An Energy Efficient strategy for Grid-based Data Dissemination supporting Mobile Sinks in Wireless Sensor Networks

Kulwardhan Singh T. P. Sharma

Abstract: ***Wireless Sensor Networks are made up of small sensor nodes with sensing capability. These sensor nodes have limited power supply, computational capability and storage. Due to constrained energy source in wireless sensor nodes, the design and implementation of energy efficient protocols is one of the most important challenge in Wireless Sensor Networks. Mobility of sink in wireless sensor networks brings new challenges in the form sink location maintenance, continuous data delivery, avoiding/reducing detour problem but reduces the hotspot problem. In this paper, we propose an Energy-Efficient strategy for Grid-based Data Dissemination supporting Mobile sinks (EEGDD) in wireless sensor networks which is more energy efficient in data dissemination to the mobile sink. This strategy is based upon permanent virtual grid structure and disseminates data from source to sink using optimal path with minimum path delay. This strategy sends query/data announcements across the certain axis only for tracking the location of the sink and hence avoid huge amount of uncontrolled flooding used in other schemes. Analytical and simulation study reveals significant improvement in energy conservation in comparison to existing scheme.***

Keyword: Wireless Sensor Network, Sink Mobility, Data Dissemination, Energy Efficient.

I. INTRODUCTION

Recent advances in wireless networking, micro-electro-mechanical systems (MEMS) and embedded microprocessors have enabled a new generation of massive-scale sensor networks suitable for a wide variety of applications ranging from large scale habitat monitoring, battlefield surveillance, disaster relief operations to small health care, process monitoring and control etc. A wireless sensor network (WSN) is usually composed of large numbers of sensor nodes. These sensors nodes continuously sense the external environment and send the stimulus data to the data centres (i.e. sinks) through multi-hop communication [1][2]. A WSN can have one or multiple sinks that send query or control commands to the source node and collect the information from source node. Therefore, Energy efficient routing protocols must be designed that consume less energy and prolong the sensor network lifetime [3][4].

The WSN using static sink creates the problem of hotspot in the neighbourhood of the sinks. In many scenarios, the mobile sink is more energy efficient than the static sink, but has the additional overhead such as sink's location maintenance, continuous data delivery and avoiding/reducing data path detour situation [5]. There are many protocols developed for WSN, which support mobile sinks such as Directed Diffusion [8], GEAR[9], GBR [10] etc. These protocols maintain the location of the mobile sink by continuously propagating the location of the sink throughout the sensor network and all sensor nodes are updated with the recent location of sinks. However, frequent updating cause traffic increase in WSN, collision in wireless transmission and more power consumption.

The Two Tiered Data Dissemination (TTDD) protocol [11] provides a scalable and efficient data delivery to multiple mobile sink. It is source oriented and provides the location information of the source nodes. However, in TTDD when multiple events occur, each source node sensing the event proactively constructs its own grid structure even if two or more sources are near to each other. This increases communication and storage overhead in TTDD architecture. As number of sources increases, the data dissemination point management overhead also increases considerably. Anchor Location Service (ALS) [12] protocol also uses virtual grid structure to find the location of mobile sinks. ALS is a grid based protocol that provides sink location information in a scalable and efficient manner. The ALS has its own constraints such as detour problem when sink has high mobility, hotspot problem for border nodes because ALS always uses its border nodes when it provides its sink location. In [14] Joen et al. proposed Sink-oriented Dynamic Location Service (SDLS) protocol solves the problem of ALS. The SDLS protocol uses the Eight-Direction Anchor (EDA) system to find the location of source node. When a event in a grid detected by two or more nodes, they may construct their own EDA system.

In this paper, we propose an Energy-Efficient strategy for Grid-based Data Dissemination (EEGDD) supporting mobile sinks in Wireless Sensor Networks. This strategy uses the global grid structure which provides the location of the Source Head Nodes (SHN) and sink's Primary Agents (PA) in the sensor field in a scalable and efficient manner. When a source/sink appears it selects a Head Node (HN) within cell as SHN/PA. This HN is responsible for data aggregation, selecting Source/Sink agents and forwarding data/query announcement and data/request delivery. In this strategy SHN forwards its location in a straight line along the x-axis and PA forwards the query message in y-axis direction to find the location of the SHN. Once sink gets the location of the SHN, a communicate path is established between SHN and PA

Kulwardhan Singh
National Institute of Technology, Hamirpur
India.
kulwardhan@yahoo.com

T. P. Sharma
National Institute of Technology, Hamirpur
India.
teekparval@gmail.com

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using Greedy Perimeter Stateless Routing (GPSR) [13] protocol for query and data delivery.

Rest of the paper is organized as follows. Section II describes the virtual grid construction, selecting head node, query and data announcement, data delivery in the proposed work. In section III, performance of the EEGDD is evaluated. Section IV concludes the work.

II. PROPOSED ENERGY-EFFICIENT GRID-BASED DATA DISSEMINATION (EEGDD)

Basic assumptions for EEGDD protocol are as follows:

- Sensor field is represented as a two-dimensional plane and is divided into equal square sized cells.
- The sensor nodes are randomly deployed and are stationary. Nodes are aware of their geographical location using global positioning system (GPS).
- Single-hop communication is used for data transmission between proximate sensor nodes and long distant data delivery is accomplished by multi-hop communication.
- EEGDD constructs a single global grid structure by assigning sensors nearest to the grid points as grid nodes and each sensor node is aware of its available energy.

A. *Grid Construction*

The EEGDD protocol constructs a global grid structure when all the sensors nodes are deployed in two dimensional square field. Each sensor node knows its location as well as location of its 1-hop neighbour node using GPS System. The grid construction is carried on two predefined parameters i.e. cell size α and baseline coordinate (X_{base}, Y_{base}) of predefined positioning system set in the mission message. The positive directions of x-axis and y-axis of predefined co-ordinate space are pointing to the East and north as shown in Fig. 1. The coordinates of the grid points (X_P, Y_P) are determine using baseline co-ordinate (X_{base}, Y_{base}) as follows:

$$\{X_P = X_{base} + i * \alpha, Y_P = Y_{base} + j * \alpha\}; \quad (1)$$

where $\{ i, j = \pm 0, \pm 1, \pm 2, \pm 3, \ldots\ldots\}$

Each grid cell is an α × α square. The node that is nearest to the grid point (GP) is selected as grid node (GN). These grid nodes act as source/sink agents when selected by sources/sinks. They can store location of the SHN/PA during the data/query announcement process initiated by the source/sink agents. Grid is constructed using simple greedy geographical forwarding technique [6]. During the grid construction process the node representing the base point(X_{base}, Y_{base}) sends the grid setup message to each of the neighbouring node that has the smallest distance to GPs using simple greedy geographical forwarding techniques. Similarly, the neighbour node continues forwarding the grid setup message till the message stops at a node (GN) that is closer to GPs than all its neighbours. However, if distance of this node from GP is less than a threshold value α/2, then this node is selected as a grid node (GN). Otherwise node simply drops this message. This condition helps to terminate the grid formation process at the border of the sensor field. The grid formation process stops at the border of the sensor area where GPs are located beyond the threshold value distance α/2.

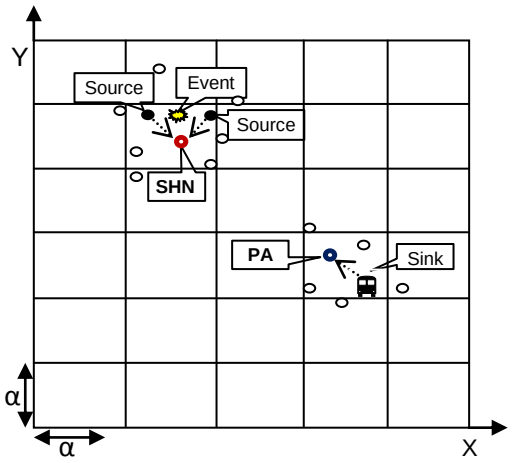

Figure 1. Global grid construction process and HN Selection

B. *Head Node Selection*

When a source/sink appears it performs a local flooding within cell to select a Head Node (HN). If HN is already exists within the cell, then same will be selected by the source/sink. The criterion for selecting HN is maximum remaining residual energy of a sensor node within the cell. The selection of HN is made periodically so that it should not run out of energy. Therefore HN within the cell is always a sensor node with the largest residual energy. Each sensor node within cell is aware about the location of HN. The HN is responsible for selecting source/sink agents, forwarding data/query announcement to source/sink agents, sending request/data from sink/source to source/sink and performs the data aggregation/fusion if necessary. The HN selected by the source acts Source Head Node (SHN) and the HN selected by the sink acts Primary Agent (PA). Fig. 1 describes the HN selection when a source/sink appears in the sensor field.

C. *Data and Query Announcement*

When a sensor node detects an event it becomes the source node. If a SHN already exists within a cell then source sends the data announcement message to it. Otherwise source starts head node selection process to select a node as SHN within cell (as mentioned in Section B) and forward the data announcement message to it. After receiving the data announcement message from source(s), the SHN selects the nearest grid node as source agent. The source agent forwards SHN location to the grid nodes representing the CPs lying horizontally on both sides of x-axis as shown in Fig. 2. Every grid node which receives the location of the SHN nodes store it and forwards the copy of same to grid node representing next CP lying on x-axis direction using simple geographic forwarding through intermediate nodes. This process continues till border node reaches.

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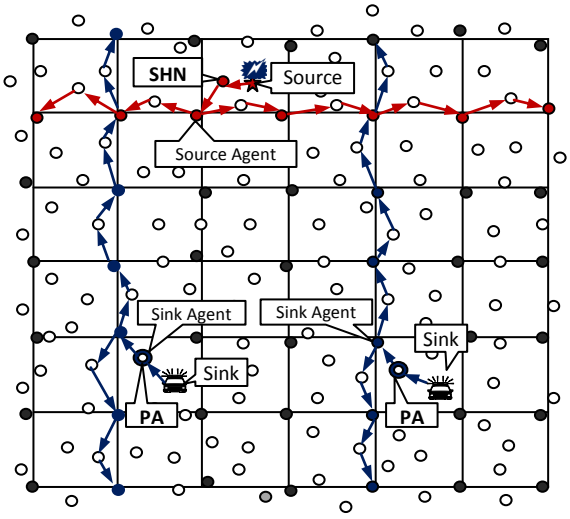

Figure 2. Data and query announcement process

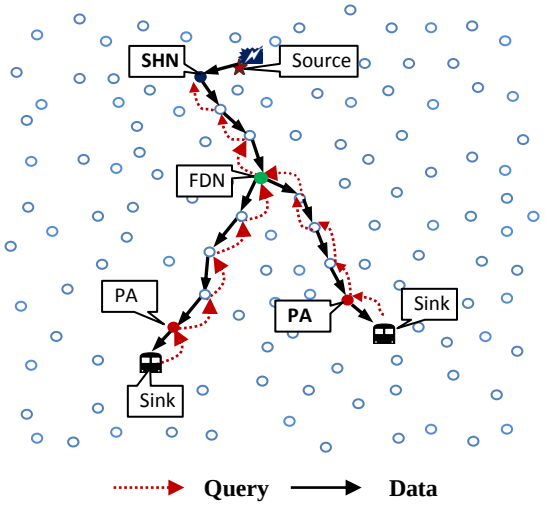

Figure 3. Data dissemination

Similarly when sink needs data, it selects Primary Agent (PA) within the cell as mentioned in section B. The PA selects the nearest grid node as sink agent. The sink agent forwards PA location to the grid nodes representing the CPs lying vertically on both sides of y-axis as shown in Fig. 2. Every grid node which receives the location of the PA store it and forwards the copy of same to grid node representing next CP lying on y-axis direction using simple geographic forwarding through intermediate nodes. This process continues till border node reaches. When this query message reaches at the grid node which contains the location of SHN, it replies back to the PA with parameters containing the location of the SHN. The PA then forwards source location information to sink.

D. Forwarding Query and Data Dissemination

Once sink receives the location of the SHN it can directly communicate with the SHN using GPSR protocol [13]. When sink needs data, it sends data request message to PA. PA initiates route setup process and sends data request message to SHN using geographical forwarding techniques. If data request message reaches at any Forwarding Dissemination Node (FDN) then query is further forwarded through the same existing path leading towards SHN. FDN is an intermediate dissemination node in the already existing path selected by another sink's PA for query/data dissemination. When SHN receives the 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 3. If a data packet reaches at the FDN which had received the data request from multiple PAs then copies of data packets is send to the all PAs from which requests were received. Then PA forwards the data to the sink. The SHN also aggregate the data if there are multiple sources within the cell. Similarly PA also performs data aggregation when it receives the data from multiple SHNs.

E. Handling Sink Mobility

As sink is mobile in the proposed strategy, therefore it is required to maintain the path for continuous delivery of data. Sink selects PA to communicate with SHN for data delivery. PA initializes the value of hop count (hc) to 0 and stores it into its cache. When sink moves out of the predefined range of current PA (i.e. more than half cell size distance), it selects the nearest sensor node (based on the strongest signal to noise ratio) as the Immediate Agent (IA) and sends the location of IA to PA. So that PA can forward the data received from SHN to IA. IA then forwards the data to the sink. As sink is mobile, it continuously updates its current location and selects New Immediate Agent (NIA). Further, it intimates the location of NIA to previous IA, so that data can be forwarded to NIA. Every time when sink selects a new sensor node as IA/NIA it increments the hop count (*hc*) by 1. When sink moves far away from PA (i.e. more than three cell size distance), it selects a New Primary Agent (NPA) and calculates the distance from SHN to NPA. If detour problem exists, it evaluates the new route for data delivery from SHN to NPA as shown in Figure 4. The old path from SHN to last IA can be evaluated as:

$$D_{SHN_PA_IA} = \sqrt{(X_{SHN} - X_{PA})^2 + (Y_{SHN} - Y_{PA})^2} + \left(hc \times \frac{\alpha}{2}\right) \qquad (2)$$

New path form source node to NPA is:

$$D_{SHN_NPA} = \sqrt{(X_{SHN} - X_{NPA})^2 + (Y_{SHN} - Y_{NPA})^2} \qquad (3)$$

If the distance D_{SHN_NPA} is half of the old path $D_{SHN_PA_IA}$ then there exists a detour problem. NPA sends a path update request to source for new path setup. Handling sink mobility and data dissemination process is shown in Fig. 4.

F. Handling Void Grid

During data announcement process when a grid node detects next grid node on x-axis as void (faulty), it forwards the data announcement request towards neighbouring grid nodes along both sides on y-axis. A grid node from which it first receives acknowledgement is selected as next grid node to forward the data announcement message further along x-axis.

Similarly, during query announcement process initiated by sink agent when a grid node detects next grid node on y-axis as void (faulty), it forwards the query announcement request towards neighbouring grid nodes along both sides on x-axis. A grid node from which it first

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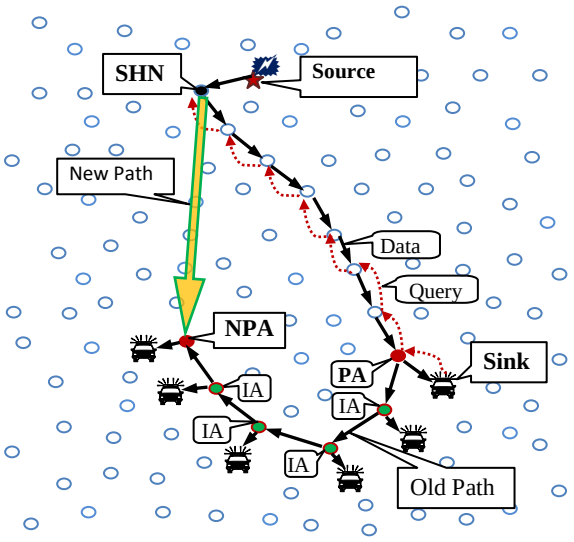

Figure 4. Handling sink mobility

receives acknowledgement is selected as next grid node to forward the query announcement message further along y-axis.

III. PERFORMANCE ANALYSIS

In this section, we evaluate the performance of the EEGDD and compared to TTDD with varying number of sources, sinks, cell size and sensor nodes. TTDD consumes more energy as it constructs grid structure per source node and performs mission updates in whole sensor network. Whereas EEGDD constructs a single global structure which is used by the source and sink for data/query announcements. Once sink gets the location of the source node, it no longer requires the global grid. Further, SHN in EEGDD performs data aggregation within the cell when there exists two or more sources thus reduces the number of packets to be transmitted. Fig.5 shows that

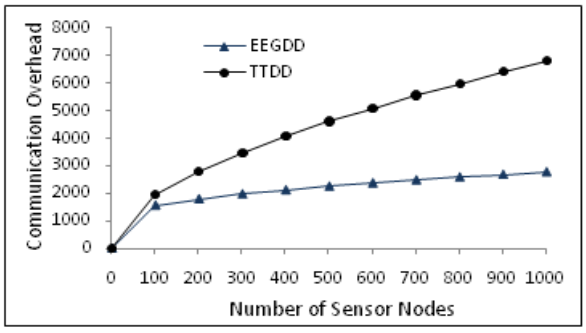

Figure 5. Overall Communication Overhead

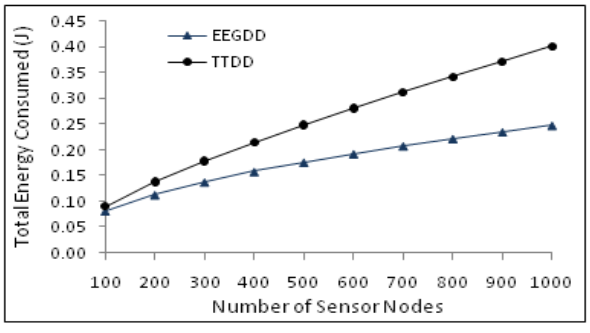

Figure 6. Energy consumption for different numbers of sensor nodes

Table 1: Simulations parameters	
Parameters	**Values**
Size of Sensor Network	2000 X 2000 m^2
$\propto_1$ ($\propto_1 = \propto_{11} + \propto_{12}$)	180nJ/bit,
$\propto_2$	10pJ/bit/m^2
Data Packet Size	64 Bytes
Query/Control Message Size	36 Bytes
Transmission Range (d)	50 m
Number of Sensor nodes	200
Numbers of Sinks	4
Distribution Type of Sensor Nodes	Uniform

the overall communication overhead of EEGDD is comparatively less than TTDD. In this performance evaluation we use the energy model as describe in [7] for WSN. 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 $\frac{1}{d^{\eta}}$.

The default simulation setting has a square sensor field of size 2000 x 2000 m^2 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, cell size, source and sinks. 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 η = 2. The transmission range of each sensor is 50 m and the value of α is set to 200 m. Table 1 summarises various simulation parameters.

Fig. 6 shows the performance of two protocols when number of sensor nodes vary. The number of source nodes and sinks are fixed but node density varies from 100 to 1000 sensor nodes in the sensor area. It is observed that

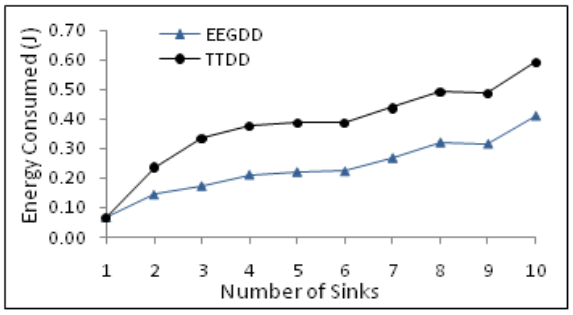

Figure 7. Energy consumption for different numbers of sinks

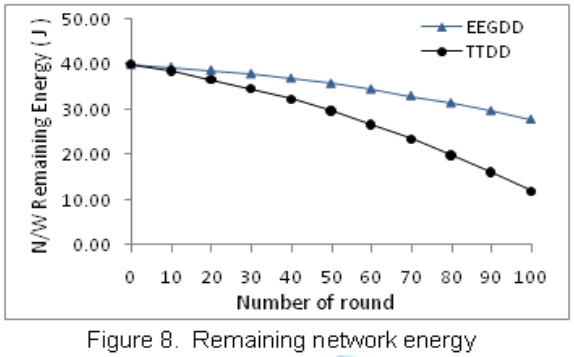

Figure 8. Remaining network energy

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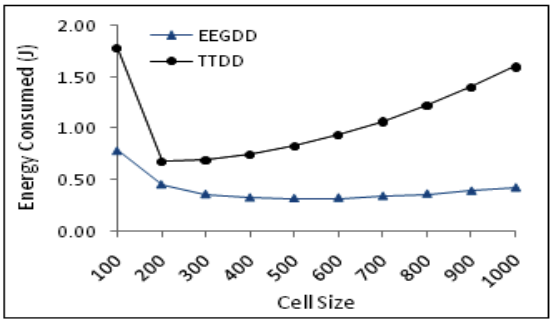

Figure 9. Energy consumed with different cell size

TTDD consumes approximately 1.5 times more energy as compared to EEGDD when numbers of sensor nodes increases.

Fig. 7 shows the performance of two protocols when number of sinks varies. It indicates that TTDD consumes almost the 2 times energy as compared to EGDD for 2 to 4 sinks. When numbers of sinks are higher, TTDD consumes approximately 1.5 times energy as compared with EEGDD. It is observed that when simulation is run for 100 rounds, EEGDD consumes less energy than TTDD. Fig. 8 shows the remaining sensor network energy after 100 simulation rounds. During the initial rounds EEGDD and TTDD approximately consumes the same energy. But as number of rounds increases TTDD consumes almost 2 times network energy when compared to EEGDD.

Since source/sink floods query/data announcement in local cell, hence energy consumption is also affected by cell size. Larger cell size has more sensor nodes and causes more local flooding. Also, smaller cell size causes frequent location update and in-cell flooding for a mobile sink. The average cell size with normal sink mobility (m=4) are more energy efficient. Fig. 9 shows that EEGDD is much energy efficient when compared to TTDD as cell size varies from 100 m to 1000 m.

IV. CONCLUSION

Proposed Energy Efficient strategy for Grid-based Data Dissemination (EEGDD) supporting Mobile Sinks in wireless sensor network exploits the location of the source node and supports sink mobility. It uses a global virtual grid structure to reduce network messages overhead and avoids construction of grid per source. EEGDD selects the HN within cell which performs the data aggregation/fusion to avoid the redundant data. Moreover in contrast to TTDD, the grid is only used for data/query announcement purpose. Once sink obtains the location of the source head node (SHN), it no longer requires the grid and directly communicates with SHN for data request/delivery.

Moreover, EEGDD handles mobile sink very efficiently and maintains the path for continuous data delivery. If any detour problem occurs, it constructs/updates a new path between source and mobile sink and thus converses sensor node energy and increases network lifetime. Simulation results also indicate that EEGDD consumes less energy as compared to TTDD when observed for different numbers of sensor nodes, sinks, and sink mobility.

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