

REDD: Reliable Energy-Efficient Data Dissemination in Wireless Sensor Networks with Multiple Mobile Sinks

K. Singh and T. P. Sharma

Abstract—In wireless sensor network (WSN) the use of mobile sink has been attracting more attention in recent times. Mobile sinks are more effective means of balancing load, reducing hotspot problem and elongating network lifetime. The sensor nodes in WSN have limited power supply, computational capability and storage and therefore for continuous data delivery reliability becomes high priority in these networks. In this paper, we propose a Reliable Energy-efficient Data Dissemination (REDD) scheme for WSNs with multiple mobile sinks. In this strategy, sink first determines the location of source and then directly communicates with the source using geographical forwarding. Every forwarding node (FN) creates a local zone comprising some sensor nodes that can act as representative of FN when it fails. Analytical and simulation study reveals significant improvement in energy conservation and reliable data delivery in comparison to existing schemes.

Keywords — Energy Efficient, REED, Sink Mobility, WSN.

I. INTRODUCTION

RECENT advances in micro-electro-mechanical systems and low power and highly integrated digital electronics have led to the development of micro-sensors that enabled a new generation of massive-scale sensor networks suitable for a wide variety of applications ranging from large scale habitat monitoring, battlefield surveillance, and disaster relief operations to small health care, process monitoring and control etc. A wireless sensor network (WSN) is usually composed of large numbers of such micro-sensor nodes. These sensors nodes continuously sense the external environment and send the stimulus data to the data centers (i.e. sinks) through multi-hop communication [1], [2]. Since sensor nodes have limited resources, therefore, energy efficient and reliable data dissemination is an important issue in these networks [3].

Some recent works [4], [5] suggest that mobile sinks are more effective means of balancing load, reducing hotspot problem and extending network lifetime. A WSN using static sink creates the problem of hotspot in the neighborhood 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. But the sink mobility reduces the hotspot problem. Many protocols exist for WSNs, which support mobile sinks such as Directed Diffusion [6], GEAR [7], 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 a sink. However, frequent updates increase traffic in WSN, causes collision in wireless transmission and consume more power. The other protocols such as TTDD [8], HEED [9], and ALS [10] are based on hierarchical approach. In these protocols, each node is assumed to be aware of its geographical location through some methods like the use of global positioning system (GPS). Their location information is used to construct a virtual grid. The sensor node location information is exploited to communicate between source and mobile sink. But these approaches are not suitable for the sensor networks where the events frequently happen. The other protocols like GBDD [11], PADD [12] support mobile sinks, but handling multiple sources and multiple sinks are still a cumbersome process. Protocols GBEER [13] and EEGDD [14] are capable for handling multiple sources and sinks, but when a forwarding node (FN) fails, data delivery is affected and need new path setup.

In this paper, we propose a Reliable Energy-efficient Data Dissemination (REDD) scheme for WSNs with mobile sinks which applies reliable data delivery strategy even when a forwarding node fails. In this strategy, sink constructs a grid when no valid grid is present in the sensor field. Any other source/sink that appears during the valid grid period shares the existing grid. REDD protocol creates and maintains a source location anchor (SLA) node which stores the location of the Source Head Nodes (SHN) appearing in the sensor field. Any sink can acquire the location of SHN from these SLAs and can communicate directly with SHN using greedy geographical forwarding. To achieve reliable and continuous data delivery, all intermediate data forwarding nodes (DFN) create a local forwarding zone (LFZ) within a transmission radius (R). The sensor nodes falling in LFZ communicate with each other using single hop and are aware of DFN. If DFN fails, the node with maximum residual energy acts as new DFN in the LFZ. When a source/sink appears it selects the nearest grid node as SHN/Primary Agent (PA). The SHN/PA is responsible for data aggregation/fusion, SLA selection, forwarding data/query

Kulwardhan Singh is research scholar in the Department of Computer Science & Engineering, National Institute of Technology, Hamirpur, India (e-mail: kulwardhan@yahoo.com).

T. P. Sharma is an associate professor in the Department of Computer Science & Engineering, National Institute of Technology, Hamirpur, India (e-mail: teekparval@gmail.com).

announcement and data/request delivery. Once sink gets the location of the SHN, a communication path is established between SHN and PA using Greedy Perimeter Stateless Routing (GPSR) [15] protocol for query and data delivery.

Rest of the paper is organized as follows. Section II describes the proposed work including virtual grid construction, node selection for topology maintenance, query and data announcement and data delivery mechanism. In section III, performance of the REDD is evaluated. Section IV concludes the work.

II. PROPOSED RELIABLE ENERGY-EFFICIENT DATA DISSEMINATION (REDD)

In this section, we describe REDD strategy for wireless sensor network in detail. The basic network model is based on the following assumptions:

- 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.
- Each sensor node is aware of its geographical location using global positioning system (GPS).
- Single-hop communication is used for data transmission between neighboring nodes and long distant data delivery is accomplished by multi-hop communication.
- The sensor nodes are homogeneous and wireless channels are bidirectional.
- Each sensor node is aware of its available energy.

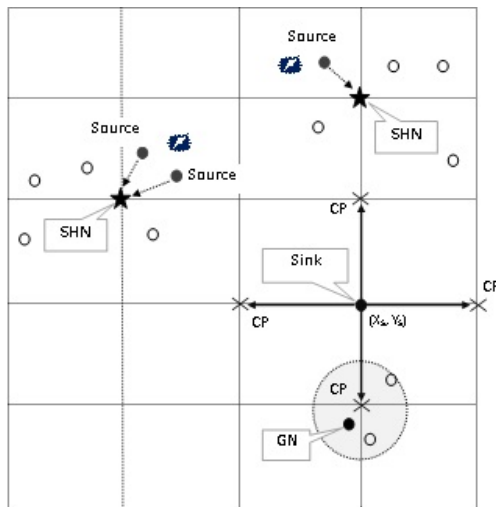


Fig. 1 Grid Construction and SHN selection

A. Grid Construction and Head Node Selection

The REDD protocol uses location information to divide the two dimensional sensing field into virtual grid when all the sensors nodes are deployed. Each sensor node knows its location as well as location of its 1-hop neighbor node using GPS System. The grid construction process is initiated by the sink that appears first in the sensor field or when no valid grid is present. The sink divides the sensor field into a grid of cells.

Each cell is $\alpha \times \alpha$ square field. The sink considers itself at one of the grid point (GP) of the grid and its coordinates (X_s, Y_s) become the starting point for formation of the grid as shown in fig. 1. All other grid points (GPs) located at $P = (X_p, Y_p)$ are calculated from sink starting point (X_s, Y_s) and cell size α as:

$$\{X_p = X_s + i * \alpha, Y_p = Y_s + j * \alpha\}$$

where

$$\{i, j = \pm 0, \pm 1, \pm 2, \pm 3, \dots\} \quad (1)$$

Sink calculates the locations of its four GPs given its own location (X_s, Y_s) and cell size α . For selection of grid node (GN) which is the node nearest to GP, the sink sends grid construction message to the node that has the smallest distance to GP. The node nearest to GP is called as GN. During the grid construction process the sink representing the base point (X_s, Y_s) sends the grid setup message to each of the neighboring node that has the smallest distance to GPs using simple greedy geographical forwarding techniques. Similarly, the neighbor node continues forwarding the grid setup message till the message stops at a node (GN) that is closer to GPs than all its neighbors. However, if distance of this node from GP is less than a threshold value $\alpha/2$, then this node is selected as a grid node (GN) [8]. 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 $\alpha/2$.

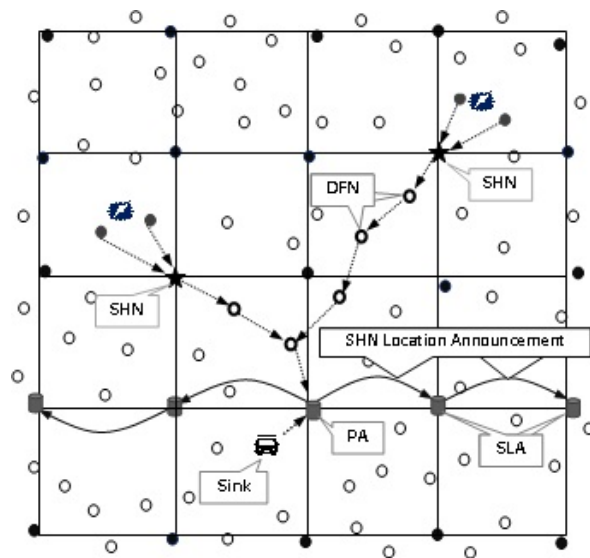


Fig. 2 Head Node and SLA selection

When an event is detected by a sensor node it becomes the source node. The source checks whether there exist a valid grid by flooding a local query within a radius α . The source discovers the valid grid if it detects GNs. Upon detection of valid grid, source selects GN that is closest to the sink as SHN

as shown in fig. 1. The SHN is responsible data aggregation/fusion, data announcements and data delivery.

Once a GN is selected as SHN it forwards the data announcement message to the PA of sink that has constructed the grid. The PA stores the location of SHN and forwards the copy of the same to the GNs lying horizontally along the x-axis. All these GNs act as source location anchors (SLAs) and keep the location information of all the SHNs appearing in the sensor field as shown in fig. 2. Any other sinks appearing in the sensor field can obtain the location of SHNs from these SLAs.

B. Forwarding Query and Data Dissemination

When sink appears and needs data, it first checks whether there exists a valid grid in the sensor field by flooding a query within a radius α . If no valid grid is present, sink starts grid construction process as mentioned in Section A. Otherwise, sink selects the nearest GN as primary agent (PA) and forwards a query announcement message to the GNs vertically along Y-axis towards the SLA. When this message reaches at the GN that is acting as SLA, it replies back to requesting PA with location information of SHNs.

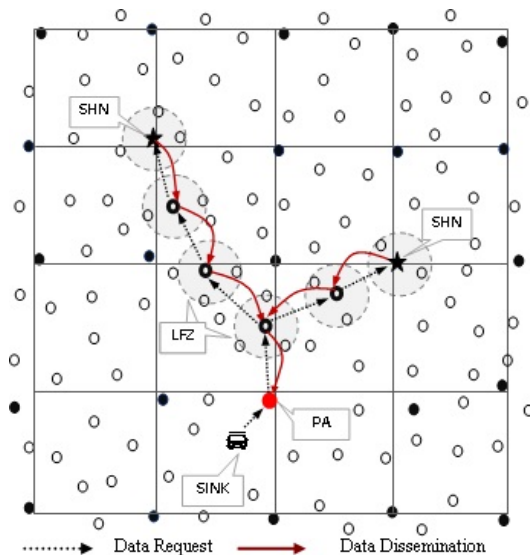


Fig. 3 Data Request and Data Dissemination

Once PA receives the location of SHNs, it sends a data request message to the SHN for data delivery using GPSR protocol. If data request message reaches at any data forwarding node (DFN) then query is further forwarded through the same existing path leading towards SHN. DFN is an intermediate dissemination node in the already existing path selected by another sink's PA for query/data dissemination. When SHN receives a data request, it generates the data packets and sends it to PA through the same path on which request message was received as shown in fig. 3. PA then forwards the data to the sink. The data/query path finally established is approximately a straight line path unless sink moves significantly from its initial position. SHN also

aggregates the data if there are multiple sources within the cell. Similarly PA also performs data aggregation when it receives the data from multiple SHNs.

C. Selecting a Local Forwarding Zone (LFZ)

All the nodes that are acting as SHN, PA or DFN create LFZ within the radius of transmission range (R) which comprises some sensor nodes that can act as next representatives of FDNs if they fail as shown in fig. 3. Once a node is selected as FDN, it starts polling to create a list of nodes that can act as alternate FDN by broadcasting a message within the radius R centred from FDN. All nodes that are lying within a radius of R , can communicate using single hop. Each of the nodes those are within distance R from FDN broadcasts a tuple comprising of its coordinate and remaining residual energy. Every node within the radius of R including FDN creates an indexed list of nodes in descending order of their residual energy. Whenever the residual energy of FDN falls below a threshold value or when GN fails, the alternate FDN is selected from the indexed list in sequence from top. Therefore, reliable data delivery can be achieved by selecting an alternate FDN in LFZ for continuous data delivery.

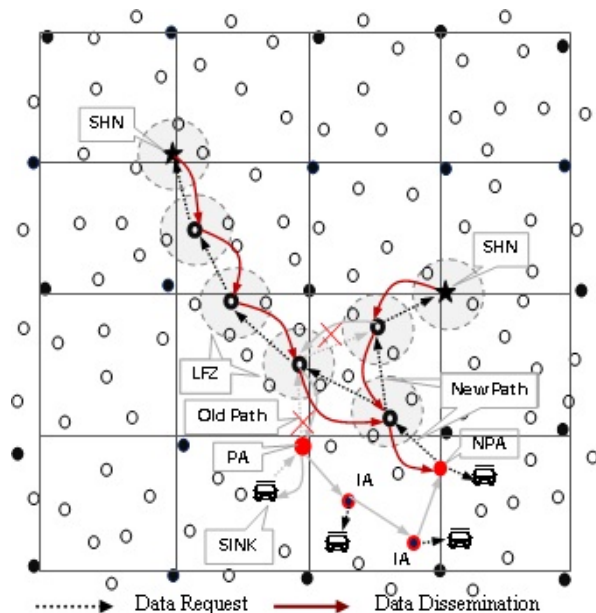


Fig. 4 Handling Sink Mobility

D. Handling Sink Mobility

Proposed strategy supports sink mobility and therefore, is required to maintain the path for continuous delivery of data. Sink selects PA to communicate with SHN for data delivery. As sink moves beyond the transmission range from PA, it selects the nearest node as immediate agent (IA) and forwards the location of IA to PA, so that PA can forward the data to IA. IA then forwards the data to sink. Every sink maintains a location information table (LINT) in its cache. Each entry in LINT table is identified as a tuple ($SHNInfo$, $NodeLoc$, hc). The $SHNInfo$ is SHN information from which sink is getting data, $NodeLoc$ is location information of FDN between SHN

and IA, hc is hop count of intermediate node from SHN. When sink updates its location and selects a new IA, it creates a new tuple entry and adds it in LINT table (where *SHNInfo* contains SHN information, *NodeLoc* contains IA location information and $hc = hc + 1$).

Every time when sink selects a new IA, it checks for detour path for all the DFN between SHN to IA. The sink evaluates the Euclidean distance for all the DFNs between SHN and IA. This distance is compared with the distance of DFN from sink on existing path. If the calculated distance is half of the existence path distance, then there exists a detour path between DFN and IA. In such a situation, IA is selected as new primary agent (NPA) and new path is setup between DFN and NPA as shown in fig. 4. Once new path is established the entries in the LINT table are modified. Thus, REDD has the ability to update the partial path when there exist a detour problem, hence possesses the ability to handle the sink more efficiently.

III. PERFORMANCE ANALYSIS

In this section, we evaluate the performance of the REDD and compare it with some existing protocols such as TTDD, PADD with varying number of sources, sinks, cell size and sensor nodes. In this performance evaluation, we use an energy model as describe in [16] for WSNs. The key energy parameters are the energy needed to sense a bit (E_{sense}), receive a bit (E_{rx}) and transmit a bit over a distance d (E_{tx}). Assuming path loss in energy model is $\frac{1}{d^n}$.

These parameters take the form as below:

$$E_{tx} = \alpha_{11} + \alpha_2 d^n \quad (2)$$

$$E_{rx} = \alpha_{12} \quad (3)$$

$$E_{sense} = \alpha_3 \quad (4)$$

where α_{11} is the energy/bit consumed by the transmitter electronics (including energy costs of imperfect duty cycling due to finite start-up time), α_2 accounts for energy dissipated in the transmit op-amp (including op-amp in-efficiencies), α_{12} is the energy/bit consumed by the receiver electronics and α_3 is the energy cost of sensing a bit. Hence, energy consumed per second (i.e. power) by a node acting as a relay that receives data and then transmits it d meters onward is:

$$P_{relay}(d) = (\alpha_{11} + \alpha_2 d^n + \alpha_{12})r \quad (5)$$

$$= (\alpha_1 + \alpha_2 d^n)r \quad (6)$$

A. Simulation Parameters

The default simulation setting has a square sensor field of size $2000 \times 2000m^2$ 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 number of sources and sinks, sink speed and average delay for 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 $\eta = 2$. The transmission range (r)

of each sensor is 50m and the value of α is set to 200m. Table I summarizes various simulation parameters.

B. Impact of Number of Sinks, Sink Speed, and Sources on Overall Energy Consumption

The performance REDD is evaluated as number of sinks and sources varies from 1 to 8 and sinks move randomly in the sensor field with a maximum speed 10m/s.

TABLE I
SIMULATIONS PARAMETERS

Parameters	Values
Size of Sensor Network	2000 X 2000 m ²
α_1 ($\alpha_1 = \alpha_{11} + \alpha_{12}$)	180nJ/bit,
α_2	10pJ/bit/m ²
Data Packet Size	64 Bytes
Query/Control Message Size	36 Bytes
Transmission Range (r)	50 m
Number of Sensor nodes	200
Numbers of Sinks	4
Distribution Type of Sensor Nodes	Uniform

Fig. 5 shows the energy consumption with varying number of sinks and there are 2 sources in the sensor field. It is observed that TTDD consumed 2 times and PADD consumes 1.5 times more energy than REDD.

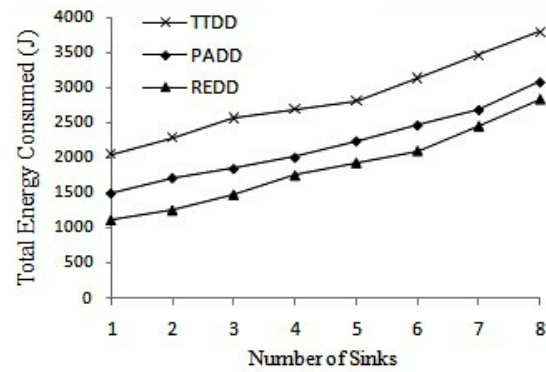


Fig. 5 Total energy consumed for different number of sinks

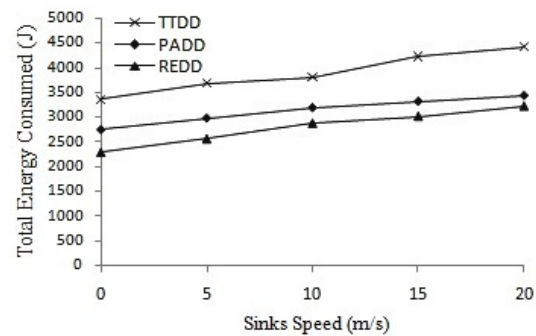


Fig. 6 Total energy consumed for different sink speed

Fig. 6 shows the impact of sink mobility on overall energy consumption. The maximum speed of the sink varies from 0, 5, 10, 15 to 20m/s. The number of sources and sinks are fixed

to 2 and 4 respectively. REDD consumes 2 times and 1.4 times less energy as compared with TTDD and PADD respectively.

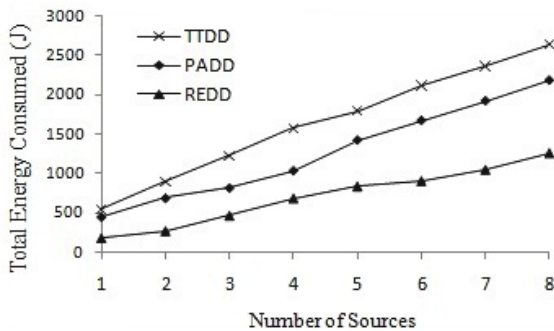


Fig. 7 Total energy consumed for different number of sources

Fig. 7 shows overall energy consumption as number of sources varies. There are 4 sinks randomly moving in the sensor field. It is observed that REDD consumes 4 times and 2 times less energy as compared with TTDD and PADD respectively.

C. Average Delay with Varying Number of Sinks

Fig. 8 shows the impact of varying number of sinks on average delay. The average delay of REDD is averagely 55% and 21% shorter than TTDD and PADD.

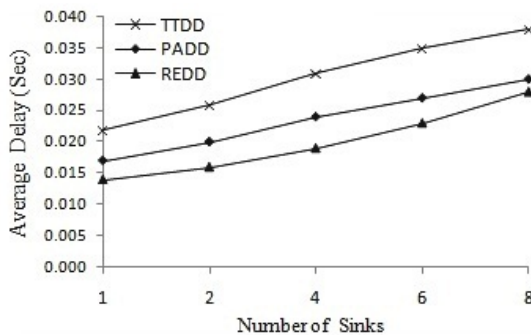


Fig. 8 Average delay for different number of sinks

IV. CONCLUSION

Proposed Reliable Energy-efficient Data Dissemination (REDD) scheme for Wireless Sensor Network with Mobile Sinks exploits location awareness of the source nodes and supports multiple sink mobility. In REDD, every data forwarding node creates a local forwarding zone within the radius of its transmission range to accomplish the reliable data delivery. Unlike other protocols like TTDD and PADD, REDD, it stores the location of source head nodes (SHN) in source location anchor (SLA). Any sink can acquire the source location from these SLAs and communicate directly with SHNs using geographical forwarding. The REDD protocol handles sink mobility very efficiently as it has the ability to update the routing path partially when there exist detour path. Every source head node or data forwarding node performs

data aggregation/fusion if required to avoid the redundant data. Simulation results also indicate that REDD consumes less energy as compared to existing schemes like TTDD and PADD when observed for different numbers of sensor nodes, sinks, and sink mobility.

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