

Employing Sink Mobility for Energy Efficient Data Collection in Wireless Sensor Networks

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Abstract— A wireless sensor network (WSN) is comprised of small, low powered self-organizing sensor nodes, densely deployed in the area to be monitored. WSN is a high scalable network deployed over a large area of interest for various applications. Since all sensor nodes are energy constrained, it becomes all more important to reduce the draining of energy of those nodes closer to the sink, simply because they are in the path of data propagation towards the sink. Further, the sink's neighboring nodes would drain their energy faster leading to disconnected network. With a mobile sink, the nodes around the sink always changes, thus balancing the energy consumption in the network and improving the network lifetime. We evaluate the effect on Network Lifetime in wireless sensor networks due to the movement of sink in random walk and predefined path.

Index Terms—Wireless sensor networks, Mobile sink, Network Lifetime, energy efficiency, Random Walk, Predefined path.

I. INTRODUCTION

Wireless Sensor Networks have become an emerging technology that has a wide range of potential applications [1] including environment monitoring, object tracking, scientific observing and forecasting, industrial, security surveillance, medical, environment and weather monitoring, traffic control and etc. A WSN consists of a large number of distributed nodes that organize themselves into a multi-hop wireless network and typically these nodes coordinate to perform a common task. As sensor devices are battery powered, energy is the most precious resource of a wireless sensor network, since replacing the battery of the nodes in large scale deployments is infeasible. Wireless sensor networks 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 sensing data, 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. Data collection is usually performed by the sensors relaying data towards a static control center (sink). Important issue is that, sensor nodes

closer to a sink tend to consume more energy than those farther away from the sinks. This is mainly because, besides transmitting their own packets, they forward packets on behalf of other sensors that are located farther away. Therefore sensors closer to a sink tend to consume more energy than those farther away from the sinks. As a result, the sensor nodes closer to the sink will drain their energy resources faster than other nodes leading to disconnected and dysfunctional network. Hence WSN lifetime can be significantly improved if the energy spent in data relaying to the sink is reduced. The use of mobile sink that can collect information from the sensor network while moving within the monitored area can lessen energy dissipation of those nodes closer to the sink. A mobile sink approach will not only remove the burden of the nodes closer to a sink, but it will provide a mechanism to reach and collect data from network areas that are disconnected, thereby increasing network lifetime. In this paper, we study the problem of extending network lifetime using mobile sink under random walk and predefined path mobility pattern. The effect of mobile sink on the overall performance is studied using performance metrics like latency, success rate, and energy under different mobility pattern. The rest of the paper is organized as follows: Related Work is discussed in section II, Sink mobility models in section III, proposed work is discussed in Section IV, Simulation results is discussed in Section V and finally, conclusions and future work are in Section VI.

II. RELATED WORK

In this section, we review the related work on mobile sinks for data collection in WSNs. The Lifetime of the Network can be significantly improved if the energy spent in data relaying especially those nodes closer to the sink is reduced. One way to avoid this is to use sink mobility. When the energy of the sensor nodes near a sink becomes low, the sink can move to a new location where energy of the sensor node is higher. By this method there will be balance in the energy consumption and will increase network lifetime. This approach is discussed in [4] with one mobile sink. Another approach [6] explores the impact of predictable sink movement when the sink is mounted on a bus moving on a predictable schedule. Data is pulled by the sink which wakes up the nodes when it gets closer to them. In [7], the authors consider only one mobile sink that moves through a straight line while collecting data from the sensor

nodes. 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. Gandham *et al.* [3] present sink relocation solutions for energy efficiency in WSNs with multiple mobile sinks. The best positions for the mobile sinks are computed using LP programming. As in [3], Vass *et al.* [5] and Azad *et al.* [8] also propose centralized methods based on mathematical programming to compute the best locations for the mobile sinks. Since these methods are off-line and centralized, the locations of all sensors and sinks are assumed to be known beforehand. Vincze *et al.* [9] propose adaptive sink mobility for energy efficiency in WSNs for event-driven application. Network-wide broadcasting is employed to propagate the location of the mobile sink. In [10] and [11], network-wide broadcasting is used to update the topological changes. In our proposed work, we have compared and studied the effect of mobile sink under random walk and random waypoint mobility pattern on Network lifetime. We have also as studied the impact on performance metrics like success rate, delivery delay and energy when sinks move on a predetermined path.

III. SINK MOBILITY

A. Mobility pattern of the sink

There are many different approaches when considering the mobility pattern that the mobile sink should follow. Depending on the application scenario and the network size and conditions, different approaches may yield diverse results and affect drastically the achieved network performance. The mobility models are usually classified in two categories: entity and group mobility models. The entity mobility model describes the movement of an individual node only with no coordination with the movement of other nodes. On the other hand, the group mobility model coordinates the movement of the nodes as a group. In our approach, the sink node move randomly according to two different mobility patterns: the Random Walk Mobility Model and Random Way Point.

1) *Random Walk Mobility Model*: It is a simple mobility model based on random directions and speeds. In this mobility model [12], a node moves from its current location to a new location by randomly choosing a direction and speed in which to travel. The new speed and direction are both pre-defined. The movement in the Random Walk Mobility Model occurs in either a constant time interval t or a constant distance traveled d , at the end of which a new direction and speed are calculated. If a node which moves according to this model reaches a simulation boundary, it “bounces” off the simulation border with an angle determined by the incoming direction. The MN then continues along this new path. This characteristic ensures that the random walk represents a mobility model that tests the movements of entities around their starting points, without worry of the entities wandering away never to return.

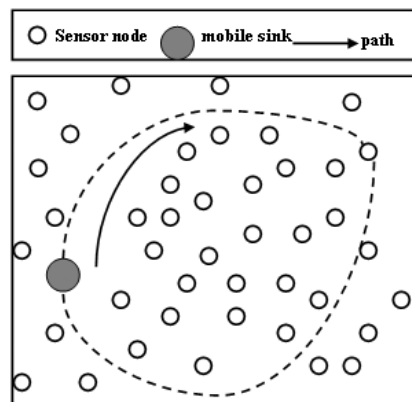


Fig. 1. A mobile sink moving in a random motion

2) *Predefined path*: In this mobility model the sink traverses the same path through network area. The trajectory of the path could a straight line or a circle and is fixed. The movement of the mobile sink follows a certain pattern that can be compute. 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. Data is collected by the mobile sink when it traverses through the region by waking up the sensor nodes. This helps in achieving energy efficiency when the sensors operate between a low power sleep mode and normal operation. The sensor nodes could monitor network conditions, and adapt the length of each period accordingly so that energy savings are achieved even in a highly dynamic network.

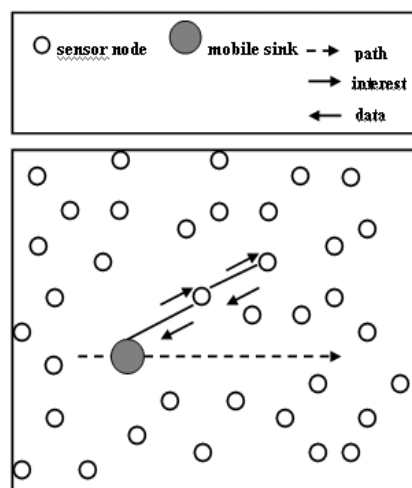


Fig. 2. A mobile sink moving along a straight line

IV. PROPOSED WORK

A. Motivation

WSN is a high scalable network deployed over a large area of interest for various applications. All sensor nodes are energy constrained. In a typical WSN scenario, all the data are routed back to the only static sink. Therefore, those nodes near the sink have to forward all the data from farther nodes and thus carry a heavier traffic load. This is the many-to-one traffic pattern of WSNs. Consequently, the nodes near the sink are more susceptible to energy exhaustion. When these nodes use up all their energy, no more data can be transmitted back to the sink, causing dysfunctional or disconnected network or premature lifetime ending of WSNs. In order to distribute the energy consumption uniformly across the network, using a multiple mobile sinks is a solution. The nodes near the sink change as the mobile sink moves.

B. Wireless sensor network model

We consider a scenario of deploying N wireless sensor nodes in a square area A . The sensor nodes are randomly scattered across the region A . There is mobile sink S which is responsible for collecting data from all sensor nodes and it acts as a gateway for the sensor network. A sensor node communicates with its one-hop neighbors using its wireless radio resources. The sensor nodes do not have global knowledge of the network. Each node and the sink are assumed to have transmission range R . The sensor nodes relay data to the sink in a multi-hop fashion. At any given time, each sensor node can be in one of three different modes, regarding the energy consumption: (a) transmission of a message, (b) reception of a message and (c) sensing of events. The energy model in our approach is as follows. The initial energy of each sensor node is α ($\alpha > 0$), while the sinks have no energy constraint. We assume that a sensor node consumes E_1 units of energy when sending one bit, while depletes E_2 units of energy when receiving one bit where $E_1 > E_2 > 0$. Therefore, for the case of transmitting and receiving a message, we assume that the radio module dissipates an amount of energy proportional to the message's size. For the idle state, we assume that the energy consumed is constant E_{idle} . We have made an assumption that the mobile sink is not resource constrained, i.e., it is assumed to be powerful in terms of computing, memory and energy supplies. *Network Lifetime* is defined as the duration from the very beginning of the network operation until the first node uses up its energy.

C. Data transmission scheme

In our work, we evaluate the performance metrics like delivery delay, energy dissipation and success rate of mobile sink under Random Walk and Random Way Point. First we consider the simplest of all possible mobility patterns i.e. random walk, wherein the mobile sink can move randomly towards all directions at varying speeds. We define S_{random} as a function that implements random walks in our scenarios. At each invocation S_{random} selects a random uniform angle in $[-\pi, +\pi]$ radians. This angle defines the deviation from the mobile sink's current direction. The speed of the movement is constant and predefined. The new position is determined by S_{random} which selects a uniform random distance $d \in (0, d_{max})$ which is the distance to travel along the newly defined

direction. In case the new position falls outside the network area, then S_{random} makes the position to fall on the boundary of the area. This is the simplest possible movement and also no network knowledge is needed. This method is very robust, since it guarantees visiting all sensor nodes in the network and also collecting data even from disconnected areas of few/faulty sensors or under the presence of obstacles. However this model may become inefficient, mostly with respect to latency. Data is collected in a passive manner, sensors cache all recorded data. Periodically a beacon message is transmitted from the sink. Each sensor node that receives a beacon attempts to acquire the medium and transmit the cached data to the sink. Transmitted data is then removed from a sensor node cache to free the memory for storing incoming sensed data. This method may lead to many collisions, when the sink visits a dense area. Thus, an appropriate MAC layer protocol with an efficient back off function is essential for the proper deployment of this protocol. This approach minimizes energy consumption since only a single transmission per sensed event is performed. However latency may increase due to long intervals between visits to the sensors. Another mobility pattern Random waypoint is performed by using a pause time between changes in destination and speed. A node begins by staying in one location for a certain period of time (i.e., a pause time). Once this time expires, the node chooses a random destination in the simulation area and a speed that is uniformly distributed between the areas according to their connectivity. The speed of the movement is constant and predefined. In this model, because of the pause time, the mobile sink could collect more data as it gives more time for the nodes to propagate the data forwarded to the sink.

V. SIMULATION RESULTS

A. Simulation scenario and metrics

In order to evaluate and validate the performance of our proposed work we have implemented and carried out simulation in NS-2 [13]. We have scattered 100 sensor nodes across an area of 150×150 m. All nodes have radio range of $R = 25$ m. The power dissipation of idle periods was set to zero to evaluate the energy consumption from the different approaches because idle time dissipation dominates the simulation and it would be difficult to compare the results. The number of data source nodes is set to 50, and they are chosen randomly from the sensor field. Each source node generates 2 packets per second during the entire simulation. The packet size is 32 bytes for all types of messages except DATA packets, which are set to 64 bytes. We have varied the number of Mobile sinks in multiplication of 2. A summary of our simulation parameters is shown in Table 1. The performance was evaluated from different aspects, but always focusing on end to end delay and energy consumption. The metrics used were:

1. Average End-to-End delay: The end-to-end packet delivery delay measured in seconds from the source node to the mobile sink.
2. Success rate: the ratio of packets received successfully at the mobile sink.
3. Average energy consumption: the energy dissipated per node in joules.

TABLE I
SUMMARY OF SIMULATION PARAMETERS

Parameter	Value
Number of nodes (N)	75
Simulation Area (A)	200x200
Wireless radio range	25m
No of source nodes	50
Source node data rate	2pkts/s
No of Mobile sinks	Variable
Mobile sink velocity	5m/s
Packet size	512Bytes
DATA packet size	64Bytes
TX power dissipation	0.660W
RX power dissipation	0.395W
Idle power dissipation	0.035W
Initial Energy	3.1 Joules

B. Simulation results

Our experimental results show the effect of sink mobility on end-to-end delay and energy dissipation of a node with respect to increase in the number of mobile sink. It is seen from Fig. 3 that as the number of mobile sink increases the end to end delay decreases in both random walk and in predicted path movement of sink. The reason is because the sensor nodes have various possibilities to send data packets to reach any one of the mobile sinks in a shortest path and in short duration. Also, more number of mobile sink makes the congestion less thereby reducing average end to end delay. An interesting observation i.e. found in Fig. 4 is that predefined path of sink takes more average end to end delay compared to random walk. The reason is that the nodes which have predetermined sink movement have to wait that much amount of time to again reach the same point in the network area whereas in random the sink could reach at any time to collect data. Also another important reason is random walk movement has more coverage area i.e. it could cover more area to collect data compared to predefined path whose coverage area is fixed. The slight increase in energy in random walk could be attributed to the fact that as the number of mobile sink increases, the control packets in the network also increases. In case of predefined path the energy dissipation becomes lesser since the nodes have to deliver the data packets only when the sink node approaches and in the remaining time it could go into sleep mode thereby saving energy. Also in case of random movement the nodes have to spend more energy in finding routes to the sink since they constantly change their location. This is not the case with predefined path since they use proactive routing.

VI. CONCLUSIONS AND FUTURE WORK

In a typical WSN scenario, all the data are routed back to a static sink. Nodes near the sink have to forward all the data from nodes that are away from the sink and thus carry a heavier traffic load. Therefore the nodes near the sink are more likely to use up their energy faster than other

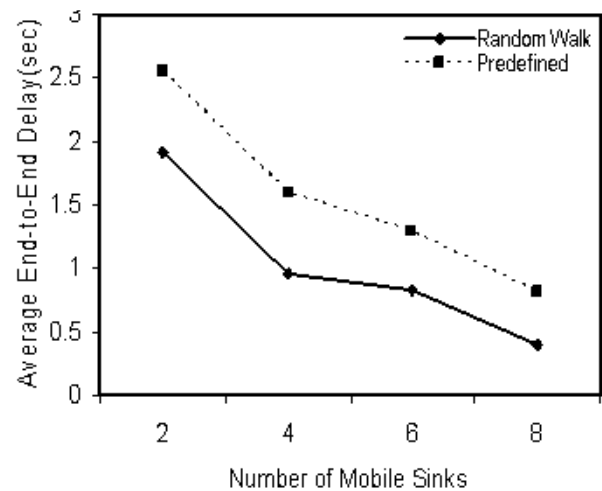


Fig. 3. Impact of mobile sinks on average end-to-end delay.

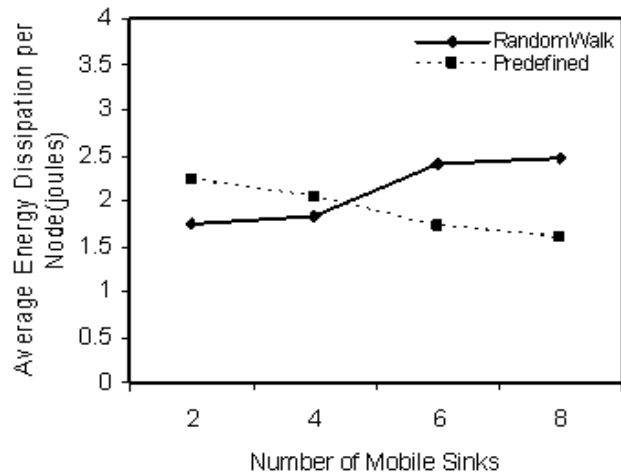


Fig. 4. Impact of mobile sinks on energy dissipation

nodes leading to dysfunctional and disconnected networks. With the introduction of mobile sink, the nodes around the sink always changes, thus balancing the energy consumption in the network and improving the network lifetime. In this paper, we investigate the impact of two mobility schemes Random Walk and Predefined models for mobile sinks in Data-collection sensor networks. Using mobile sink there is reduction in the number of hops that a data has to traverse to reach the destination. The experimental results also confirm that with more number of mobile sinks reduces the congestion at the nodes closer to the sink and thus reduces end to end delay. Also, we have found that among the two mobility schemes Predefined path performs slightly better than Random Walk in terms of less energy dissipation. End to end delay is more in predefined path than random mobility of the sink. We plan to further investigate the effect of the sink speed, network area sizes and sensor node densities on the performance of wireless sensor networks.

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