the data package, it was assigned by the sensor node the packet created; state presents the current state of the data packet, including the initial state, the forwarding state and end state ; hops used to define the data packet's life cycle, when the message is passed from one node to another node, the amount of hops plus one, in order to control the times of packets transmitted, and avoid too much bandwidth consumption, it need to be set an upper limit value of the data package life cycle; DestID represents identifier of destination node; data field contains the data information that packet stored.

### 2.2. Gain Query Routing Algorithm

Query gain matrix (query gain matrix, QGM) is the key components to maintain routing information in the query routing algorithm. Before constructing QGM, define two auxiliary data structures Query Table and Sensor Table. Query Table of one node contains a set sends or forwards from this node and eventually query the hit query vector set. While another node Sensor Table records the node forward one query to its neighbors and finally query neighbor set of the hits. Therefore, the Sensor Table of some node is subset of all neighboring node collection. When the query is hit, all nodes (not including the destination node) from the source node to the destination node will record the query in the Query Table of this node, and recorded the neighboring nodes of this query hit path in the node Sensor Table.

Give an object set O containing k elements, a query vector set Q containing n elements and a node set S containing m element, for any one object  $oa \in O(1 \leq a \leq k)$ , any one query  $qj \in Q(1 \leq j \leq n)$  and any node  $s_i \in S(1 \leq i \leq m)$ , then the query result object collection is  $o_{qj} \in O(1 \leq j \leq n)$ . QGM is a matrix  $(m \times n)$  shown as below:

$$\left. \begin{matrix} s_1 \\ \vdots \\ s_i \\ \vdots \end{matrix} \right\} \begin{matrix} \left( \begin{array}{cccc} gain_{10} & gain_{11} & \cdots & gain_{1j} & gain_{1n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ gain_{i1} & gain_{i2} & \cdots & gain_{ij} & gain_{ia} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ gain_{n1} & gain_{n2} & \cdots & gain_{mj} & gain_{mk} \end{array} \right) \end{matrix} \quad (4)$$

Each of matrixes is composed of a complex data structure. The number of rows for QGM on a node should be equal to the length of the corresponding Sensor Table;

the number of columns is equal to the length of the corresponding Query Table.

Each node maintains a neighboring node list and a query gain matrix. The neighboring node list can update and maintain by the methods of the broadcast and monitoring query request. Any node can create a query and then query messages through intermediate nodes routing is forwarded to the destination node.

In the initial stages of query processing, the Query Table, Sensor Table on each node and the corresponding QGM are empty.

Figure 1 depicts exponential decaying transmission of the gain value in the query gain routing algorithm.

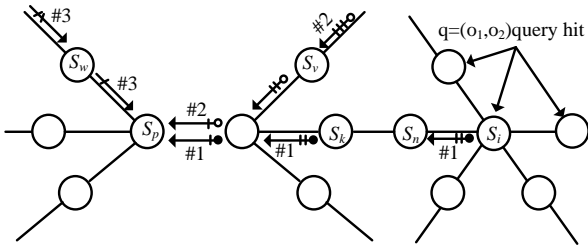


Figure 1. The exponential decaying transmission of gain value

Each circle in Figure 1 represents a sensor node, circles filled with gray represent query hit nodes, and each arrow represents some query hits path that gain value transmits. In Figure 1, there are altogether three hits query paths are labeled #1, #2 and #3; assuming a node  $s_p$  issues query  $q_j$  contains an object, and transmits the query to the neighboring node  $s_i$ , Finally, query is hit on the target node  $s_i$ . If the present hops value of query message is less than TTL, then it will forwards query continually to the neighbor nodes of  $s_i$ , for searching more nodes which satisfy the query. Assuming  $q_j$  is the  $j$ -th element in the Query Table of  $s_p$ ,  $s_i$  is the  $i$ -th element in the Sensor Table of  $s_p$  then  $add \langle \{s_i, s_k, \dots, s_u, s_i\}, value \rangle$  to  $gain_{ij}$ , the computing method of  $gain_{ij}$  is:

$$|gain_{ij}| = \sum_{s_i \in d} \frac{(1-a)\beta_{st} + n_a}{dist(s_p, s_i)} \quad (5)$$

Where:  $|gain_{ij}|$  represents the total gain value from  $s_i$  passed to  $s_p$ . The specific procedure of  $gain$  query routing was shown as algorithm 1.

Algorithm 1 Query gain routing algorithm

Input: wireless sensor network size, TTL, query the number of nodes.

Output: the message id, message hops.

- 1) Taking the query message  $m_{es} \langle id, s_p, state, hops, q_j, path \rangle$  from node  $s_i$
- 2) If  $q_j$  hit then on the node  $s_i$

- 3) Forward  $m_{es}$  to neighboring node of  $s_i$  to calculate the total number of hits;
- 4) For all sensors in  $m_{es}$ . path do
- 5) If  $s_p$ . QueryTable  $\neq$  AND  $q_j \in s_p$ . QueryTable then
- 6) Return  $q_j$  to position  $j$ ;
- 7) Else  $s_p$ . QueryTable. add ( $q_j$ );
- 8) Sensor  $s_i \leftarrow m_{es}$ . path. next ()
- 9) If  $s_i \in s_p$ . SensorTable then
- 10) Return  $s_i$  to position  $i$ ;
- 11) Else  $s_p$ . SensorTable. add ( $s_i$ );
- 12) According to formula (5), calculating the gain value  $v_k$  from  $s_i$  passed to  $s_p$
- 13)  $Gain_{ij}$ . add ( $m_{es}$ . path,  $v_k$ );
- 14)  $s_p \leftarrow s_i$ ;
- 15) End if
- 16) End if
- 17) End for
- 18) Return mes. id, mes. hops;
- 19) End if

In algorithm 1, the space complexity of each node is  $O(m \times n)$ , when QGM is full on some node, then the latest least used storage item will be replaced. Because Query Table and Sensor Table on each node are linear length, so their storage cost is negligible compared with QGM. Since each node in the query routing algorithm gain does not need the global information of any network, it only need the neighboring node's related information of this node, the successful queries target records of target node only pass along the query path between adjacent nodes, so query cost is low. Record node and transfer the load energy information during the query routing process, to balance the energy consumption of each node in query path.

### 3. Load Balancing Mechanism

The inconsistency between the distribution of hot object and node processing capacity is the one of the reasons of leading the sensor node to load imbalance. A good query routing strategy should be able to balance the load distribution of all sensor nodes. This can avoid some of the node to become a bottleneck and thus run out of energy prematurely, and it is also important to prolong the life cycle of the entire network. Let the size of load item  $k$  on node  $s_i$  equal to  $s_i, k$ , the accessing times of load item  $k$  during some time on node  $s_i$  equals to  $v_i, k$ , the load for load item  $k$  on node  $s_i$  equals to  $i, k$ , then  $L_i, k = s_i, k \cdot v_i, k$ . The actual load  $L_i$  of node  $s_i$  is the

total load of all load items on this node, that is  $L_i = \sum_{j=1}^i L_j, k$ , where  $m$  is the load item numbers of node  $s_i$ . Let the processing capacity of the node  $s_i$  be  $c_i$ , load threshold of node  $s_i$  be  $p_i$ , the load rate for  $s_i$  be  $\mu_i$ , then  $\mu_i = L_i / c_i$ . When a node's load rate  $\mu_i$  is not over its load threshold  $p_i$ , the node will be called under loaded node; On the contrary, it will be called overloaded node. Load balancing algorithm's goal is to achieve the global load balancing under the make the load transfer times as less as possible. The measure standard for load balancing can be defined by the variance of all nodes load:

$$g(A, G) = \frac{\sum_{i=1}^m (L_i - \bar{L})^2}{m}$$

Where: A represents query routing algorithm; G stands for Wireless Sensor Networks;  $L_i$  is a sum of all load items load of node  $s_i$ ;  $\bar{L}$ -the average value of wireless sensor network load.

#### 4. Experimental Simulation and Analysis

This simulation environment for this article use MICA2 node Crossbow produced as standard, the node's communication distance is 50 m. As the cost of wireless sensor network data transmission between nodes is far exceed the costs of data arithmetic processing, computing processing cost is ignored in simulation experiment, and only use the transferring cost to measure the total energy consumption.

Typically, it cost  $\sigma_{ir} + b \delta_{ir}$ , that the node sends a message of length  $b$  Byte. Which  $\sigma_{ir} = 0.635mj, \delta_{ir} = 0.0145mj / \text{Byte}$ . Accordingly, it cost  $\sigma_{ir} + b \delta_{re}$  that the node receive a message of the length  $b$  Byte, which  $\sigma_{ir} = 0.389mJ, \delta_{ir} = 0.00867mJ / \text{Byte}$ .

In this paper, use random data to simulate sensing data of wireless sensor network nodes in the simulation process. Specific methods are as following: First, initialize randomly the value  $v$  that each node on each dimension to be  $\text{rand}(0, 1)$ . In each subsequent every experiment, the max change range of value  $v$  is  $f(0 < f < 1)$ , compared to the last round of experiment. Assuming the value of the  $i$ -th dimension is  $v(r)[i]$  in round  $r$ , the value change is  $v(r)[i] + \text{rand}(-f, f)$  in round  $r + 1$ , and it is always ensured to be into  $[0, 1]$ .

Additionally, let the query gain matrix size in the query gain routing algorithm be  $20 \times 50$ ,  $\partial = \alpha = 0.6$ ,  $\lambda = 2, c = 10$ , the other experimental parameters and the default values are shown in Table 1.

Table 1. Experimental parameters and default values

Experimental parameters	Default
Network coverage area/ $m^2$	500×500
Number of sensor nodes	500
Aggregation nodes	8
Average Metrics Network Node	13
Replica distribution	Zipf ( $\partial = 0.83$ )
Query distribution	Zipf ( $\partial = 0.92$ )
Size of sensing data/Byte	42
Size of query data/Byte	30
Average query length	3.147

In this paper, several common query routing algorithm performance were compared and analyzed, including the Rumor routing algorithm (RR), query routing tree (QRT) algorithm and query gain routing (QGR) algorithms. Which, QGR algorithm is divided into basic QGR algorithms and QGR algorithm (QGR-LB) with load balancing mechanism.

First set of experiments mainly study in the case of the different queries in different query hops distance (hops), the query success rate of using a variety of query routing strategy.

Query hops distance was mainly used in reflecting the distant degree relative data sources node to the sink node. In this set of experiments, the total number of sensor nodes using the default value 500, the simulation results shown in table 2. In the same circumstances, the query success rate of QGR and QGR-LB is higher than the QRT and RR, when the average jump distance is equal to 7, QGR and the query success rate of QGR-LB and QRT is 15.1% higher than QRT, 46.3% higher than RR. If QGR is the same as the successful query rate of QGR-LB, then it indicates the load balancing mechanism based on route has no effect on improving the query success rate indicator.

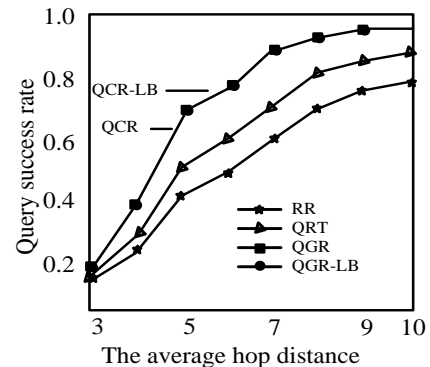


Figure 2. Effect of average hops on the query success rate

Second set of experiments mainly compares in the cases of different node density, the query success rate for different query routing strategies. In this set of experiments, the number of sensor nodes change from 200 to 800, the simulation results shown in Figure 3. In the same circumstances, QGR and QGR-LB query success rate is



higher than the QRT and RR, and with the number of nodes increasing, the range of QGR and QGR-LB query success increasing rate is significantly higher than QRT and RR, it indicates when the node number increase, the record of query routing historical information accuracy in the query gain matrix is improved accordingly.

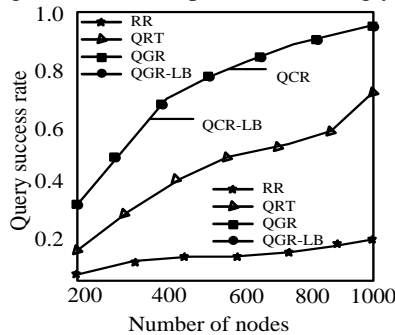


Figure 3. Effect of node density on the query success rate

Third set of experiments mainly compares in the case of different query hops, the necessary energy consumption for using a variety query routing strategies. In this set of experiments, the total number of sensor nodes using the default value of 500, the simulation results shown in Figure 4. With the average jump distance increasing, the necessary energy consumption for a variety of query routing strategies increases accordingly. However, in the same circumstances, QGR energy consumption is lower than the QRT and RR, when the average jump distance is equal to 7, QGR energy consumption is 28.3% lower than the QRT, 38.9% lower than the RR. In addition, QGR-LB energy consumption is 18.3% lower than the QGR, it indicates the load balancing mechanism based on route can reduce energy consumption.

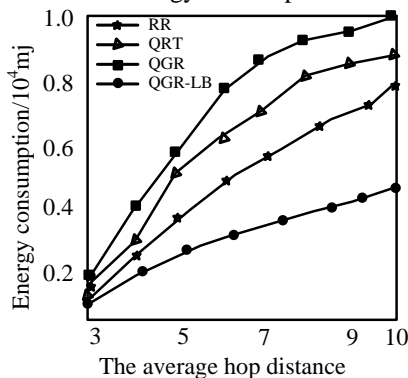


Figure 4. Average jump distance of the energy consumption

Fourth set of experiments compares in the case of the different nodes densities, the energy consumption of different query routing strategies. In this set of experiments, the number of sensor nodes change from 200 to 800, the simulation results shown in Figure 5. In the same circumstances, QGR-LB energy consumption is lowest, and

with the number of nodes increasing, the energy consumption decreased slightly; the energy consumption of QGR was significantly lower than RR and QRT in the same circumstances and with the number of nodes increasing, QGR energy consumption increasing range is lower than QRT and RR. Experiment shows that: with number of nodes increasing, the efficiency of load balancing mechanism based on the route is better.

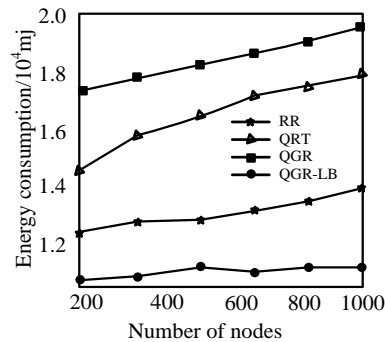


Figure 5. Impact of node density on energy consumption

## 5. Conclusion

Query success rate and energy consumption is the key indicator of impact performance of wireless sensor network query routing. The query success rate of existing wireless sensor network query routing algorithm is not high and the energy consumption is large, and there are some limitations. This paper presents a query gain routing algorithm, in routing node selection process, without relying on global topology information of network, which has good flexibility and adaptability. In addition, the route-based load balancing mechanism can be used in the process of query routing process.

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