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Data Aggregation Subject to QoS Constraints for Tracking Moving Objects in WSNs

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Abstract: ***A QoS-constrained Deviation-Avoidance Tree with anchor node (Q-DATa) approach is presented in this paper. The Q-DATa approach can support efficient update/query operations as well as meet QoS constraints for the operations. The proposed Q-DATa approach designates, according to the QoS constraints, some anchor nodes that can aggregate and store the sensory data, so that the query from sink and the updates from sensor nodes are sent to the anchor node to meet their QoS constraints. A simulation study was conducted to validate the approach. The results show that Q-DATa inherits the merits from the DAT approach and also guarantees the QoS in terms of delay and loss rate requirements. Furthermore, on the weighted delay value, the Q-DATa approach outperforms the DAT approach, under most of the conditions.***

Keywords: WSN, Data Aggregation, QoS, Object Tracking

1. INTRODUCTION

A WSN [1] consists of a number of inexpensive wireless sensor nodes, which are deployed in a distributed manner. Each tiny sensor node can support several functionalities such as sensors, radio, processors, so that it can sense and obtain the environmental data, communicates with neighbors to exchange data, and processes the acquired and received data.

One of the most important applications [2] of the wireless sensor networks is tracking moving objects [3-8]. In the literature, the problem of developing efficient routing [9-10] and data aggregation [11-12] for tracking and predicting the location of moving objects in WSNs have been investigated. There are two elementary operations required to tracking moving object in WSNs. One is to update the location information of the target object moving in the WSN, and the other is to query current location of the target object. In [5], a Deviation-Avoidance Tree (DAT) structure was proposed to resolve the issue of the trade-offs between query cost and update cost. The DAT approach makes use of two algorithms, the deviation-avoidance algorithm and the highest-weight-first algorithm, to minimize the total communication cost of update and query operations. However, DAT approach does not address the issue of QoS guarantee [13-16] on the update and query operations.

In this paper a QoS-constrained Deviation- Avoidance Tree with anchor node (Q-DATa) approach is proposed. The approach can support not only efficient update and query operations but also QoS guarantee for the two operations. The scheme of anchor nodes that store sensory data is adopted in Q-DATa, so that the query and update operations can meet their QoS constraints. First, the Q-DATa approach constructs a tree structure like the DAT approach does. Second, based on the tree structure and the QoS requirements, the anchor nodes are designated in the tree. Furthermore, a simulation study was conducted to investigate the delays and loss rates of query and update operations for both of DAT and Q-DATa approaches.

The rest of the paper is organized as follows. Section 2 briefly introduces the related work. Section 3 describes the proposed Q-DATa approach and Section 4 discusses the simulation study. Finally, we conclude this paper in Section 5.

2. RELATED WORK

Some data aggregation approaches[7, 11-12] were proposed in order to reduce energy consumption of WSNs by combining the raw data coming from different sources into aggregated data and then transmitting the data. In [11], a detailed comparison of the completeness and energy efficiency for aggregated and non-aggregated data is investigated. The results show that the data aggregation not only reduces power consumption but also increases reliability. In [7] an architecture with multiple-tier data aggregation for target tracking application is proposed. With the architecture, the trade-offs between energy, timeliness and data availability for data aggregation was explored. Besides, the timing of aggregating data in WSNs was investigated in [12]. This study shows that the aggregation period affects the tradeoff between data freshness and energy savings, and can be updated dynamically in an approach to provide a proper number of data query responses.

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In [5], a Deviation-Avoidance Tree (DAT) structure was proposed to address the issue of the trade-offs between query cost and update cost for tracking moving objects in WSNs. The DAT approach guarantees that all descendant nodes in topology will not deviate from their shortest paths to the sink. The DAT approach makes use of two algorithms, the deviation-avoidance algorithm and the highest-weight-first algorithm, to minimize the total communication cost of update and query operations. The goal of deviation-avoidance algorithm is to ensure that each sensor node has the shortest path to the sink. Moreover, the highest-weight-first algorithm is used to choose the route that has the largest event's weighting. Note that a larger event weighting means that the target object moves across the route frequently. Thus, before constructing the network topology, we need to collect the arrival and departure events for each pair of neighboring sensors. On basis of DAT topology, the query and update operations for tracking moving objects in WSNs can meet both of the shortest path and least energy consumption requirements. However, the QoS issue for DAT approach is not addressed in [5]. Thus, our study is to extend the DAT approach to support QoS on the query and update operations for tracking moving objects in WSNs.

3 PROPOSED Q-DATa APPROACH

3.1 Architecture of Q-DATa

Since the proposed Q-DATa approach employs the baselined architecture of the DAT approach, we briefly present the architecture as follows. In the DAT approach, if sink wants to obtain the information of the object, it must issue a query to the current sensor node that has successfully sensed the object along the forwarding path of the DAT tree, *T*. For example, when the sink wants to obtain the current location of Car 1, it sends a query to node 17 as shown in Fig. 1. Thus, the delay (d_q) of delivering a query to the current sensor node that senses the object can be represented as follows.

$$d_q = H_q \times d_h \,, \tag{1}$$

Where H_q denotes the hop count that the query traverses from sink to the current sensor node, and d_h is the delay time between two adjacent nodes.

On the other hand, the update operation in the DAT approach would carry out when the object moves from node *a* to node *b*. Firstly, node *a* will deliver an object departure event toward sink, and node *b* also transmits an object arrival event toward sink. The departure and arrival events will arrive at the lowest common ancestor (LCA) node to finish the update operation as shown in Fig. 1. Thus, we can define the update delay in the DAT approach as follows.

$$d_u = d_b + \left[\max\left(H_{dep}^{lca}, H_{arv}^{lca}\right) \times d_h\right], \tag{2}$$

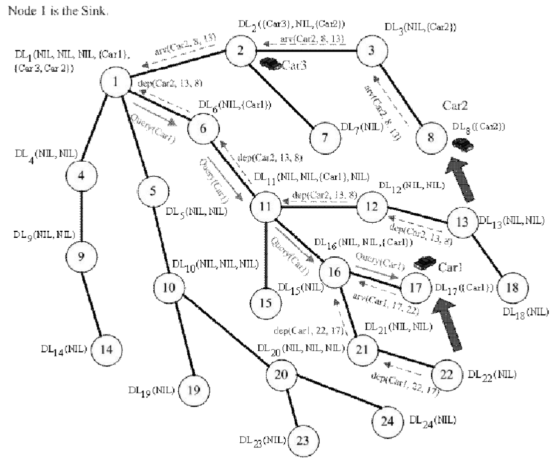


Fig. 1. The DAT architecture.

Where H_{dep}^{lca} is the hop count of the path from the node that issues departure event to the LCA node, and H_{arv}^{lca} denotes the hop count of the path from the node that delivers the arrival event to the LCA node. Moreover, when a sensor node detects the object arrival or departure, it must broadcast the event to its neighboring nodes to figure out the movement from a node to another node. Thus, we denote the delay time of figuring out the departure or arrival events as d_b. More details of the DAT approach can be referred to [5].

Based on the above observations, the path that is used to forward query and update events can be too long, so that the delays of query and update operations may not meet the urgent QoS requirement for tracking critical moving objects. In order to resolve this issue, we propose a Q-DATa approach to enhance the DAT approach.

3.2 Anchor Node Selection

The main concept of the proposed Q-DATa approach is to introduce the anchor node that is closer to sink into the object tracking tree *T* as shown in Fig. 2. The anchor node will aggregate and store the information of objects (e.g., object name, object current location, etc.) that are detected by the children nodes that belong to the anchor node. If the sink wants to obtain the information of the object, it could issue a query to the anchor node instead of the sensor node that really detects the object.

Obviously, the anchor node is preferred to be located near sink to shorten the query delay. However, this would result in heavy traffic in the anchor node because the anchor node stores more object information that is delivered from the leaf nodes and has to receive and process more queries to these objects. In order to address the loading problem of anchor node, we can select the anchor node to meet both the hardware constraints of the sensor node (e.g., buffer size, processing capability, etc.) and the maximum query delay. First, a proper anchor node must meet the query delay constraint as follows.

$$d_q \le D_q \,, \tag{3}$$

Where D_q is the maximum query delay in order to achieve real-time object tracking. On basis of the constraint as shown in Eq. 3, we can further induce that the distance in hops between anchor node and sink must satisfy the following condition.

$$dist(Anchor, Sink) \leq \left\lfloor \frac{1}{2} \times \frac{D_q}{d_h} \right\rfloor, \quad (4)$$

Thus, the anchor nodes can be selected as follows. First, an object tracking tree *T* is built according to the DAT approach. Then, it computes the distance from sink to an intermediate node i that is a candidate of the anchor node. If the distance between sink and the node i meets the constraint as shown in Eq. 4, the node i can be selected as the anchor node.

3.3 Query and Update Operations

Figure 3 illustrates the operations of Q-DATa approach for tracking moving objects. When an object *Car 1* moves from node 22 to node 17, the node 22 and 17 will issue an object departure event *dep*(*Car1, 22, 17*) and an object arrival event *arv*(*Car1, 17, 22*), respectively, to the anchor node (node 11) in order to update the object information table. When the sink wants to obtain the information of object *Car 1*, it only needs to send a query to node 11 and, thereafter, node 11 will report the *Car 1* information.

Especially, if the anchor node is an ancestor of the LCA node between the departure nodes and the arrival node in the object tracking tree *T*, the departure and arrival event packets must be forwarded to the anchor node in order to update its information table. As shown in Fig. 3, the anchor node is located at node 11, which is an ancestor of the LCA node (node 16). Thus, the departure/arrival event packets must be forwarded to the anchor node (node 11) in order to update the object information table.

On the other hand, if the anchor node is located at an offspring node of the LCA node between the departure node and the arrival node in object tracking tree *T*, the update packet must be delivered to the LCA node like the DAT approach does. For example (see Fig. 3), the anchor nodes (node 3 and 11) are offspring nodes of the LCA node (node 1). Therefore, the departure and arrival packets will be forwarded up to node 1 through node 3 and node 11, respectively. Thus, the detected lists in the nodes located on the paths from the anchor nodes to node 1 are updated.

Thus, we can obtain the update delay of the Q-DATa approach as follows.

$$d_u = d_b + \left[\max\left(H_{dep}^{AN}, H_{arv}^{AN}, H_{dep}^{lca}, H_{arv}^{lca}\right) \times d_h\right], \quad (5)$$

Where $H_{dep}^{A.N}$ is the hop count of the path from the node that delivers the departure event to the anchor node, and $H_{arv}^{A.N}$ is the hop count of the path from the node that issues the arrival event to the anchor node.

3.4 QoS Aspects of Q-DATA Approach

The query and update delay in a WSN is a crucial issue when strict QoS requirements are imposed on the object tracking. In order to evaluate the query and update delay in the WSN, we define a weighted average delay δ for a WSN that supports query and update operations on object tracking as follows.

$$\delta = P_q \times d_q + P_u \times d_u, \quad (6)$$

Where P_q is the probability of query event occurring in the sensor network and P_u is the probability of update event occurring in the sensor network. Both P_q and P_u satisfies the condition of $P_q + P_u = 1$. With the weighted average delay, we can evaluate the delay of a WSN with respect to not only the query and update delays but also the probabilities of query and update events.

In addition to the weighted average delay of a WSN, we also evaluate the packets loss rates for delivering the query and update events. In this paper, we assume the query and update events would generate a single packet to be forwarded to the anchor node or LCA node. In a WSN, each sensor node can successfully transmit a packet to its neighbor node with the probability of P_s. Thus, the loss rate for query operation can be represented as follows.

$$P_{lq} = 1 - P_s^{H_q^a} \quad (7)$$

where H_q^a denotes the hop count that the query traverses from sink to the anchor node. Similarly, the loss rate for update operation of the Q-DATa approach is as follows.

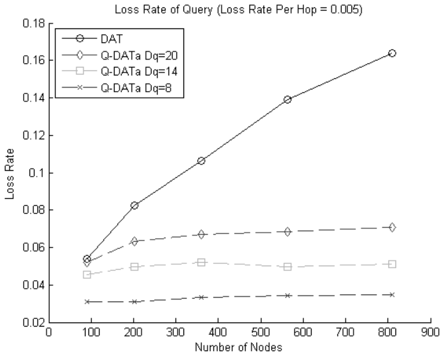
$$P_{lu} = 1 - P_s^{\max(H_{dep}^{A.N}, H_{arv}^{A.N}, H_{dep}^{lca}, H_{arv}^{lca})} \quad (8)$$

With the above QoS metrics, we can further evaluate the proposed Q-DATa approach against the DAT approach.

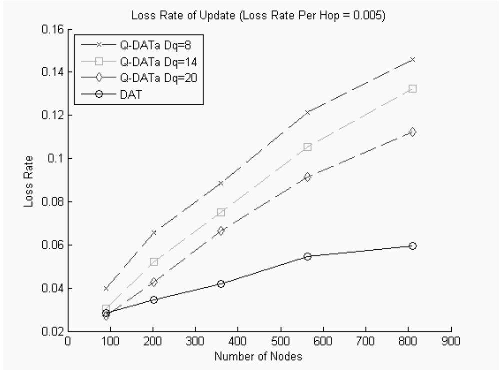
4 Simulation Study

4.1 Simulation Model

We have conducted simulations by making use of MATLAB. The WSN is with a network topology in which 810 sensor nodes are randomly distributed in an area of $30m \times 30m$. The communication range of each node is a circle with radius of 1.5*m* and the object tracking tree *T* is built according to the DAT approach (i.e., the shortest path concept). We simulate the object moving in the WSN according to a mobility model as shown in Fig. 4. For each unit of time, the object randomly selects one of the nine possible actions and moves according to the action it selects. These nine actions include staying at the same location and moving to the nine adjacent grid nodes. For the simulation, we generate 10 network topologies as well



(a) Loss rate of query



(b) Loss rate of update

Fig. 6. Loss rates of query and update.

as the 10 object tracking trees, and the object moves 10,000 times for each of the 10 network topologies.

4.2 Simulation Results

(a)*Query and update delay:* Figure 5(a) shows the query delays of the DAT and Q-DATa approaches. For the proposed Q-DATa approach, we set three different values, 8, 14, and 20, for the upper bound on query delay. As shown in Fig. 5(a), the Q-DATa approach outperforms than the DAT approach since the Q-DATa approach adopts the anchor nodes in the object tracking tree. On the other hand, Fig. 5(b) shows the update delay. The update delay of the DAT approach is smaller than that of the Q-DATa approach. Because adopting the anchor nodes may increase the length of updating path, the update delay of Q-DATa approach is thus increased.

(b) *Loss rate:* Figure 6 shows the simulation results of the loss rates for query and update operations for the two approaches. The loss rate per hop is set to be 0.005 (i.e., $1-P_s = 0.005$). As shown in Fig. 6(a), the Q-DATa has lower loss rate for query operation than that of the DAT, since the path of forwarding query in Q-DATa is shorter than that in DAT approach. However, the loss rate for update operations (see Fig. 6(b)) in Q-DATa is larger than that of the DAT approach. This is because Q-DATa's updating path is longer than DAT's updating path.

(c)*Weighted average delay:* To completely evaluate the performance, in terms of delay, of the two approaches, we must consider not only the query and update delays but also the probabilities of executing the query and update operations. Thus, we have defined the weighted average delay (δ) in Eq. 6. Moreover, we conduct the simulations with different values of P_q and P_u and observe the δ value of the two approaches. As shown in Fig. 7, the δ value of the DAT approach under the conditions of $0 \le P_q \le 0.1$ and $0.9 \le P_u \le 1$ outperforms than the Q-DATa approach does. But, under the conditions of $0.1 < P_q \le 0.3$ and $0.7 \le P_u < 0.9$, the Q-DATa with $D_q = 20$ has the best δ value than the others. And, under the conditions of $0.3 < P_q \le 1$ and $0 \le P_u < 0.7$, the Q-DATa with $D_q = 8$ achieves the best δ value. The above simulation results show that the

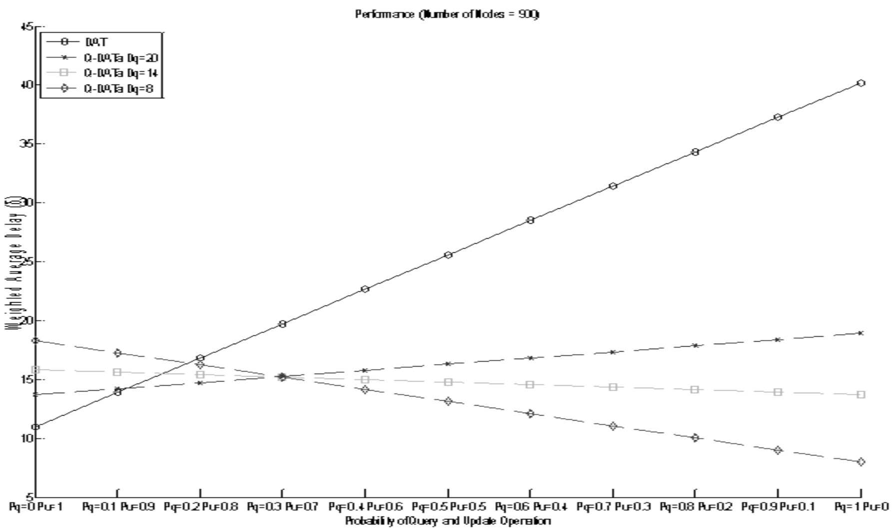


Fig. 7. The δ values of the two approaches.

DAT outperforms the Q-DATa only if the probability of executing update operation is nine times of the probability of executing query operation. Otherwise, a WSN can adopt the Q-DATa approach, since the δ value of the Q-DATa approach is better than that of the DAT approach under other conditions.

5 Conclusions

Tracking moving object is one of the most important applications of WSNS. The DAT structure is designed to support efficient data aggregation on tracking moving objects in WSNs. It can efficiently minimize the total communication cost of both update and query operations. However, DAT approach does not address the issue of QoS guarantee on the update and query operations. In this paper, a Q-DATa approach was proposed. The approach can support not only efficient update/query operations but also QoS guarantee for the two operations. Our approach introduces the anchor nodes into the structure to shorten the query delay. The simulation results show that the Q-DATa has shorter query delay and lower query loss rate than those of the DAT. In general, if the probability of executing update operation is over nine times of the probability of executing query operation, the DAT approach is preferred due to the better δ value. Besides the above special case, the Q-DATa approach outperforms than the DAT approach since the δ value of the Q-DATa approach is better than that of the DAT approach under most of the conditions.

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