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Energy Efficient Data Collection Using Logical Co-ordinate System

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Abstract--In large scale wireless sensor networks, identifying the location of sink is very essential for energy efficient data gathering. Some protocols require planning of the mobile sink's moving path in advance. However, due to changes in farmland conditions the pre-calculated moving trajectories may not be applicable in some cases. Certain protocols suggest that a mobile sink announce its location information frequently throughout the network. But it suffers from serious control message overhead. In this paper, a low complexity data reporting protocol is used which helps the sensor nodes to easily identify the location of the mobile sink without the help of GPS or landmark. A logical co-ordinate system for routing and forwarding data packets is established. To enhance energy efficiency in data gathering, greedy forwarding is used which selects the shortest route to forward data. Simulation results show that this data reporting protocol has reduced control overhead and yields satisfactory performance in finding shorter routing paths.

Keywords: Wireless Sensor networks, Mobile Sink, Logical coordinate system, Greedy forwarding, low complexity routing.

I. INTRODUCTION

In recent years, wireless sensor networks (WSNs) have emerged as a new information-gathering paradigm in a wide range of applications, such as medical treatment, outer-space exploration, battlefield surveillance, emergency response, forest fire detection etc [1]. Sensor nodes are usually deployed throughout the field for collecting data in the surrounding environment. Initially, data was reported to a static sink through long, multi-hop error prone routes. Recent researches used mobile sinks to gather data from sensor nodes. Mobile sinks can be animals or vehicles equipped with radio devices.

They are sent in to the field and they communicate directly with sensor nodes resulting in shorter data transmission paths and reduced energy consumption.

But when mobile sinks are used for data gathering many new challenges are introduced. Many research efforts have been focused on scheduling movement patterns of a mobile sink to visit some special places in a deployed area, in order to minimize the time of gathering data. In such approaches, the moving path of the sink is scheduled in advance [2]. However, the farmland environment is prone to changes. When such changes occur the sink node becomes unable to change its moving path. The sink does not have the capability to change its moving path or pattern dynamically. The movement pattern is static and is fixed in advance. Several Mobile Elements Scheduling protocols which achieve data collection through controlled sink mobility are not suitable for changing field conditions.

In certain other approaches, the path of the sink is not planned in advance. Instead the mobile sink announces its location information frequently throughout the network when it is moving [3]. These approaches meet with the problem of serious control message overhead. Also due to frequently changing location of sink, the packets have to be detoured through long routes. This costs a large amount of energy.

To identify the location of the moving sink, a logical coordinate system is used in this paper. It increases the flexibility in the movement of the mobile sink. In order to utilise energy efficiently, data packets are forwarded through the shortest path. It is achieved through Greedy forwarding.

The paper is organised as follows. Related work is presented in Section 2. The algorithm design is presented in Section 3. Section 4 presents the results of simulation. Section 5 presents the conclusion.

II. RELATED WORK

Recent research efforts have been focused mainly on leveraging the mobility of data sink. The challenges involved in this work are:

1) The movement of mobile sink should be flexible. 2) The location of mobile sink should be identified accurately. 3) Shortest route should be selected for forwarding data.

A mobile sink's current location being broadcasted to the whole network is a simple solution to the above challenges. This approach is sink oriented and it suffers from the serious disadvantage of severe control message overhead. Thus this method is ineffective in collecting small amount of data from the network. Several mechanisms have been suggested to reduce control messages. The TTDD protocol constructed a two-tier data dissemination structure in advance to enable fast data forwarding. Fodor et al. achieved lowered communication overhead, by using a restricted flooding method [4]. In such methods the routes are updated only when the topology changes.

Another category of protocols called Mobile Elements Scheduling Protocols planned the mobile sink's moving path in advance. A work on Mobile collectors focused on minimizing the length of each data gathering tour by controlling the mobile sink's movement to query every sensor node in the network. The MES methods require a mobile sink to cover every node in the sensor field, which makes it hard to accommodate to large scale networks and introduces high latency in data gathering.

Virtual co-ordinate routing methods have been used which consider the virtual co-ordinates of the mobile sink and the sensor nodes in the network to determine their locations [5]. A Greedy algorithm has been proposed for data reporting using logical co-ordinates rather than geographic co-ordinates [6]. A vector form of virtual coordinates has been proposed, in which each element in the vector represents the hop count to a landmark node [7].

GRAdientBroadcast (GRAB) [9] is a robust data delivery protocol which consists of a new set of mechanisms and protocols designed specifically for robust data delivery in face of unreliable nodes and fallible wireless links.

GRAB builds and maintains a cost field, providing each sensor the direction to forward sensing data. GRAB forwards data along a band of interleaved mesh from each source to the receiver. GRAB controls the width of the band by the amount of credit carried in each data message, allowing the senderto adjust the robustness of data delivery.

Virtual Cord Protocol (VCP) [8], exploits virtual coordinates to provide efficient and failure tolerant routing and data management in sensor networks. VCP maintains a virtual cord interconnecting all the nodes in the network and which, operating similar to a distributed Hash Table (DHT), provides means for inserting data fragments into sensor nodes and retrieving them. Furthermore, it supports service discovery using indirections. VCP uses two mechanisms for finding paths to nodes andassociated data items: First, it relies on the virtual cord that always provides a path toward the destination. Second, locally available neighbourhood information is exploited for greedy routing.

III. SYSTEM DESIGN

In this paper, a logical coordinate system is established which helps in identifying the location of the mobile sink very easily. Two main parameters namely hop-count and sequence number help in determining the location of the sink node. The sink node broadcasts its location information when it reaches specific points in the field which can be termed as 'trail points' of the mobile sink.

A. Architecture

After the location of the sink is determined, packets are routed by the neighbouring nodes to the sink. For routing, the shortest path is found by Greedy forwarding method.

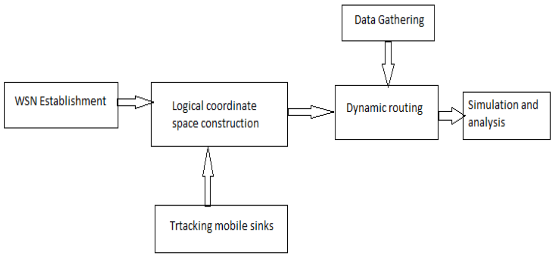

Fig 1. Data Collection Architecture

Fig 1 shows the architecture of a data collection system. A proactive data reporting protocol that is self-adaptive to various application scenarios is used. Mobile sinks move continuously in the field in relatively low speed, and gather data on the fly. Control messages are broadcasted at certain points in much lower frequency than ordinarily required in existing data gathering protocols. These sojourn positions are viewed as “footprints” of a mobile sink. Considering each footprint as a virtual landmark, a sensor node can conveniently identify its hop count distances to these landmarks. These hop count distances combined represent the sensor node’s coordinate in the logical coordinate spaceconstructed by the mobile sink.

Similarly, the coordinateof the mobile sink is its hop count distances from thecurrent location to previous virtual landmarks. Havingthe destination coordinate and its own coordinate, eachsensor node greedily selects next hop with the shortestlogical distance to the mobile sink. Thus the location of the sink is identified by the sensor nodes and data is routed along the shortest path to the sink.

B.WSN Establishment

The sensor nodes are usually scattered in a sensor field. Each of these scattered sensor nodes have the capability to collect data and route data back to thesink and the end users. Data are routed back to the end user by a multi-hop infrastructureless architecture through the sink.

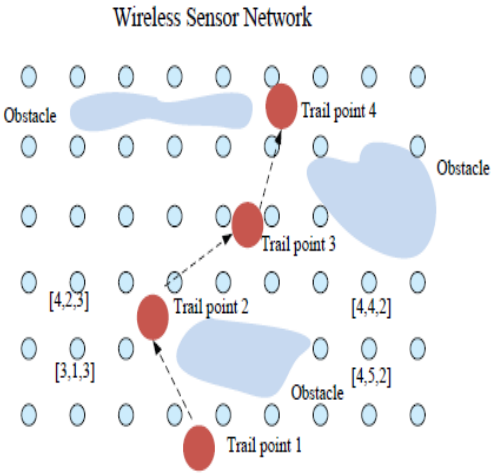

Fig 2. WSN Establishment

The fig 2 shows a simple wireless sensor network and the trail points of mobile sink in the network.

C .Establishing Logical coordinate space System

During this phase, sensor nodes updatetheir trail references corresponding to the mobile sink’strail messages.At beginning, all sensor nodes’ trail references are initialized to $[-1, -1, \ldots, -1]$ of size d_v. A special variable λ that is used to track the latest message Sequence number is also set to -1. After the mobile sink *S* enters the field, it randomly selects a place as its first trail point $\pi 1$, and broadcasts a trail message to all the sensor nodes in N. The trail message, <msg.seqN,msg.hopC>, is set to <1, 0 >, indicating that this is the first trail messagefrom trail point one, and the hop count to *S* is zero.

The nodes nearest to *S* will be the first ones to hear this message. By comparing with λ, if this is a new message, then λ will be updated by the new sequencenumber. And node n_i’s trail reference v_i is updated as follows. First, every element in $v_i$is shifted to left byone position. Then, the hop count in the received trail message is increased by one, and Replaces the right-most element $e_i^{d}{}_{v}$inv$_i$ .After $n_i$updated its trail reference, this trail message is rebroadcasted with the same sequencenumber and an incremented hop count. The same procedurerepeats at all the other nodes in N.

Within onemove of *S*, all nodes in the network have updated theirtrail references according to their hop count distancesto *S*’s trail point $\pi 1$. If a node receives a trail messagewith a sequence number equals to λ, but has asmallerhop count than it has already recorded, then the lasthop count field in its trail Reference is updated, and thistrail message is rebroadcasted with the same sequencenumber and an incremented hop count. Trail messagesthat have sequence number less than λ will be discardedto eliminate flooding messages in the network.

Destination identification is the main task carried out using logical co-ordinate space construction.The sojourn places of a mobile sink, named trail points, are footprints left by a mobile sink, and theyprovide valuable information for tracing the currentlocation of a mobile sink. Considering these footprintsas virtual landmarks, hop count information reflectsthe moving trajectory of a mobile sink. A logical d_v dimensionalcoordinate space is then established.

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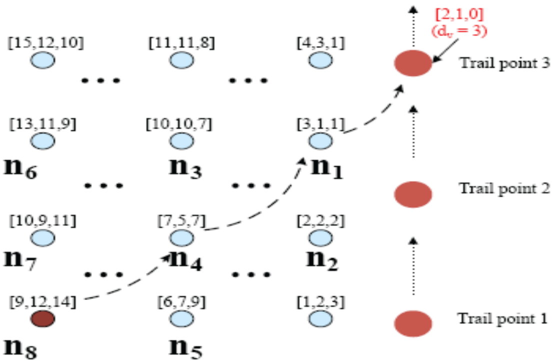

Fig 3.Logical Coordinate Space system.

Fig 10 shows the logical co-ordinates constructed by the mobile sink as well as the other data reporting sensor nodes.

D. Greedy Forwarding

Once a node has updated the elements in its trail reference, it starts a timer that is inverse proportional to the right-most element in its trail reference. $T_{init}$and μ are predefined constants. The choice of timer function, T_{init}, and μ may vary. However, it is assumed that the timer durations are significantly longer than the propagation time of a trail message, so that timers on all nodes are viewed as starting at the same time. The timer mechanism is mainly used to differentiate data reporting orders. So the clock on each sensor node doesn't need to be perfectly synchronized. Since the right-most element in a node's trail reference is the latest hop count information from this node to a mobile sink, the inverse proportional timers ensure that nodes faraway from *S* have shorter timer durations than those closeto *S*, thus will start data reporting first.

When a node's timer expires, it initiates the data reporting process. Every sensor node in the network maintains a routing table of size O(b) consisting of all neighbors' trail references. This routing table is built up by exchanging trail references with neighbors, and it is updated whenever the mobile sink arrives at a new trail point. When a node has receivedall its neighbors' trail references, it calculates their distances to the destination reference according to*2-norm* vector calculation, then greedily chooses the node with the smallest distance as next hop to relay data. If there is a tie the next hop node can be randomly selected.

Fig 4 compares the normal SODD approach and the new logical co-ordinate approach introduced in this paper. Data is transferred through a shorter route efficiently in this method. It takes 4 hops in this method to reach the sink whereas using SODD approach it takes 6 hops to reach the sink.

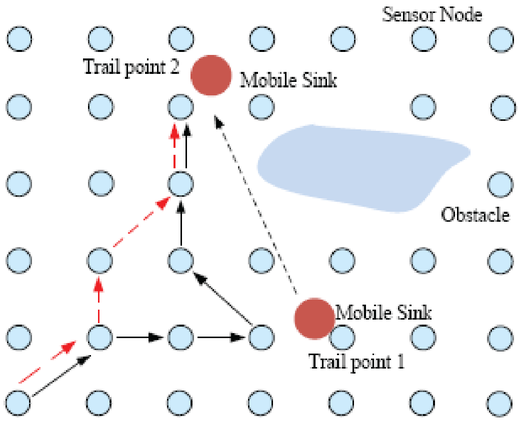

Fig 4. Greedy Forwarding

Greedy Forwarding thus determines the shortest route and forwards data to the mobile sink. It conserves a large amount of energy which is otherwise wasted by sending data through long and error prone routes.

IV. SIMULATION AND RESULTS

A network N that consists of *N* sensor nodes and *M* mobile sinks is considered. All the sensor nodes are data sources. Sensor nodes are deployed in a grid topology for ease of understanding. However, the analysis can be extended to other uniformly distributed topology. Therefore, the edge of the grid is roughly $\sqrt{N}$.

Energy consumption mainly includes datapacket forwarding cost, E_{data}, routing table maintenancecost, $E_{routing}$, and trail message transmission cost, E_{trail}.Two factors affect the energy cost of data forwarding:number of data packets and the average route length.The number of data packets is determined by the numberof data sources in a network, in this case, *N*. Theaverage route length, on the other hand, may varydepending on the locations a mobile sink has travelled. An upper bound of the average route length is estimatedby considering the situation that a mobile sink appearsrandomly at a location inside the deployed field. In thiscase, we can find *N*2 pairs of sensor nodes that any onepair of nodes' distances to the mobile sink added up toat most $\sqrt{2N}$.

Thus, the average route length should beupper bounded by $N2 \cdot \sqrt{2N/N}$. We use a coefficient c,where $0 < c \leq 12$, to describe the average route length.Hence, we have,$E_{data} = \beta \cdot c \cdot \sqrt{2N} \cdot N$

This energy cost upper bound for data reporting won'tbe affected by the number of mobile sinks, since everydata reporting message will travel through the shortestpossible path. Increased number of mobile sink will onlydecrease the total energy cost for data reporting.The total number oftrail messages depends on the network size, N, the numberof trail points visited by each mobile sink, $D\pi$, andthe number of mobile sinks, M. The energy consumptionfor trail message transmission is given by:$E_{trail} = \alpha \cdot M \cdot N \cdot D\pi$

The energy consumption for each node tomaintain local routing information is linearly proportionalto the number of its neighbors, denoted by b. Ifthere are multiple mobile sinks, the energy consumptionincreases as each node keeps a different trail referencefor each mobile sink. Because of the broadcast nature ofwireless media, this type of control message only needsto be transmitted once by each sensor node. Therefore,the energy cost for routing information maintenance issummarized by:

$E_{routing} = \alpha \cdot N \cdot M$

The overall energy consumption is:

$EST = \beta \cdot c \cdot \sqrt{2N} \cdot N + \alpha \cdot M \cdot N \cdot D\pi + \alpha \cdot N \cdot M$

The energy cost for data reporting in TTDD is determinedby amount of data packets and length of routing paths. Data packets are routed towardsa mobile sink that appears randomly in the deployed field.

$E\_{data} = \beta \cdot c \cdot \sqrt{2N} \cdot N$

According to TTDD protocol, the whole deployed areais divided into small cells. A query for data is onlyflooded inside one cell. However, as we are consideringa data collection process that aims at getting all senseddata in the network, it is reasonable to argue that thissingle query will affect each of the data sources, thuswill be propagated by all sensor nodes in the network.Therefore, we have,

$E_{query} = \alpha \cdot M \cdot N \cdot bcast$

where*bcast*is the number of such query broadcasts.In the grid construction phase every data source inthe network propagates a descriptive message about itsdata to the whole network, so that certain nodes willbecome anchors for a particular data source. Since everynode is a potential data sources, the energy cost for thisprocedure is

$E_{grid} = \alpha \cdot N \cdot N$

Adding the energy consumption of different taskstogether, we have

$E_{TTDD} = \beta \cdot c\sqrt{2N} \cdot N + \alpha \cdot M \cdot N \cdot bcast + \alpha \cdot N \cdot N$

Since $D\pi$representsthe number of broadcasts a mobile sink makes during thedata gathering procedure, and *bcast*indicatesthe number of times a sink initiates a query in TTDD,these two variables can be set as equal. Thereafter, thedifference can be ignored here. Another difference isbetween the routing information exchange cost and gridconstruction cost. Typically, the number of mobile sinksshould be significantly less than total number of sensornodes, i.e., $M << N$, and $\alpha \cdot N \cdot M << \alpha \cdot N \cdot N$.

In the SODD approach, whenever a mobile sink movesto a different location, it broadcasts its current position tothe whole network. As the message propagates a routingtree is established. Each node reports back its senseddata to parent node and finally, all data are mergedat the root. This SODD approach suffers from losingtrack of the sink when location update is infrequent.To ensure fair comparison, a broadcast frequency higherthan typically required by dynamic routing protocol is used to ensureproper termination of SODD. We use one mobile sinkin this set of simulations. The mobile sink moves in arectangular or circular fashion in both algorithms. Weset the data gathering threshold to 98%.

During simulation various impact factors like average route length, energy consumption, and delay are considered. The dynamic routing protocol shows increased performance in all scenarios.

V.CONCLUSION

The low complexity data reporting protocol used in this project enables energy efficient data gathering. It uses logical coordinates to infer distances, and establishes data reporting routes by greedily selecting shortest path to destination reference. This protocol is capable of tracking mobile sink through logical co-ordinate spaces. It possesses desired features of logical routing without requiring GPS devices or landmarks installed. It is capable of adapting to various sensor field shapes and different moving patterns of mobile sinks. Further, it eliminates the need of special treatments for changing field situations. The impact of various design factors is investigated and simulation is performed. The results demonstrate that the data reporting protocol effectively reduces energy consumption.

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