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Duplicate Sensitive Data Aggregation In Heterogeneous WSN

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Abstract
Data aggregation in resource constrained wireless sensor networks is a challenging task. Most of the work done in this area, address the problem for static networks with predetermined topologies. The count and sum accuracy is a major concern due to the very nature of sensors. In order for data aggregation to be effective, it needs to be coupled with efficient routing. This paper addresses the problem for random deployment of heterogeneous sensors. The experimental results prove that the proposed data aggregation technique is energy efficient with high percentage of accuracy. The framework that is presented in this paper serves well both continuous and event based detection systems.

Keywords WSN, Aggregation, Heterogeneous, Random

Introduction
Sensors are tiny devices that detect a change and functionally produce an output in the form of a signal. When these sensors are networked they offer a wide range of exciting new applications. Sensor networks are already used in military, environment monitoring, intelligent control, traffic management, medical treatment and manufacture industry. The key challenge in wireless sensor networks is to maximize network lifetime. Energy efficiency is the most important issue in wireless ad hoc networks and sensor networks. In event-driven networks, data is sent whenever an event occurs. In continuous dissemination networks, every node periodically sends data to the sink. The sensors send the sensed data to a control center or to a fixed destination.
In practice, homogeneous sensors are rare and are used by specific applications with predetermined topologies. The advancement of MEMS has enabled a new network of sensors with varying transmission powers, which can form an ad hoc network with a number of applications. The architecture of homogenous nodes forming a network and sending data to the base station is not suitable for real time applications. For example, a sensor fixed on a car, a light post sensor and a mobile phone sensor can either directly send the temperature of a location to the base station or act as a next hop neighbour and pass the data to another node. Typically the query is issued from the user to the base station and the base station in turn sends the query to the nodes. Due to the very nature of the sensor nodes, they can sense only within their range and thus would yield only partial result to the query. These partial results from different regions need to be collaborated before sending data to the base station. For example, if the user wants to know the number of tigers in a forest, the base station may have to consolidate the data from different regions and send it to the user. Alternatively the sensors themselves can collaborate and send the aggregated results back to the base station. Also in multi hop communications, whenever an event occurs all the nodes in the region would respond to the event. The base station will get multiple copies of the same data. To avoid redundancy of data, data aggregation techniques have been proposed. Instead of sending multiple copies of the same data, data would be consolidated as it passes from one hop to another. Thus the redundancy can be avoided. As there would be multiple paths of communication between the sensors and the sink, the base station would still receive multiple copies of the aggregated data. This poses a new problem for aggregation such as count and sum. There is a chance of getting inaccurate results because of duplicates in the results. Also all the sensor nodes would participate in data aggregation and it would amount to depletion of energy. There is very less research on energy efficient data aggregation for heterogeneous sensor networks. In this paper, data aggregation points are identified and the sensors would be spared of all computational burden.
If the data aggregation is based on sum and count rather than max and min, there would be additional problems of duplicates. The multipath robust algorithms can be classified as duplicate sensitive and duplicate insensitive. To maintain the accuracy of the data that is aggregated, duplicate sensitive algorithms are proposed. They increase the computational burden of the sensor nodes and they follow a specific topology like tree or ring. In this paper a novel robust duplicate sensitive data aggregation technique for the random topology is proposed. Simulation results show that this technique is more effective compared to the traditional approaches in terms of network lifetime and latency and is more suitable for real world applications. The remainder of the paper is organized as follows. Section 2 provides a brief overview of the related work. Section 3 explains the system model. Section 4 gives a comparative analysis with the existing techniques. Section 5 and 6 concludes the work with the advantages and disadvantages.

Related Work
Data aggregation is a process in which information is gathered and expressed in a consolidated form. It is especially relevant in WSN to increase the network life time. In sensor networks, combining partial results at intermediate nodes, significantly reduces the amount of communication and hence the energy consumed [1, 2, 3].The various data aggregation techniques are found in [4]. The authors had given an elaborate study of

data aggregation methods. In paper [5], the authors had proposed the data aggregation model called directed diffusion. Directed diffusion is a novel data-centric, data dissemination paradigm for sensor networks. Directed diffusion has some novel features: data-centric dissemination, reinforcement-based adaptation to the empirically best path, and in-network data aggregation and caching. It is proved to energy efficient and minimizes the per-node configuration. The impact of network density on data aggregation was studied by authors in [6]. Data aggregation in real time is proposed by authors in [7]. Some quality of service data aggregation techniques are discussed in [8 – 13]. It is possible for the compromised nodes to send false data to the base station. Thus for secure applications, a number of protocols are proposed in [14 - 17]. In paper [18], synopsis diffusion approach was used to secure WSN against attacks in which compromised nodes contribute false sub aggregate values. The authors had presented a novel lightweight verification algorithm by which the base station can determine if the computed aggregate (predicate Count or Sum) includes any false contribution. Routing plays a significant role in data aggregation in WSN. Routing with aggregation is discussed in [19, 20].

In paper [21], the authors have focused on constructing a Load-Balanced Data Aggregation Tree (LBDAT). More specifically, three problems are investigated, namely, the Load-Balanced Maximal Independent Set (LBMIS) problem, the Connected Maximal Independent Set (CMIS) problem, and the LBDAT construction problem. To make data aggregation more efficient, in paper [22], the authors introduced the concept of packet attribute, defined as the identifier of the data sampled by different kinds of sensors or applications, and then proposed an attribute-aware data aggregation (ADA) scheme consisting of a packet-driven timing algorithm and a special dynamic routing protocol. Inspired by the concept of potential in physics and pheromone in ant colony, a potential-based dynamic routing is elaborated to support an ADA strategy. In paper [23], the authors presented an ant colony algorithm for data aggregation in wireless sensor networks. Every ant will explore all possible paths from the source node to the sink node. In order to increase the probability of intersection of routing paths, the mechanism extends the routing paths. In [24, 25] concealed data aggregation techniques are proposed.

Another approach used by several data aggregation systems for sensor networks is to construct a spanning tree rooted at the base station, and then perform in-network aggregation along the tree. The intermediate results propagate level-by-level up the tree, with each node getting partial results from all its children before sending a new result to its parent. Tree-based aggregation approaches, are prone to communication losses resulting from node and transmission failures. TinyDB [26, 27] follows a tree like structure to schedule and optimize the queries. It assumes only sensors would participate in the aggregation and it does not spare any sensor because of energy constraints. Because each communication failure loses an entire subtree of readings, leading to a significant error in the query answer. Researchers have proposed the use of multi-path routing techniques for forwarding sub-aggregates [28] to solve this problem. For aggregates such as Min and Max which are duplicate-insensitive, this approach provides an error free solution. For duplicate-sensitive aggregates such as Count and Sum, however, multi-path routing leads to double-counting of readings, resulting in incorrect aggregate results. A robust and scalable aggregation framework called Synopsis Diffusion [29] has been proposed for computing duplicate-sensitive aggregates such as Count and Sum. There are two primary elements of this approach - the use of a ring-based topology instead of a tree-based topology for organizing the nodes in the aggregation hierarchy, and the use of duplicate-insensitive algorithms for computing aggregates based on Flajolet and Martin's algorithm for counting distinct elements in a multi-set. The ring model which is very popular has a disadvantage of predetermined setup and thus not suitable for real world applications. In earlier schemes, each node that sensed the event has some computational burden. The goal of this work is to improve efficiency of data aggregation in heterogeneous setup. The problem of duplicates in sum and count are addressed. In the proposed work, data aggregation points are identified and only in those points, data aggregation would take place. Those nodes which are not data aggregation points need to only forward the data.

System model

The system consists of heterogeneous nodes, data aggregation points and events as illustrated in Fig 1.

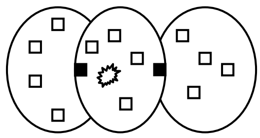

Figure 1: The System Model – Nodes, DA points and Events.

Typically the user sends the query through internet to the base station. The base station propagates the query further down to the sensor regions. When a matching reply is ready at the base station, the base station forwards it to the user.

Base station aggregation

Whenever an event occurs, the node sends the data directly to the base station. The base station receives multiple copies of the same data through so many nodes. It involves redundancy. The base station determines the aggregation based on the location of the node and the location of the event. The location of the event is almost the same point (x + , y+) for static event. The base station can remove the duplicate entries using some filtering algorithm and increment the counter only if there is any change in location.

Suppose it is a mobile agent, the location (x,y) would be different for different nodes. The base station collects at least three readings from the nodes and determines the accuracy of the count or sum. If there is no event reported from the

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original point of interest or if there is a location change, it is assumed to be a mobile event. So count will not be incremented. Although base station aggregation works fine, it involves a lot of redundant data. The major concern of WSN is to conserve energy as much as possible. So this scheme exhausts the energy of the nodes quickly as all the nodes participate in the process.

First level data aggregation

Intermediate data aggregation means aggregation that is being done by the sensors themselves. It could be categorized for static events and mobile events. The data aggregation is done on two levels. In the first level, the cluster based data aggregation is done by electing a data aggregation point. In the second level, the data aggregation is done between the adjacent data aggregation points. This helps to eliminate duplicates and gives a near accurate solution.

Static event data aggregation

When the user queries on an aggregated data, it is directed towards the sensor nodes in the specified region. Whenever an event occurs, the nodes around the event would sense the data. The first node that senses the event broadcast the event data. The event data contains node id, energy level, type of the event and the location of the event. All the nodes within the range that also had detected the same event do not broadcast the details. They instead increase the belief state of the event by 1 by listening to the broadcast. Since it is a heterogeneous setup, it is assumed that there would be a number of high energy nodes around the event. The node with the highest energy level is self elected as the data aggregation point. This is done by exploiting the broadcast nature of the sensors. The high energy node may not be able to detect any specific event. Usually the sensors that detect the events are custom made to do only specific sensing task. The high energy node just collects the data and passes the aggregated data to the base station. It is likely that the high energy node can directly transmit the data through any communication protocol instead of hopping from one node to another. The DA point broadcasts the event details continuously as there would be some sleeping nodes. The nodes that had detected the event wait for two epochs and then broadcast a voucher packet for the event. The nodes are not synchronized due to their heterogeneity. Therefore, the waiting period helps all the nodes in the region to construct the voucher packet and send to the DA point. The voucher packet contains the node id, belief state of the event and the location. It is possible for the same event to happen in more than one location. For example, the number of tigers in a region could be more than one. Same sensor may send two different location voucher packets. The data aggregation point now aggregates the data based on the voucher packets. It is possible for different events to be sensed by the sensors in the range. The data aggregation point will have a list of events and their corresponding voucher status.

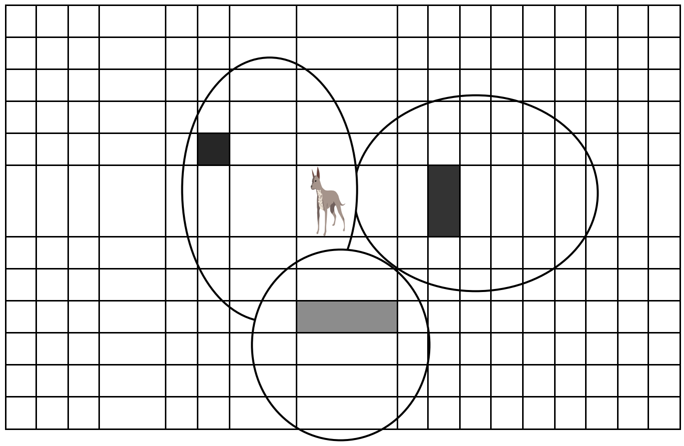

Figure 2: Different DA points detecting the same event

Mobile event

Same events sensed by sensors in different location are likely to be mobile events. Based on location of the event, the data aggregation point consolidates the data. If the location is the same, the node would remove the duplicates. If the locations are different there are two possibilities. Apart from being another event, the event could be mobile also. So to deal with mobile event, the node waits for one more epoch to aggregate the data. If it receives from the same nodes, then it is assumed to be a new event. If one or more nodes have changed the location of the event, it is considered to be a mobile event. The data aggregation point gets the details for at least 3 epoch readings. Depending on the accuracy level of the query the number of readings could be increased or decreased. As it is a heterogeneous setup, the synchronization among the nodes is not possible. They will have varying sleep – wakeup cycle. The successive epoch readings are important to get the accuracy of the event. For example, if the event is mobile, the nodes will send different locations for the same event and it will result it being counted as 2. If in the next epoch, the first node has changed its location of the same event, the event is concluded to be a mobile event. This is with the assumption that within the two intervals of time, the event data can not be significantly different. It is also possible for the event to move out of the region of the sensed nodes. It again confirms the belief state of the DA point. The DA will remove the entry if in the final epoch reading, the event is not reported. It is assumed that the other range would report this event to its DA point. Thus duplicate count is eliminated.

Second Level Data aggregation

As in figure 2, it is possible for some nodes that detect the same event to have different data aggregation points. In that case, the same event would be recorded by more than one data aggregation point. So before sending the data to the base station, the data aggregation points should make sure the accuracy of the aggregated data. The DA point computes the perimeter of the events based on the location of the event data. Every data aggregation point virtually compute the radius based on the location of the event data and form a circle with the DA point in the center. Then the DA point would broadcast the Request packet with the DA entry. All the other DA nodes which are within the range, will send the reply packets. Other nodes in the region will not participate after examining the broadcast packet. Normally the data propagates towards the base station. But in order to eliminate the duplicate entries, the data aggregation points send the data in all other aggregation points adjacent to it. Each DA point then consolidates the data based on the location of the event. The belief state could be increased or decreased based on this data. The DA points, exchange the events data and further consolidations are done at each aggregation point. The DA points retain the events with maximum voucher number. The DA with minimum voucher number transfer the voucher number to the DA with maximum voucher number. In that case, the voucher number would get added to the existing voucher number. Then the DA with less voucher number removes the event data from its table. For example, consider the following scenario. The DA D1 details are in table 1, D2 details are in table 2 and D3 details are in table 3.

Table 1: D1

DA point	Event Loc	Voucher
D1	E11(12,14)	10
D1	E12(10,30)	5
D1	E13(9,26)	3

Table 2: D2

DA point	Event Loc	Voucher
D2	E21(12,14)	3
D2	E22(22,40)	7
D2	E23(19, 6)	13
D2	E24(35,4)	4

Table 3: D3

DA point	Event Loc	Voucher
D3	E31(2,22)	6
D3	E32(5, 20)	7
D3	E33(19, 6)	3
D3	E34(35,4)	12

From the table we can find that E11(12,14) and E21(12,14) refer the same event picked up by different data aggregation points. The number of voucher packets in D1 is 10 and in D2 is 3. So the event gets recorded by D1 with voucher entry 13 and discarded by D2. Similarly E23(19,6) found entries in D2 and D3. Since D2 has more number of voucher entries, D3 discards the event. D2 updates the voucher number to 16. Similarly E24 and E34 are the same. So D3 records the event with voucher number 16. The final aggregated table would be as follows in table 4.

Table 4: Consolidated Event Data

DA point	Event Loc	Voucher
D1	E11(12,14)	13
	E12(10,30)	5
	E13(9,26)	3
D2	E22(22,40)	7
	E23(19, 6)	16
D3	E31(2,22)	6
	E32(5, 20)	7
	E34(35,4)	16

The DA points in the adjacent regions in all directions, share the data and aggregates the data based on the location. This is with the assumption that in a heterogeneous setup, there are bound to be powerful nodes that can act as data aggregation points. In case if there are no high energy nodes, the nodes themselves will elect a node with a slightly higher energy and follow the procedure. In that case, it may not be highly energy efficient. There are some events which could be mobile as well as static. For example, a car could be moving for some time and then parked at a particular place. The data aggregation points in the different regions could record that as two separate events. So the count will be increased. This is an application specific scenario and depending on the requirement the number of epochs and the coordination between the aggregation points could be increased.

Algorithm

1. A node senses an event (Ei) at location (x,y)
2. Sends broadcast packet [Node id + Event id+ Location + Energy Level]
3. Listens to other broadcasts
4. A high energy node sends a broadcast to be the DA point.
5. Other nodes construct a voucher packet [Node id + Event id+ Location + belief]
6. They send their voucher packets to DA point.
7. The voucher details are maintained in DA point as a table.
8. Repeat the process for 3 epochs
9. If the location of the event is consistent, then the DA concludes it as a static event.
10. If the location of the event changes, it is considered to be a mobile event.
11. The DA sends a request packet [Node id + Location]
12. Other DA points send reply packets [Event data]
13. Each DA consolidates the event data as follows
14. Compare two event tables E1 and E2
15. If the same location is found for an event ev^i, check for voucher number
16. If E1 has less voucher number,
    a. Transfer it to E2
    b. Remove the entry
17. Else
    a. Transfer it to E1.
    b. Remove the entry
18. Event data is sent to the base station

Continuous monitoring systems

In continuous monitoring systems, when a query is issued it is propagated to the sensor region. The nodes receive the query and the first node that has data responds to the query by broadcasting the details. The data aggregation point is elected as per the previous algorithm. Other nodes broadcast the belief states to the DA point. The voucher packet contains the actual difference between the readings. For example, to find the average temperature in a specific region, the first node sends to the DA 30.1 deg. Later all the nodes in the region, after listening to the broadcast, send a voucher packet to the DA only if there is a significant change in the readings. The DA point consolidates the data and sends it to the base station. Table 5 shows sample readings for continuous monitoring systems. The second level aggregation is optional in this case as the temperature is likely to be the same in an area. Depending on the accuracy level, the setting can be changed.

Table 5: Sample data

Node	Type	Location	Température
0	0	(21.5, 23)	19.4235
1	1	(24.5, 20)	19.4233
2	2	(19.5, 19)	19.4230
3	0	(22.5, 15)	19.4236
4	0	(24.5, 12)	19.4233
5	1	(19.5, 12)	19.4232

Results

Figure 3 shows the accuracy of the various techniques. The proposed model has accuracy as nearly as synopsis diffusion approach. But synopsis diffusion considers only static predetermined setup which is not suitable for real world applications. Fig 4 shows the remaining energy level of the system. The proposed model is well ahead of other techniques as an optimized routing technique is used.

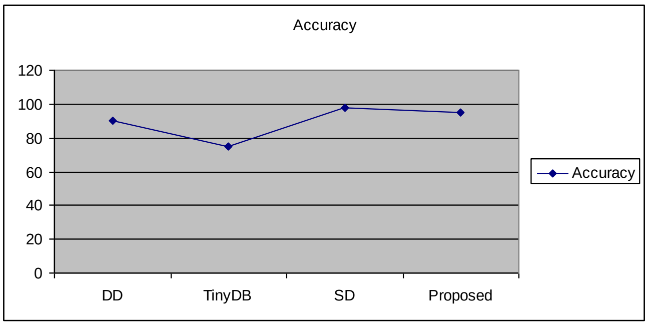

Figure 3: Accuracy

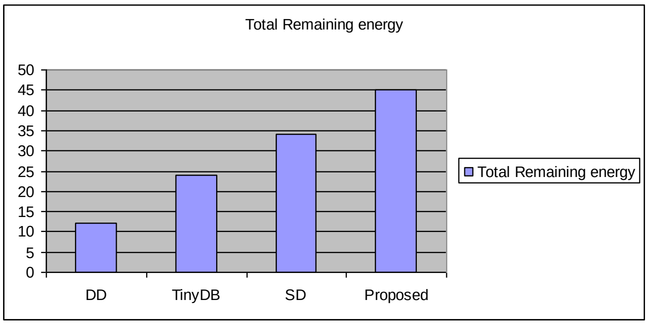

Figure 4: Total Remaining Energy

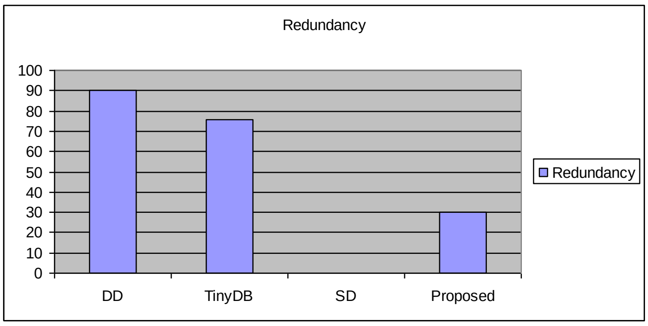

Figure 5: Redundancy

Also the proposed model does not use much control packets. The fig 5 shows the redundant data generated. Synopsis diffusion does not involve redundancy as the nodes set the binary digit 1/0. Though the proposed model also generates redundant data, it could be argued for robustness. As communication links are prone to failures, a decent percentage of redundancy could be acceptable.

Advantages

- Energy efficiency
  - Almost no computational burden on the sensor nodes and thus energy is saved.
  - Only broadcast voucher packets are sent and a few cycles of sending req/rep control packets are eliminated.
  - Optimized routing algorithm is used. DA points are introduced.
- Accuracy
  - Depending on the query and the accuracy needed, the number of epochs can be increased or decreased. More accurate results will have more latency and it is tolerable.
- Reliability
  - A number of DA points will be sending the data to the base station and it is similar to multipath roust algorithms. The coordinated efforts of the DA points would yield a reliable solution.
- Fault Tolerance

- A number of DA points will be sending the data to the base station and it is similar to multipath roust algorithms. Even if the a path fails, the other DA points would carry the data to the querying node.

- Latency
  - An optimized routing algorithm is used which will make sure lower latency.
- Redundancy
  - This model minimizes the redundant data to an extent as compared to other models.

Conclusion

A framework for data aggregation in heterogeneous setup is discussed in this paper. The major challenge of duplicate counting is addressed in this paper. The proposed model is highly robust, accurate and energy efficient based on the assumption that, in a heterogeneous setup there would be high energy nodes. The scheme will work only if the heterogeneous sensors are programmed based on the algorithm. The paper does not address the security aspects of data aggregation.

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