Localized Routing Trees for Query Processing in Sensor Networks

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ABSTRACT

In this paper, we propose a novel energy-efficient approach, a localized routing tree (LRT) coupled with a route redirection (RR) strategy, to support various types of queries. LRTs take care of the sensors near the sink and reduce the energy consumption of these sensors, and RR reduces the energy cost of data receptions. Compared to the existing approaches, simulation studies show that LRT together with RR has significant improvement on the query capacity.

Categories and Subject Descriptors

C.2.4 [**COMPUTER-COMMUNICATION NETWORKS**]: Distributed Systems—*Distributed databases*

General Terms

Design, Performance

Keywords

Localized routing tree, data aggregation, sensor database

1. INTRODUCTION

With the advance of computing and communication technologies, sensor networks play an important role in many applications, such as environment monitoring and military event detection. In these applications, a type of query, called *zone-based* query, which obtains answer from readings of sensors in a sub-area of a network, needs to be supported. An example of zone-based query is shown as follows:

Type = Max(temperature),
Interval = 50s, Duration = 60 minutes,
Zone = [100, 100, 200, 200].

This query is used to collect the highest temperature from sensors within a rectangular area (zone) every 50 seconds for 60 minutes. From the viewpoint of data collection, the example zone-based query is an aggregative query, which can be further classified into holistic queries and non-holistic queries. *Median*, *Distinct Count*, and *Histogram* are holistic queries. *Max*, *Min*, and *Avg* of sensor readings are examples of non-holistic queries.

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Since sensors are generally powered by batteries, the energy constraint of sensors challenges the design of energy-efficient query processing. Many data aggregation approaches have been proposed to address this issue. However, there are three major issues that have been overlooked or ignored in these approaches.

1. An important issue that sensors near the sink drain their energy much faster than distant sensors has been overlooked. As a simple example shown in Figure 1, sensors located within the smallest circle centered at the sink have the highest forwarding workload. The area within the smallest circle is called the *first critical region* (named as Region-1). The radius of Region-1 equals the transmission radius of a sensor. The area between the smallest circle and the second smallest circle is called the *second critical region* (named as Region-2), and so on.

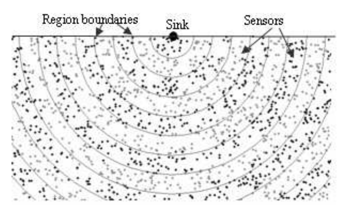


Figure 1: Distribution of random deployed sensors

2. Existing approaches build routing tree (RT) rooted at the sink, which is not energy efficient to support various types of aggregative queries.
3. Only the reduction of transmission cost is considered, and no attempt has been made to reduce the data reception cost.

In this paper (see [1] for a full version), we address the above problems and propose a novel energy-efficient approach, a localized routing tree (LRT) coupled with a route redirection (RR) strategy, to efficiently support various types of zone-based aggregative queries. The advantages of our approach are as follows.

1. LRT efficiently supports holistic and non-holistic zone-based queries.
2. LRT takes into account the sensors near the sink to reduce their energy consumption, which leads to prolonged lifetime of a sensor network.
3. LRT, coupled with the RR strategy, reduces the energy consumption of data receptions of sensors near the sink.

2. LOCALIZED ROUTING TREE

We propose a new approach for routing tree construction, called Localized Routing Tree (LRT), to address the issues that sensors near the sink (especially Region-1) deplete their energy faster and the problems of RTs rooted at the sink. In our approache, there are four steps to accomplish a query task: *query distribution*, *LRT construction*, *data collection*, and *data forwarding*. Query distribution is responsible for disseminating queries to query-related sensors, which is preformed by using the existing flooding techniques. In the LRT construction phase, a localized routing tree is built for collecting data. In the data collection step, the sensed data are collected by the local roots of the constructed LRTs. Finally, these local roots forward the aggregated or raw data to the sink in the data forwarding step. We use *query capacity*, rather than average total energy cost, as performance measure of query plans of a sensor network. The query capacity is defined as the total number of complete query responses received by the sink when the *lifetime of the network* is over, where the lifetime of a network is defined as the time from initial start of the network to the moment when a certain percent of sensors is disconnected from the sink.

For a given zone-based query, sensors can be classified into three types: *sensing*, *forwarding*, and *normal* sensors. A sensing sensor is a sensor within the query zone with sensing tasks and a forwarding sensor routes sensed data to the sink, but it does not perform any sensing task. A normal sensor is a sensor which is not of the above two types. We construct LRTs by using the idea of location-based routing. Each sensing sensor is assumed to know the sink location, the area of the query zone, and the locations and IDs of its neighbors. There are three steps for LRT construction.

(1) Computing the root reference points.

Initially, all sensing sensors compute the coordinate of a unique geographical point, called *root reference point*. The root reference point is selected as the intersected point between one edge of the query zone and the line segment connecting the sink and the center of the zone (R_1 in Figure 2).

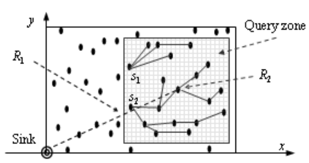


Figure 2: Constructed RT and root reference point

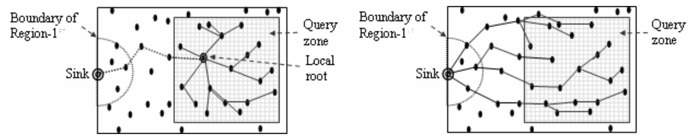
(2) Selecting local roots

Sensing sensors use their locally maintained locations of their neighbors to determine if they are *local roots*. For each sensing sensor s, if s has the shortest distance to the root reference point among all neighbors of s, then s is selected as a local root. If a sensing sensor is not a local root, it is an *internal node*.

(3) Selecting a parent node.

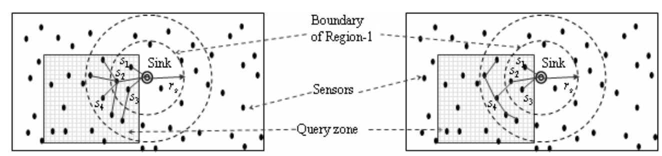
To construct a LRT, each internal node s selects a neighbor sensing sensor, which has the shortest distance to the root reference point among all the neighbors of s, as s's parent node.

Compared to the existing approaches, which build RTs rooted at the sink, LRTs are built within a query zone and are rooted at sensors within the query zone. As illustrated in Figure 3(a), for a non-holistic query, an LRT is built with a local root. This local root can collect all the sensor readings within the query zone, compute the result, and select a single path to forward the result to the sink. However, for the same query, the existing approaches build an RT rooted at the sink, which have three paths through sensors in Region-1 to forward data to the sink as shown in Figure 3(b). Therefore, compared to the LRT in Figure 3(a), the RT in Figure 3(b) consumes more energy of sensors in Region-1. Furthermore, for holistic queries, the existing approaches using RTs rooted at the sink can not efficiently process holistic zone-based queries since all sensor readings should be sent to the sink without any data aggregation. This process consumes a large amount of energy of sensors in Region-1. Even though no intermediate aggregation is allowed in LRT, the local root, shown in Figure 3(a), collects all readings within the query zone, compute the answers to the holistic queries, and send the answers to the sink in a single packet. In this way, the energy depletion rate is slowed down for sensors in Region-1.



(a) RT rooted at the local root (b) RT rooted at the sink

Figure 3: LRTs and RTs rooted at the sink



(a) RT without route redirection (b) RT with route redirection

Figure 4: Illustration of basic idea of route redirection

We also propose a route redirection (RR) scheme, which aims to reduce energy consumption of data receptions of sensors in Region-1 and is applied to non-holistic queries only. Consider the network shown in Figure 4(a), where a query zone contains three sensing sensors s_1, s_2, and s_3 in Region-1. We can not reduce the total number of transmissions of s_1, s_2, and s_3, since they must transmit their sensed data to the sink. However, we can reduce the number of receptions of s_1, s_2, and s_3 by carefully redirecting routes among two-hop sensors of the sink. A k-hop sensor of the sink is a sensor whose hop distance to the sink is k. In Figure 4(b), two-hop sensing sensors of the sink redirect their sensed data to s_4, which then transmits the aggregated data to s_2. In Figure 4(a), the total number of receptions of the sensors in Region-1 is 5. With route redirection in Figure 4(b), the number of receptions is reduced to 1.

We compare the performance of LRT with RTs routed at sink (SRT) by simulation studies. Compared to the existing approaches, the experimental results show that our approach can increase 10%-100% of the total query capacity for non-holistic queries. For holistic queries, an order of magnitude increase of the query capacity can be achieved.

References [1] Jie Lian, Lei Chen, Kshirasagar Naik, M. Tamer Özsu, G. Agnew. Localized Routing Trees for Query Processing in Sensor Networks. Technical Report CS2005-15, University of Waterloo, 2005.