ENERGY-EFFICIENT ROUTING SCHEME USING MOBILE SINKS IN WIRELESS SENSOR NETWORKS

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Abstract— Energy awareness is an essential design issue in wireless sensor network. Therefore, attention must be given to the routing protocols since they might differ depending on the application and network architecture. It is desired to design the energy efficient routing protocols to conserve the poser supply of sensor node and prolongs its lifetime. Recently sink mobility has been exploited in numerous schemes to prolong the lifetime of wireless sensor networks (WSNs), but sink mobility bring a new challenges in wireless sensor network; such as sink location maintenance, continuous data delivery, avoiding/reducing detour problem etc. In this paper, in order to reduce energy consumption and minimize the overhead of rerouting frequency, we propose an Energy-Efficient Routing Scheme using Mobile Sinks (EERS-MS) in Wireless Sensor Networks. This scheme uses the grid that is constructed by the sink appearing first in the sensor field or when no valid grid exists. In this scheme source(s) utilizes the sink location information to communicate with sink(s). Data is disseminated to the sink through grid nodes (GN) using greedy geographical forwarding techniques. Analytical and simulation study reveals significant improvement in term of both energy efficiency and routing performance in comparison to existing schemes.

Keywords— Wireless Sensor Network (WSN), Sink Mobility, Data Dissemination, Energy Efficient.

I. INTRODUCTION

The Wireless Sensor Networks (WSNs) are made up of wireless nodes endowed with sensing capabilities that are deployed for implementing a host of different applications. Wireless sensor networks (WSNs) are widely used in many industrial and civilian application areas, including industrial process monitoring and control, machine status monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control. Typically, a large number of tiny sensor devices called motes constitute a WSN, where motes are considered as constrained in resources, such as limited on-board memory, short-range radio transceivers and limited battery power. These sensor nodes form a decentralized, multi-hop, self-organized network system. Depending on the application environment, nodes are interfaced with various sensors for monitoring some phenomenon of interest (temperature, humidity, pressure, etc.) and forward the stimulus data to the data centres (Sinks) through multi-hop communication [1][2].

To prolong network lifetime, the energy consumption of individual sensor nodes is important, as well as balanced energy consumption among all the sensor nodes is also desired [3]. In traditional WSNs, sensor nodes are distributed in the sensing field whereupon detecting some event of interest, nodes report the sensed event back to some static sink(s) through single-hop or multi-hop communication. One major drawback of such communication infrastructures is occurrence of hot-spot or sink-hole problem in the neighborhood of the sink(s). This is because sensor nodes close to the static sink will consume more energy and thus their energy will deplete quickly. To overcome hot-spot or sink-hole problem, the concept of mobile sink was introduced in WSN[4], that not only results in balanced energy consumption among the nodes but can also be exploited to connect isolated segments of the network. The mobile sink(s) are more energy efficient than the static, but has the additional overhead such as sink's location maintenance, continuous data delivery and dynamic route adjustments with sink mobility[5][6].

There are various routing protocols proposed for WSN in order to deal efficiently with the sink mobility [7,8,9]. The mobile sink has the multifold advantages like hotspot problem removal, energy efficient, longer network lifetime etc., but also include new challenges such as sink location management and dynamic route adjustments. There are many protocols developed for WSN, which support the mobile sink(s) such as Directed Diffusion [10], GEAR[11], GBR [12]. These protocols maintain the location of the mobile sink by continuously propagating the location of the sink throughout the sensor network, so that all sensor nodes are updated with the recent location of the sink(s). But frequent updating cause traffic increase in WSN, collision in wireless transmission and more power consumption. TTDD[13] provides two disseminating tiers for large-scale sensor networks with multiple mobile sinks. TTDD architecture exploits the fact that the sensor nodes are stationary and are location aware and queries of multiple mobile sinks are confined within the local only. In TTDD, on event detection each source node proactively constructs a grid throughout the sensor field. Therefore, as number of sources increases, the data dissemination point management overhead increases considerably. Similarly, ALS[14] protocols also uses the virtual grid structure to find the location of mobile sinks. On occurrence of an event, the source node will register itself with the nearest source agent. The source agent will send four query packets in orthogonal directions to find the location of the sink agent. Once the source agent receives the sink agent's location, it forwards it to the source, which finally sends the data packets to the sink agent using the GPSR protocol [15]. This protocol has some drawbacks such as source can't identify the location of the sink if it has not constructed the anchor system, detour problem occurs when sink has high mobility, hotspot problem for border nodes. Jeon H. et al. proposed SDLS[16] protocol in 2009, which uses the global grid structure to identify the location of the source node. Upon detecting an event of interest, a source node immediately reports its location information using the Eight-Direction Anchor system. Mobile sinks query the network to collect the location of source nodes. After getting the location of the source node, the sink can directly sends the data request query to the source node with consideration of source node's location and direction of sink's movement. Chi Y. et al. proposed EAGER[17] in 2013, which is based on the virtual-grid structure and keeps one grid head active within each grid cell to disseminate data. EAGER uses a rerouting approach to identify and reconstruct new data dissemination paths between multiple mobile sinks and the source.

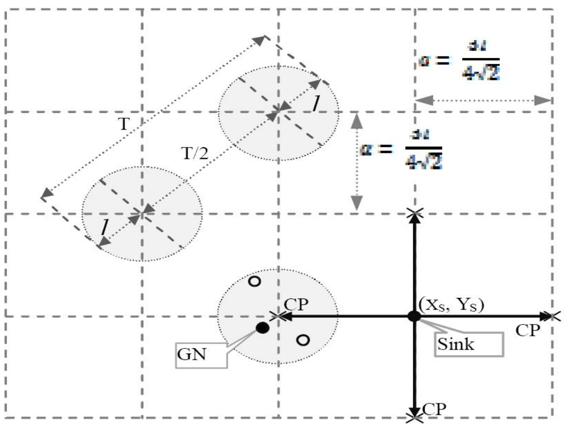

Fig. 1. Grid Construction and Cell Size Determination

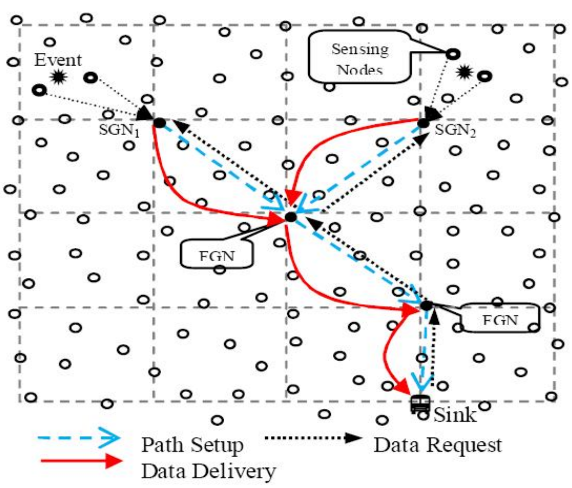

Fig. 2. Data Announcement and Data Delivery.

In this paper, we propose an Energy-Efficient Routing Scheme using Mobile Sinks (EERS-MS) in Wireless Sensor Networks, which disseminates data between the source and multiple mobile sinks in order to prolong the network lifetime. In this scheme, the grid is constructed by the sink appearing first in the sensor field or when no valid grid exists. The Grid Nodes (GNs) are used to forward the data/query between source and mobile sink. This scheme uses the rerouting mechanism for topology change due to mobile sink. In this scheme, the shortest path is used for main data delivery and also has the ability to modify partial or full path to avoid detour problem. Rest of the paper is organized as follows. Section 2 describes the virtual grid construction, determining cell size, initial data path setup, data delivery and handling sink mobility. In section 3, performance of the (EERS-MS) is evaluated. Section 4 concludes the work.

II. ENERGY-EFFICIENT ROUTING SCHEME USING MOBILE SINKS (EERS-MS)

The basic assumption considered for EERS-MS protocol are mentioned below:

- The sensor field is represented as a two-dimensional plane constructed along x-axis and y-axis and divided into equal sized cells.
- The sensor nodes are randomly deployed in two dimensional square fields. The Sensor nodes remain stationary and aware of their geographical location using GPS system or localization algorithm[18]. The coordinates (x,y) obtained thus serve as the node unique node identification number (NodeID).
- Data/query is disseminated using single-hop or multi-hop communication.
- EERS-MS uses the grid that is constructed by the sink appearing first in the sensor field or when no valid grid exists. All other sources and sinks appear thereafter use the same existing grid.
- Each sensor node is aware of its available energy. One or more mobile sinks are deployed in the sensor field to gather data.

2.1 Grid Construction and Cell Size Determination

In EERS-MS scheme, the grid construction is initiated by the sink appears first in the sensor field or when no valid grid exists. Sink starts grid construction process by keeping itself at one of crossing point (CP) of the grid with coordinates (X_S, Y_S). The grid is constructed in same way as mentioned in SLDD[16]. The two dimensional geographical coordinates (x, y) of this sink thus become starting point for formation of grid of square sized cells. In this scheme, the node nearest to the CP and within raduius of l (where l = T/8 and T is the transmission range of a sensor node) from CP is selected as Grid Node (GN). Each GN can communicate with its neighbouring GNs in a single hop communication. Thus, in EERS-MS, the cell size is determined by the radio range of sensor node. As each GN can forward the data to all neighboring GNs in a single hop, therefore, two GNs lying diagonally can't be apart more than their transmission range T as shown in fig 1. Thus, the cell size α is determined as:

$$\alpha = \frac{3T}{4\sqrt{2}} \quad (1)$$

All other crossing points (CPs) located at P = (X_P, Y_P) are calculated using starting point (X_S, Y_S) and cell size α as:

$$\{X_P = X_S + i * \alpha,\ Y_P = Y_S + j * \alpha;\ \} \quad (2)$$

Where i, j= ±0, ±1, ±2, ±3, ……..}

For any GN, all its neghbouring GNs are lying within its transmission range. Therefore, it can communicate with its surrounding GNs in single hop using greedy forwarding method.

2.2 Initial Routing Path Setup

In this section EERS-MS describes the initial routing path setup from source to sink upon occurrence of an event. As grid constructed by sink, therefore, every node in the cell is aware about the location of the sink and the location of the grids nodes (GNs) of the cell in which it lying.

When a sensor node detects an event, it selects the GN that is nearest to the sink. This GN becomes the Source Grid Node (SGN) and responsible for path setup and data delivery to sink. The SHN sends the path setup message to upstream GN towards sink, which in turn further forwards the message to its upstream GN towards sink. This process continues till message reaches at the sink. All intermediate GNs on the routing path are called as Forwarding Grid Node (FGN). If path setup message reaches at a GN that is already acting as FGN, then the message further forwarded through the already existing path leading towards sink.

2.3 Data Request and Data Delivery

Upon the receipt of the data announcing message, sink selects the nearest sensor node as primary agent (PA). PA sends a data request message to the SGN through the reverse path. When SGN receives the data request, it generates the data packets and sends it to PA through the same path in which request message was received as shown in Figure 2. Then PA forwards the data to the sink.

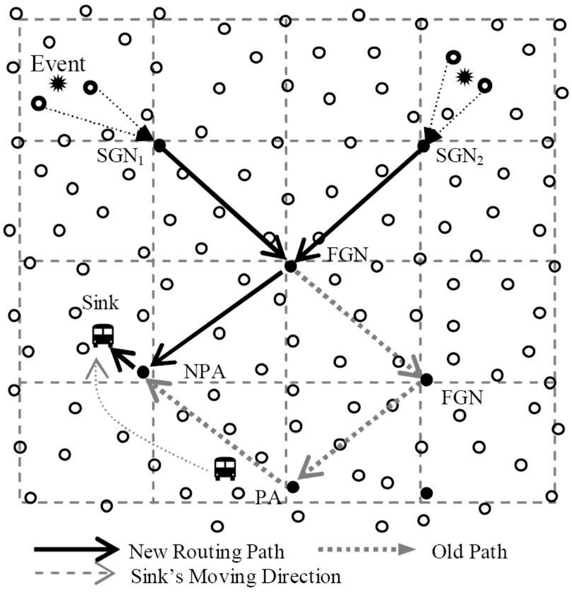

Fig. 3. Handling Sink Mobility

2.4 Handling Sink Mobility

As proposed scheme supports the sink mobility, therefore it is required to maintain the path for continuous data delivery. When sink moves, the node that is nearest initial CP is selected as Primary Agent (PA). PA communicates with the mobile sink while it moves within one hop distance. PA is responsible for receiving he query from the sink and forwards the data to it. Every sink maintain a location information table (LINT) in its cache. Each entry in LINT table contains a tuple of information (Node_Info, NodeID, *hc*). The Node_Info indicated the role of node (i.e. whether node is SGN, FGN, PA or IA), NodeID is location/coordinate a node and *hc* is hop count of node from SGN. Entries in the table are in descending order of hop count (*hc*) from SGN to PA. As *hc* counts the numbers of hops SGN away from GNs. Therefore, h_c for SGN is set to 0 and increment at each hop on routing path toward sink. The table information is updated as and when the route is modified. This table information also helps to avoid the detour problem if occurs.

Table1: Lication Information Table (LINT)

Node_Info	**NodeID**	h_c
SGN	X_{SGN} , Y_{SGN}	0
FGN1	X_{FGN1} , Y_{FGN1}	1
FGN2	X_{FGN2} , Y_{FGN2}	2
PA	X_{PA} , Y_{PA}	3

If sink moves in a region that is within one hop distance from the PA, then there is no change in path. But, when sink moves beyond PA range then it selects the nearest GN as Immediate Agent (IA). If IA is a FGN on the existing path, then it become New PA (NPA) and removes the old upstream path from NPA to PA. If IA is not a FGN, then it sends a message to its neighbor GNs. If any neighboring GN is acting as FGN on existing path except PA, then IA selects the FGN that is nearest to SGN as NPA and removes the upstream path from NPA to PA. Otherwise, IA become NPA and receives the data through old PA. In this situation if NPA also initiate a process to check the detour problem using LINT table. If it finds any detour problem, then it establish new path between NPA and downstream GN from where detour problem occurred. Once new path is setup, the downstream GN sends path termination message through old path. When NPA receives this message, it stops receiving any more data from PA. This will helps to avoid loss of data flowing through old path.

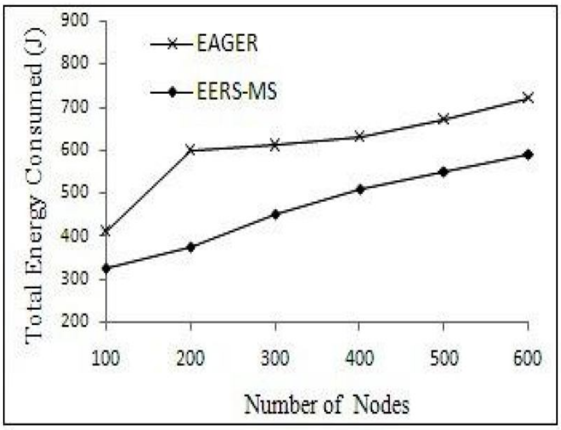

Fig. 4. Total energy consumed for different number of nodes

III. PERFORMANCE ANALYSIS

In this section we eveluate the results of the simulations that were conducted to compare the performance of EERS-MS with the EAGER. The performance of EERS-MS is evaluated by comparing it to EAGER in terms of in terms of total energy consumption, average delay with varying number of nodes, sinks and sink mobility. In this performance evaluation we use the energy model as described by Bhardwaj M. et al. [16]. The key energy parameters are the energy needed to sense a bit (Esense), receive a bit (Erx) and transmit a bit over a distance d (Etx). Assuming path loss in energy model is $1/d^{\eta}$. The default simulation setting has a square sensor field of size 2000 x 2000 m2 in which 200 sensor nodes are uniformly distributed. Some of these sensor nodes act as sources and generate one data packet per second. Simulation model is run 100 times and the observation is based on the varying numbers of sensor nodes, sinks and sinks mobility. There is one or more mobile sink(s) in the sensor field. The size of control/query packet is 36 bytes and data packets are 64 bytes. Path loss is set as $\eta = 2$. The transmission range T of each sensor is 100 m and the value of α is evaluated according to equation (1).

3.1 Effect of node density on total energy consumption

In this subsection we evaluate the total energy consumption with varying node density. The number of sensor node varies from 100 to 600 and four numbers of sinks are moving in the field at a speed of 10 m/s. The total energy consumed by EERS-MS is less energy as compared to EAGER as shown in fig 4. This is because node density doesn’t impact much in case EERS-MS protocol as the data/query communication through GN only. Also, in EERS-MS the sink’s location is used for path setup instead of flooding a route request packet (REQ) as in EAGER.

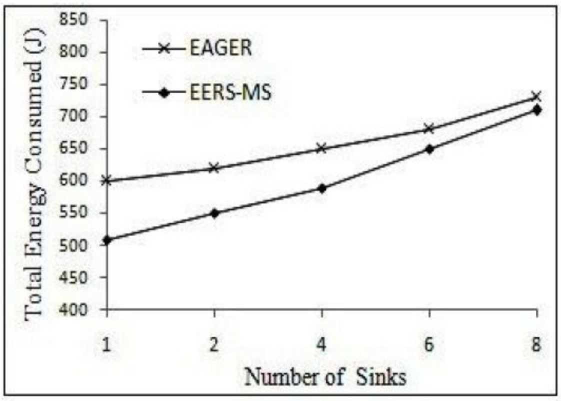

Fig. 5. Total energy consumed for different number of sinks

3.2 Effect of number sink on total energy consumption

Fig 5 shows the total consumed energy for the different numbers of mobile sinks. Number of sinks are varies from 1, 2, 4, 6, 8 whereas the node density in the field is 200 nodes. The total energy consumed by EERS-MS is less energy as compared to EAGER as shown fig 5.

3.3 Effect of sink speed on total energy consumption and avarage delay

In this subsection we evaluate the total consumed energy with varying sink speed. There are 4 sinks in the field and maximum speed of the sinks varies from 5, 10, 15, 20m/s. There are 200 sensor nodes deployed in the field. The total energy consumed by EERS-MS is considerable less as compared to EAGER when speed of sink is below 18m/s as shown in fig 7. But, as sink speed increases EERS-MS consume more energy. Fig 7 shows the average delay with varying sink speed. The EERS-MS has less average delay as compared to EAGER. This is because EERS-MS has the ability to modify partial or full path efficiently to avoid any detour problem.

CONCLUSION

Proposed Energy-Efficient Routing Scheme using Mobile Sinks (EERS-MS) in Wireless Sensor

Network is an energy efficient scheme which prolong the network life time using mobile sinks. In EERS-MS, the grid is constructed by the source node appearing first in the sensor field or when there exists no valid grid. Cell size is entirely determines using the transmission range T, so that any source/sink appears thereafter can detect the valid grid using single hop communication. In this scheme sink location is used to setup up the shortest path between source and sink. Moreover, EERS-MS handles mobile sink very efficiently and maintains the path for continuous data delivery. It also construct/update a partial or new path between source and mobile sink if any detour problem occur thus conversing the sensor node energy and increasing the network lifetime. Simulation results also indicate that EERS-MS consumes less energy as compared to EAGER when observed for different numbers of sensor nodes, sinks, and sink mobility.

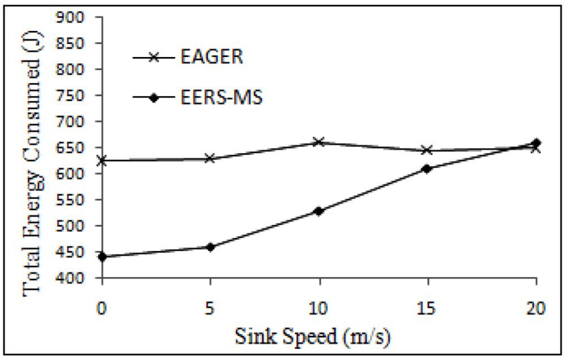

Fig. 6. Total energy consumed for different sink speed.

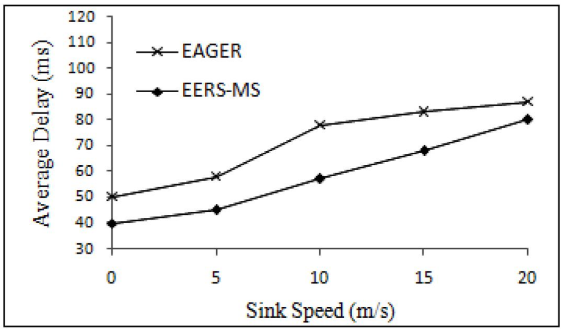

Fig. 7. Avarage delay for different sink speed.

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