SINKTRAIL: A PROACTIVE DATA REPORTING PROTOCOL FOR WIRELESS SENSOR NETWORKS

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Abstract- A large-scale Wireless Sensor Networks (WSNs), leveraging data sinks' mobility for data gathering has drawn substantial interests in recent years. Current researches either focus on planning a mobile sink's moving trajectory in advance to achieve optimized network performance, or target at collecting a small portion of sensed data in the network. In many application scenarios, however, a mobile sink cannot move freely in the deployed area. Therefore, the pre-calculated trajectories may not be applicable. To avoid constant sink location update traffics when a sink's future locations cannot be scheduled in advance, we propose two energy efficient proactive data reporting protocols, SinkTrail and SinkTrail-S, for mobile sink-based data collection. The proposed protocols feature low-complexity and reduced control overheads. Two unique aspects distinguish our approaches: 1) allow sufficient flexibility in the movement of mobile sinks to dynamically adapt to various terrestrial changes; and 2) without requirements of GPS devices or predefined landmarks. SinkTrail establishes a logical coordinate system for routing and forwarding data packets, making it suitable for diverse application scenarios. We systematically analyze the impact of several design factors in the proposed algorithms. Both theoretical analysis and simulation results demonstrate that the proposed algorithms reduce control overheads and yield satisfactory performance in finding shorter routing paths.

Keywords- Wireless Sensor Networks, Energy Efficiency, SinkTrail and SinkTrail-S

I. INTRODUCTION

WIRELESS Sensor Networks (WSNs) have enabled a wide spectrum of applications through networked low-cost low-power sensor nodes, e.g., habitat monitoring, precision agriculture, and forest fire detection. In these applications, the sensor network will operate under few human interventions either because of the hostile environment or high management complexity for manual maintenance. Since sensor nodes have limited battery life, energy saving is of paramount importance in the design of sensor network protocols. Recent research on data collection reveals that, rather than reporting data through long, multihop, and errorprone routes to a static sink using tree or cluster network structure, allowing and leveraging sink mobility is more promising for energy efficient data gathering. Mobile sinks, such as animals or vehicles equipped with radio devices, are sent into a field and communicate directly with sensor nodes, resulting in shorter data transmission path sand reduced energy consumption. However, data gathering using mobile sinks introduces new challenges to sensor network applications. To better benefit from the sink's mobility, many research efforts have been focused on studying or scheduling movement patterns of a mobile sink to visit some special places in a deployed area, in order to minimize data gathering time. In such approaches a mobile sink moves to predetermined sojourn points and query each sensor node individually. Although several Mobile Elements Scheduling (MES) protocols have been proposed to achieve efficient data collection via controlled sink mobility, determining an optimal moving trajectory for a mobile sink is itself an NP-hard problem and may not be able to adapt to constrained access areas and changing field situations. Where mobile sinks collecting data mainly follow trails or field boundaries in order not to damage crops, and change trajectories dynamically according to farmland situations. Typically, without scheduling the trajectory for a mobile sink in advance; a data gathering protocol using mobile sinks suggests that a mobile sink announce its location information frequently throughout the network. Many Sink Oriented Data Dissemination (SODD) protocols use such approach, e.g., Directed Diffusion, Declarative Routing Protocol (DRP) and GRAB. Whereas different aggregation methods may be adopted, this approach is much more flexible in terms of sinks' movement, but incurs significant control message overheads. An example data reporting path of SODD is presented using black solid route In addition to large amount of energy consumption on flooding control messages, change of routing paths due to the sinks' movement, and energy cost on detouring large data packets (originally targeted at the previous sink location, now changed to the current sink location) severely impair protocol performances.

In this paper, we propose SinkTrail, a proactive data reporting protocol that is self-adaptive to various application scenarios, and its improved version, SinkTrail-S, with further control message suppression. Main contributions of this paper are as under:

- In SinkTrail, 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 space constructed by the mobile sink. Similarly, the coordinate of the mobile sink is its hop count distances from the current location to previous virtual landmarks. Having the destination coordinate and its own coordinate; each sensor node greedily selects next hop with the shortest logical distance to the mobile sink. As a result, SinkTrail solves the problem of movement prediction for data gathering with mobile sinks.

II. RELATED WORK

In the following, we review state-of-the-art routing schemes for WSN's with sinktrail.

A. System Analysis

Leveraging data sinks' mobility in sensor data collection has been a topic of tremendous practical interests and drawn intensive research efforts in the past few years. The most challenging part of this approach is to effectively handle the control overheads introduced by a sink's movement. At the first look, broadcasting a mobile sink's current location to the whole network is the most natural solution to track a moving mobile sink. This type of approach is sink oriented and some early research efforts, e.g., have demonstrated its effectiveness in collecting a small amount of data from the network. Several mechanisms have been suggested to reduce control messages. The TTDD protocol, proposed in constructed a two-tier data dissemination structure in advance to enable fast data forwarding.

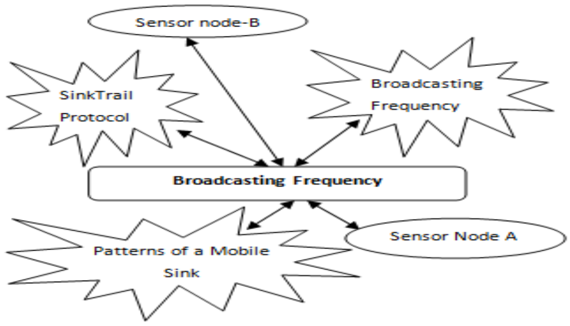


Fig. 1. Basic strategies for sensor networks with a sinkTrail

A spatial-temporal multicast protocol is proposed to establish a delivery zone ahead of mobile sink's arrival. Control messages are flooded to wake up nodes in the delivery zone proposed DRMOS that divides sensors into "wake-up" zones to save energy. A lowered communication overheads by proposing a restricted flooding method; routes are updated only when topology changes.

A mobile sink should move following a circle trail in deployed sensor field to maximize data gathering efficiency. One big problem of the multicasting methods lies in its flooding nature. Moreover, these papers either assume that mobile sinks move at a fixed velocity and fixed direction, or follow a fixed moving pattern, which largely confines their applications. The SinkTrail protocol with message oppression minimizes the flooding effect of control messages without confining a mobile sink's movement, thus is more attractive in real-world deployment. Another solution utilizes opportunistic data reporting. Shah and Shakkottai studied data collection performance when a mobile sink presents at random places in the network. The method relies heavily on network topology and density, and suffers scalability issues when all data packets need to be forwarded in the network. Another category of methods, called Mobile Element Scheduling (MES) algorithms. Considered controlled mobile sink mobility and advanced planning of mobile sink's moving path, minimizing the length of each data gathering tour by intentionally controlling the mobile sink's movement to query every sensor node in the network. When data sampling rates in the network are heterogeneous, scheduling mobile sinks to visit hot-spots of the sensor network becomes helpful. Example algorithms can be found in. Although the MES methods effectively reduce data transmission costs, they require a mobile sink to cover every node in the sensor field, which makes it hard to accommodate to large scale and introduces high latency in data gathering. Even worse, finding an optimal data gathering tour in general is itself an NP-hard problem, and constrained access areas or obstacles in the deployed field pose more complexity. Unlike MES algorithms, SinkTrail, with almost no constraint on the moving trajectory of mobile sinks, achieves much more flexibility to adapt to dynamically changing field situations while still maintains low communication overheads. SinkTrail uses sink location prediction and selects data reporting routes in a greedy manner. To predict sink locations to enhance data reporting, SinkTrail employs a different prediction technique that has much lower complexity. Moreover, SinkTrail does not rely on the assumption of location-aware sensor nodes, which could be impractical for some real-world applications. The routing protocol of SinkTrail is inspired by recent research on virtual coordinate routing. A greedy algorithm for data reporting using logical coordinates rather than geographic coordinates. A vector form virtual coordinates, in which each element in the vector represented the hop count to a landmark node. SinkTrail adopts this vector representation and uses past locations of the mobile sink as virtual landmarks. To the best of our knowledge, we are the first to associate a mobile sink's "footprints" left at moving path with routing algorithm construction. The vector form coordinates, called trail references, are used to guide data reporting without knowledge of the physical locations and velocity of the mobile sink.

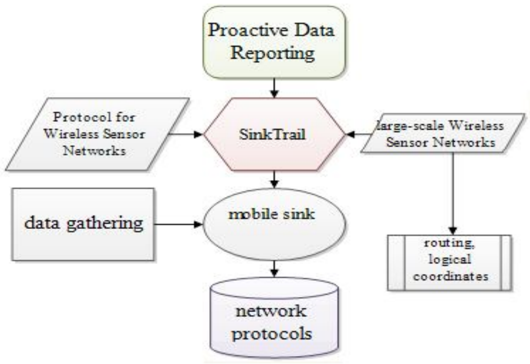


Fig. 2. WSN node architecture and SintTrail with Mobile sink

B. Existing System

The habitat monitoring precision agriculture and forest fire detection. In these applications, the sensor network will operate under few human interventions either because of the hostile environment or high management complexity for manual maintenance. Since sensor nodes have limited battery life, energy saving is of paramount importance in the design of sensor network protocols. Recent research on data collection reveals that, rather than reporting data through long, multihop, and errorprone routes to a static sink using tree or cluster network structure, allowing and leveraging sink mobility is more promising for energy efficient data gathering .Mobile sinks, such as animals or vehicles equipped with radio devices, are sent into a field and communicate directly with sensor nodes, resulting in shorter data transmission paths and reduced energy consumption. However, data gathering using mobile sinks introduces new challenges to sensor network applications. To better benefit from the sink's mobility, many research efforts have been focused on studying or scheduling movement patterns of a mobile sink to visit some special places in a deployed area, in order to minimize data gathering time. In such approaches a mobile sink moves to predetermined sojourn points and query each sensor node individually, drawbacks are:

- The protocols have been proposed to achieve efficient data collection via controlled sink mobility determining an optimal moving trajectory for a mobile sink is itself an NP-hard problem and may not be able to adapt to constrained access areas and changing field situations.

- A data gathering protocol using mobile sinks suggests that a mobile sink announce its location information frequently throughout the network.

C. Proposed System

In Wireless Sensor Networks (WSN), data gathering using mobile sinks typically incurs constant propagation of sink location indication messages to guide the direction of data reporting. Such behavior is undesirable, especially when the sensor network scale increases, as frequent message flooding will cause serious congestion in network communication and significantly impair the sensor network lifetime.

In this paper, we propose a proactive data reporting protocol, SinkTrail, which achieves energy efficient data forwarding to multiple mobile sinks, and effectively reduces the number of sink location broadcasting messages. SinkTrail is unique in two aspects:

1. It allows sufficient flexibility in the movement of mobile sinks to dynamically adapt to unknown terrestrial changes; and

2. Without assistance of GPS or predefined landmarks, SinkTrail establishes a logical coordinate system for predicting and tracking mobile sinks' locations, thereby significantly saves energy consumed during the data reporting process.

We systematically analyze the impact of several design factors in SinkTrail and explore potential design improvements. The simulation results demonstrate that SinkTrail outperforms the Frequent Flooding Method (FFM) in finding shorter routing path and consumes less energy during data gathering process.

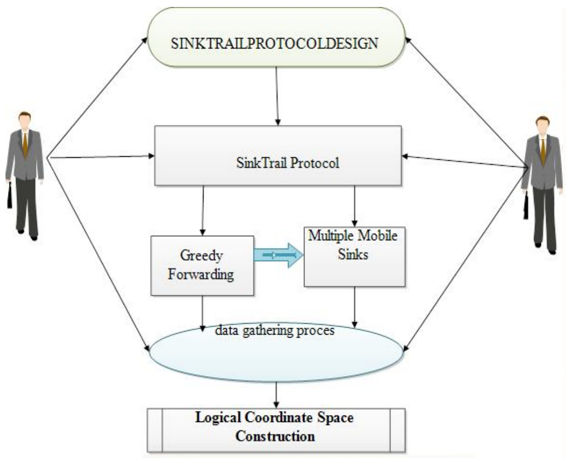


Fig. 3. Communication and Coordination of SintTrail Protocol

- The results and demonstrates the advantages of SinkTrail algorithms over previous approaches. The impact of several design factors of SinkTrail is investigated and analyzed
- The advantage of SinkTrail is that the logical coordinate of a mobile sink keeps invariant at each trail point, given the continuous update of trail references.
- Incorporating sink location tracking, we compare the overall energy consumption of SinkTrail with these protocols. Simulation results for SinkTrail-S are also presented to show further improved performance.

III. ASSUMPTIONS AND SIMULATION METHODOLOGY

A. Protocol Design

Consider a large scale, uniformly distributed sensor network IN deployed in an outdoor area. An example deployment Nodes in the network communicate with each other via radio links. We assume the whole sensor network is connected, which is achieved by deploying sensors densely. We also assume sensor nodes are awake when data gathering process starts (by synchronized schedule or a short "wake up" message). In order to gather data from IN, we periodically send out a number of mobile sinks into the field. These mobile sinks, such as robots or vehicles with laptops installed, have radios and processors to communication with sensor nodes and processing sensed data. Since energy supply of mobile sinks can be replaced or recharged easily, they are assumed to have unlimited power.

B. Destination Identifications

SinkTrail facilitates the flexible and convenient construction of a logical coordinate space. Instead of scheduling a mobile sink's movement, it allows a mobile sink to spontaneously stop at convenient locations according to current field situations or desired moving paths. These sojourn places of a mobile sink, named trail points in SinkTrail, are footprints left by a mobile sink, and they provide valuable information for tracing the current location of a mobile sink.

C. Broadcasting Frequency

The impact of sink broadcast frequency is two sided. If the mobile sink broadcasts its trail messages more frequently, sensor nodes will get more up-to-date trail references, which is helpful for locating the mobile sink. On the other hand, frequent trail message broadcast results in heavier transmission overheads. Suppose the time duration between two consecutive message broadcasting.

D. Network Maintains Routing

Every sensor node in the network maintains a routing table of size consisting of all neighbors' trail references. This routing table is built up by exchanging trail references with neighbors, and it's updated whenever the mobile sink arrives at a new trail point. Although trail references may not be global identifiers since route selection is conducted locally, they are good enough for the SinkTrail protocol. Because each trail reference has only three numbers, the size of exchange message is small. When a node has received all its neighbors' trail references, it calculates their distances to the destination reference, 2; 1; 0 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.

E. SinkTrail Protocol

The proposed SinkTrail protocol can be readily extended to multisink scenario with small modifications. When there is more than one sink in a network, each mobile sink broadcasts trail messages follows. Different from one sink scenario, a sender ID field, msg.sID, is added to each trail message to distinguish them from different senders. Algorithms executed on the sensor node side should be modified to accommodate multisink scenario as well. Instead of using only one trail reference, a sensor node maintains multiple trail references that each corresponds to a different mobile sink at the same time. Fig. 5 shows an example of two mobile sinks. Two trail references, colored in black and red, coexist in the same sensor node. In this way, multiple logical coordinate spaces are constructed concurrently, one for each mobile sink. When a trail message arrives, a sensor node checks the mobile sink's ID in the message to determine if it is necessary to create a new trail reference.

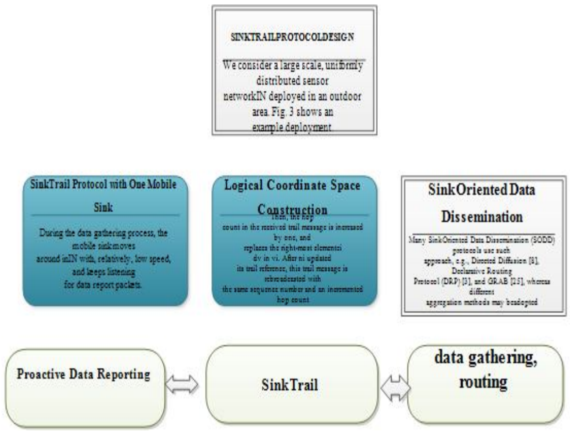


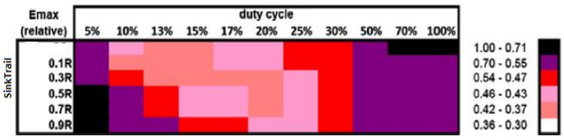
Fig. 4. Class Diagram of SintTrail Protocol

The moving pattern of a mobile sink can affect the energy consumption for data collection, as directional change in a mobile sink's movement is unavoidable due to occasional obstacles depicted. To numerically model the moves conducted by a mobile sink, we trace the moving trail of a mobile sink on a plain and measure the directional change at each trail point. Specifically, suppose at some time the mobile sink arrives at trail point we define the angular displacement as the angular variation of moving directions.

F. Overview of Simulation results

Our simulation shows that a sinkTrial can potential reduce Emax compared to Ebar at the center of the sensor field in particular for longer duty cycle.

Table. 1. Reference value for the SinkTrail at 0.9R with Emax



We see that for constant duty cycling the Emax ratio exbit a convex behaviors with various. Exceptions are the extreme duty cycling values, where there is less influence of the Emax ratio. For constant SinkTrail, the Emax ratio also has a convex shape with a clearly visible optimal range for the duty cycle value.

Table. 2. Reference value for the SinkTrail at 0.9R with Ebar

We see that for Ebar this ratio increases for constant duty cycling value with the sinkTrail. The ratio has a convex shape with a clearly visible optimal range for the duty cycle value. For increasing SinkTrail range for the duty cycle value.

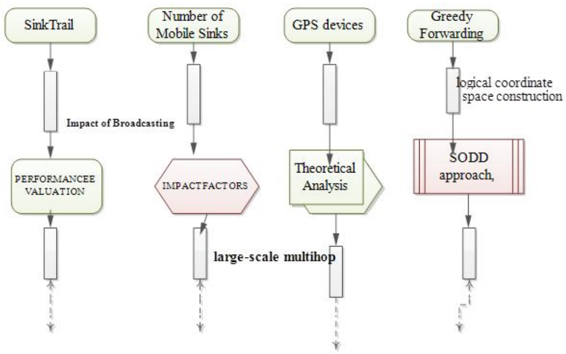


Fig. 5. Sequence Diagram of SintTrail Protocol

The optimal duty cycle value of the nodes in general increases monotonically with the mobility radius of the sinkTrail. In terms of Exam, the energy-optimal duty cycle value increased from around 13% for a sinktrail to around 20% for a sinktrial at a optimal duty cycle.

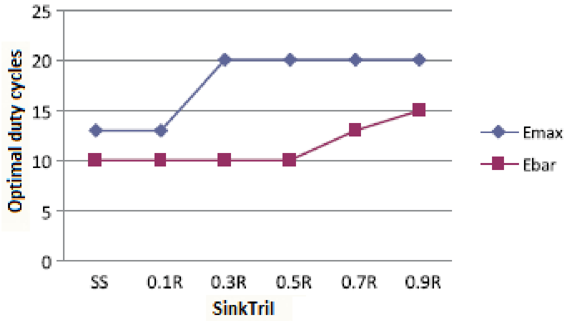


Fig. 6. Energy-optimal duty cycle value

CONCLUSION

We have reviewed what has been researched in SinkTrail and its improved version, SinkTrail-S protocol, two low-complexity, proactive data reporting protocols for energy-efficient data gathering. SinkTrail uses logical coordinates to infer distances, and establishes data reporting routes by greedily selecting the shortest path to the destination reference. In addition, SinkTrail is capable of tracking multiple mobile sinks simultaneously through multiple logical coordinate spaces. It possesses desired features of geographical routing without requiring GPS devices or extra landmarks installed. SinkTrail is capable of adapting to various sensor field hapes and different moving patterns of mobile sinks. Further, it eliminates the need of special treatments for changing field situations. We systematically analyzed energy consumptions of SinkTrail and other representative approaches and validated our analysis through extensive simulations. The results demonstrate that SinkTrail finds short data reporting routes and effectively reduces energy consumption. The impact of various design parameters used in SinkTrail and SinkTrail-S are investigated to provide guidance for implementation. We are currently working with collaborators in the GreenSeeker system. Through one-hop sensing, the GreenSeeker system applies the precise amount of Nitrogen adaptive to spatial and temporal dynamics of the farmland, increasing yield and reducing Nitrogen input expense. The SinkTrail protocol can be further integrated with the GreenSeeker system to enable large-scale multihop sensing on demand and automate spray systems for optimal fertilizer and irrigation management.

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