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Improving Network Lifetime Using a Mobile Sink with a New Energy Efficiency and Minimum Delay Movement Strategy for WSNs

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ABSTRACT

In this paper, we focus on maximizing lifetime of a Wireless Sensor Network (WSN) using a mobile sink with a new movement strategy. We have considered a hierarchical network with some clusters that cluster heads are responsible for collecting data from their own clusters. We have proposed an energy formula that determines the moving times of sink based on residual energy of sensor nodes. Furthermore, we have used an approach to calculate optimum path, if sink recognizes that it must move. With our new strategy, we can see that network life time is increased extremely.

KEY WORDS: Clustering; Energy efficiency; Minimum delay; Mobile sink; Wireless Sensor Network (WSN).

I. INTRODUCTION

Wireless sensor networks (WSNs) can be seen as a large collection of small wireless devices that can organize themselves in an ad hoc network capable of sensing environmental conditions within their range and have constrained energy, processing and communication resources. After the sensing phase, a sensor node needs to transmit the data to a base station, where an application will process the data. However, a wireless sensor network usually lacks infrastructure and sensor nodes must organize themselves in order to create routes that lead to a sink. Therefore, WSNs perform multi hop data propagation in order to relay data to a static base station (or data sink) [1]. In a static sensor network deployed for periodic data reporting if sensors are uniformly deployed, then the sensors near the sinks consume more energy than those deployed in other parts of the monitored area and will die first. This is because besides sending their own sensed data, they also participate in forwarding data on behalf of other sensors that are farther away from the sink and thus they will deplete their energy more quickly [2,3], so the lifetime of the sensors close to the sink becomes the bottleneck for the network lifetime. One of the pivotal parameters considered in designing the protocols for WSNs is network lifetime. Substantial improvement in network lifetime can be achieved: (1) by reducing the number of hops travelled by an event packet to reach its destination (i.e., a BS) and (2) by reducing the energy consumption across all the nodes in the network [4]. The reminder of this paper is organized as follows: section 2 presents a review of mobility support for WSNs. Section 3 is our networks model and assumptions in this work. Then we present our strategy and also the details of the sinks movement approach in section 4. Finally we conclude the paper in Section 5.

II. RELATED WORK

WSNs usually contain two types of nodes: sensor nodes and sink (or base station) nodes. A sensor node is a small device that has limited power, sensing and computation capabilities, while a sink node has more resources in terms of power, computation, and mobility. Sometimes sensor nodes are grouped in clusters using various mechanisms and one of the sensors is selected as cluster head based on various criteria. A cluster head manages the sensors in its cluster, gathers information from them, and forwards data to/from the sink [5]. There are two different types of algorithm: (1) algorithms where sinks are moving on predetermined paths and (2) algorithms where sinks move autonomously. In this section, we review the related work on mobile sinks for data collection in WSNs. In [6], the authors consider only one mobile sink that moves through a straight line while collecting data from the sensor nodes, as can be seen in Figure1. This approach reduces the number of hops a packet has to travel in order to reach the sink and it also saves energy and increases network lifetime. The sink broadcasts an interest message to the neighboring sensor nodes while moving through the straight line. The sensor nodes will receive the interest message and possibly forward to their own neighbors. Each sensor node will start

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transmitting data to the mobile sink when an event matches the sink's interest. They uses acknowledgments to make sure the sink has received the packet successfully, and a sensor node will transmit other packets only after it has received an acknowledgment message from the sink.

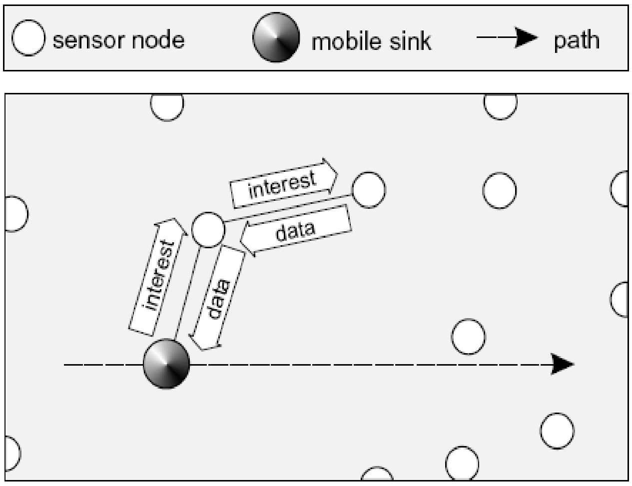

Figure1. A mobile sink moving along a straight line [6]

Luo et al. propose a solution to minimize energy consumption in a wireless sensor network with a mobile sink [7]. In this way, the nodes located close to it change over time. Data collection protocols can then be optimized by taking both base station mobility and multi-hop routing into account. They assume that the sensors are deployed within a circle and conclude that the best mobility strategy is the periphery of the network, Figure2. Then consider jointly mobility and routing algorithms in this case, Figure3, and show that a better routing strategy uses a combination of round routes and short paths.

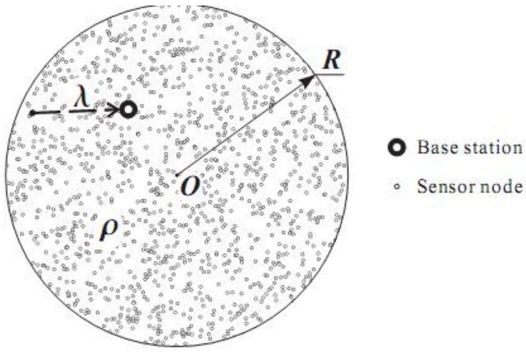

Figure2. Joint mobility and routing strategy [9]

In [8], the authors present a routing protocol, MobiRoute, to support wireless sensor networks with a mobile sink. In their approach, the movement trajectory consists of several anchor points between which the sink moves and at which the sink sojourns. The sink visits certain anchor points in the network area and remains still while collecting data at each one of them. The sink samples the global power consumption of all nodes while stationed in an anchor point. It uses this data to create power consumption profiles and calculate the optimal resting time at each anchor point. Another approach that optimizes the sink's trajectory is presented in [9]. They consider a mobile data observer, called SenCar, which could be a mobile robot or a vehicle equipped with a powerful transceiver and battery, works like a mobile base station in the network. SenCar starts the data gathering tour periodically from the static data processing center, traverses the entire sensor network, gathers the data from sensors while moving, returns to the starting point, and, finally, uploads data to the data processing center. Sensors in the network are static and can be made very simple and inexpensive. They upload sensed data to SenCar when SenCar moves close to them. They show that the moving path of SenCar can greatly affect network lifetime. Then present heuristic algorithms for planning the moving path/circle of SenCar and balancing traffic load in the network. Furthermore, SenCar can avoid obstacles while moving.

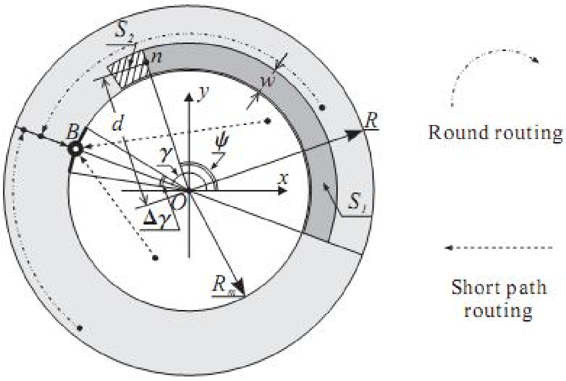

Figure3. JMR network model [9]

In [10], the authors explore predictable sink mobility in order to save energy in a WSN. They model the data collection process as a queuing system, where random arrivals model randomness in the spatial distribution of sensors. Data is pulled by the sink by waking up the sensor nodes based on proximity. The sink broadcasts a beacon message continuously while traveling through the network. Sensor nodes listen to the wireless channel periodically in order to check if there is any sink nearby. Then, the sink sends a wake up signal to the nodes it knows to be within range. The sensor nodes predict when the sink is likely to be nearby and start listening to the wireless channel. In [11] the authors presented 3 protocols that exploit sink mobility in order to improve overall network performance. Each protocol assumes different degrees of mobility and is combined with an appropriate data collection protocol. These protocols are based on randomized methods and introduce a novel approach in loose coordination. One of the challenging issues investigated in this paper is the design of a protocol for WSNs using multiple mobile data collectors that offer low latency event delivery for emergency preparedness applications. Saad et al. [12] present a solution to the problem of planning an arbitrary moving trajectory for a mobile sink in hierarchical structure sensor networks. The mobile sink traverses the entire network uploading the sensed data from cluster heads in time driven scenarios. The mobile sink trajectory is planned such that all heads require no multi-hop relays to reach the mobile sink. The proposed system aims at extending the lifetime of the sensor network by achieving a high level of energy efficiency and fair balancing of energy consumption across all network heads. An autonomous moving strategy (AMS) that applies to a WSN consisting of many sensor nodes and a mobile sink in charge of gathering sensed data periodically is proposed in [13]. Both sensor and sink nodes are aware of their location. Each data gathering period consists of three phases: (1) the sink sends a notification message to inform sensor nodes of its position, (2) sensor nodes report their data to the sink through a multi-hop path by employing a location-based routing algorithm, as both the sink location and the neighbors locations are known, (3) the sink decides its new location-based on the sensors energy levels gathered in the previous phase and arrives at the new location before the next gathering period starts. Wang et al. [14] propose a solution for increasing WSN lifetime by employing adaptive location updates for the mobile sink. Each node and the sink know their own location and the location of their one hop neighbors. After network deployment, the sink broadcasts its location information to the entire network. The routing process is divided into two stages: (1) data packets are forwarded from sensor nodes to a destination area, denoted DNA, and (2) data packets are forwarded to the sink in the destination area. When a sensor node has a data packet to send to the sink, it will first forward it to a node in the small area centered to a virtual center (VC). When the data packet reaches DNA, the second routing stage begins. The packet is forwarded to the sink based on a topology-based routing protocol, instead of being flooded within the destination area. Initially, VC has the location of the sink and the destination area is a disk with the center in VC and fixed radius. If the sink moves within the destination area, then it has to broadcast its location only within the destination area. Otherwise, the new sink location information has to be flooded in the whole network and a new destination area has to be built.

III. NETWORK MODELS AND ASSUMPTIONS

We consider a hierarchical architecture with a number of clusters that each cluster has one cluster head (CH) and a number of sensor nodes. Our network has one mobile base station (sink). Figure4 depicts the network model considered. The following are the assumptions in our work:

- Our network is a heterogeneous WSN that consists of a large number of sensor nodes with limited capabilities and a mobile sink with unlimited capability.
- Sensor nodes are static.
- Each CH knows its location.
- Sink is aware about the number of cluster heads in network.
- We consider a periodic data gathering application where the sensor nodes periodically send sensed event packets to their cluster head via multi-hop communication. Each CH has a cluster of sensor nodes reporting to it.

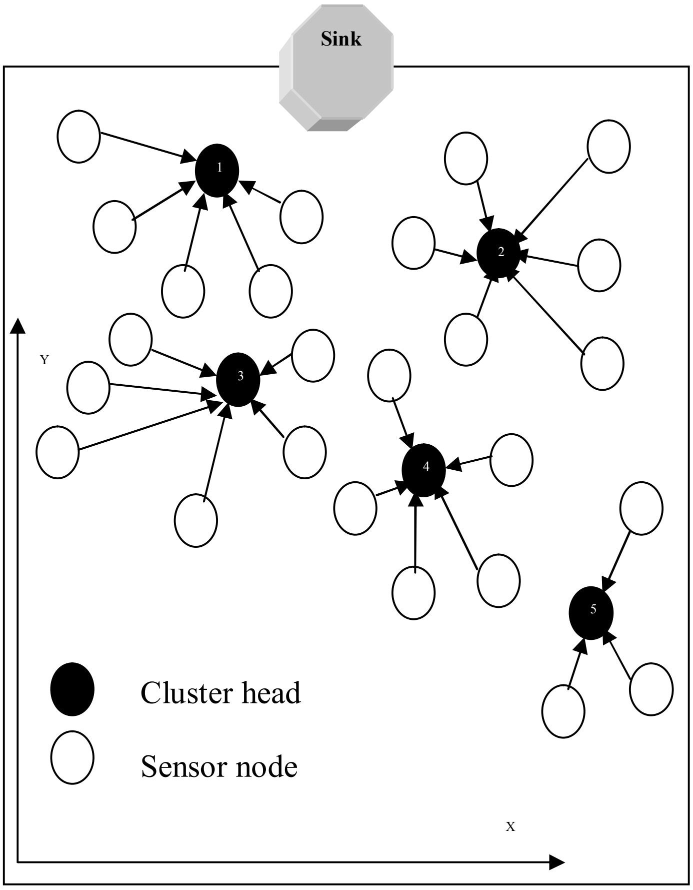

Figure4. Clustered sensor network model

IV. MOBILE DATA GATHERING STRATEGY

Problem statement: Given a heterogeneous WSN of static sensor nodes, and a mobile sink, find a movement strategy of the sink such that minimum delay is provided for the aggregate event packets while maximizing the network lifetime.

The Energy Consumption Model

In this section, we have proposed a formula for energy consumption. We believe that in WSN, the total energy consumption of the active nodes during data gathering operation is made up of these parts: the energy consumption by each node to forwards and processes the received packets, clustering period, the period of sending aggregated data by cluster heads, mean number of hops between cluster heads and sink node, the number of cluster heads. The simplified energy consumption model for each round of clustering for sends aggregate data from all cluster heads to sinks can be defined as:

$$e \times \frac{T}{t} \times n \times N_{ch} < \sum_{i=1}^{k} Er_i \qquad (1)$$

where e is the energy consumption by each node to forwards and processes the received packets, T is the clustering period , t is the period of sending aggregated data by cluster heads, n is mean number of hops between cluster heads and sink node , and N_{ch} is the number of cluster heads. Er_i is the residual energy of median node i, and k is total number of median nodes that participate in forward aggregated data packet from cluster heads to sink. In formula(1), the right side shows total residual energy of median nodes that participate in forward aggregated data packet from cluster heads to sink, and k in sigma is equal to : $k = n \times N_{ch}$, the left side gives total energy consumption of WSN during one round(T), for forwarding an aggregated data packet from cluster heads to sink.

At the beginning of each clustering period (T), sink has to calculate the threshold T_r as follows:

$$T_r = e \times n \times N_{ch} \qquad (2)$$

Moreover, at the beginning of each aggregation period (t), sink must calculate total residual energy of median nodes that participate in forward aggregated data packet from cluster heads to the sink, if this residual energy was greater than the threshold, T_r, it does not need to sink movement, otherwise it must begins a movement according to an optimum round that is calculated at the beginning of T. Formula (3) shows this comparison:

$$\sum_{i=1}^{k} Er_i > T_r \qquad (3)$$

Predefined Movement Strategy: Find an Optimum Hamiltonian Round

In formula (3) if residual energy is less than the threshold T_r then sink should move to gathering all data from CHs. In this paper, we would have considered an optimum Hamiltonian round that is calculated by sink according to Euclidean distance table. This table is provided by sink, at the beginning of each clustering period as follows: Sink broadcasts a CH-LOCATION message to supply primary information about CHs location. Each CH that received this message creates a message of its Cartesian coordinates and sends it to the sink. After receiving messages from all CHs, sink calculates Euclidean distance between each CH and other CHs, as well as between each CH and itself according to distance formula:

$$d(i,j) = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \qquad (4)$$

Where x_i, x_j, y_i, y_j are Cartesian coordinates of two cluster heads, CH_i, CH_j .

Then sink executes an optimum Hamiltonian round by Euclidean distances table that traverse all CHs and return back to its first location.

Description and Finding Optimum Hamiltonian Round in an Instance WSN

In figure4 an instance of wireless sensor network is depicted. In this section we show that the sink node how calculates an optimum Hamiltonian round at the beginning of each clustering period. Assume that Cartesian coordinates of all CHs in network in figure4, are in table 1.

Table 1. Cartesian coordinates of all CHs and sink in figure4

	X	Y
sink	5	10.5
Ch1	3	9.3
Ch2	7.5	8.2
Ch3	3.5	6.5
Ch4	6	5.4
Ch5	8.9	3.5

Beginning of sink, to find an optimum Hamiltonian round that traverses all CHs, two following steps should perform:

Step1. Create Euclidean distances table

Sink should form Euclidean distances table using formula (4). In this illustration the Euclidean distances table is showed in table2.

Table2. Euclidean distances related to table1

	Sink	Ch1	Ch2	Ch3	Ch4	Ch5
Sink	0	5.4	11.5	18.2	27	53
Ch1	5.4	0	21.4	8	24.2	68.4
Ch2	11.5	21.4	0	18.8	10	24
Ch3	18.2	8	18.8	0	7.4	38
Ch4	27	24.2	10	7.4	0	12
Ch5	53	68.4	24	38	12	0

Step2.Finding optimum Hamiltonian round

In this step sink finds an optimum Hamiltonian round. We have applied a dynamic algorithm like travelling salesman algorithm that sinks should execute it at the beginning of each clustering period to find optimum round. Beginning of sink, we have executed this algorithm on table2 data and it finds two following optimum rounds:

1) sink →1→ 3 →4 →5 →2→ sink
2) sink →2→ 5→ 4→ 3→ 1→ sink

Conclusion

In recent years, wireless sensor networks have been showing their important role in a variety of applications that require fast response. Most solutions are focused in static sinks. It has already been shown in the literature that static sinks perform poorly in terms of network lifetime and delivery delay. In this paper, we have proposed an energy consumption formula that determines the moving times of sink based on residual energy of sensor nodes. Also we have used a travelling salesman algorithm to find an optimum Hamiltonian round that it must perform by sink at the beginning of each clustering period. Our new approach has contributions to reducing packet delivery delay and increasing network lifetime with little overhead. Our mobile sink strategy is responsible for reducing the number of hops that a data packet must traverse.

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