Energy-Efficient Grid-Based Data Dissemination in Wireless Sensor Networks

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ABSTRACT
In Wireless Sensor Networks, data dissemination to multiple sinks consumes a lot of energy. Various data dissemination schemes have been proposed over the years to reduce the energy consumption in Wireless Sensor Networks. In this paper, we have proposed a virtual infrastructure based data dissemination scheme which reduces the energy consumption in grid construction process. Grid construction process is initiated by the source appearing in the sensor field when no valid grid is present. All other sources appearing during the valid grid period share existing grid. This scheme provides a solution for calculating cell size of the grid and handling multiple sinks in WSN. We have also proposed an energy efficient scheme for handling dissemination node failure.

General Terms
Data Dissemination, Wireless Sensor Network.

Keywords
Dissemination Node, Mobile Sink, Expected Zone, Source Id.

1. INTRODUCTION
Typical wireless sensor networks consist of sinks, events, and a large number of sensor nodes. The sensor nodes are low-cost, low-power, but multi-functional devices. A large number of the sensor nodes are randomly distributed over a vast field to self-organize a large-scale wireless sensor network [1]-[10]. The sensor nodes monitor some events in surrounding environments, such as heat, sound, vibration, presence of objects, and so on. If a sensor node detects an event, the sensor node produces data and makes data announcement to sinks subscribing the data. The sensor node denotes a *source node* and this procedure is called *data dissemination* [3].

The main issues in data dissemination to mobile sinks in WSNs are-

1. How to determine the cell size of the grid?
2. How to deal with the dissemination node failure problem?
3. There may not be a sensor node at the exact estimated location of the grid crossing point. So how to deal with the uncertainty in sensor node location?

In this paper we propose a data dissemination scheme in which a grid structure is used such that the sensor nodes located at grid crossing points (Dissemination nodes) need to acquire the forwarding information. There are two levels of grid structure for query and data forwarding:

1. The lower tier is within the local grid square cell of current location of sink or source.
2. The higher tier is made of the dissemination nodes of the grid.

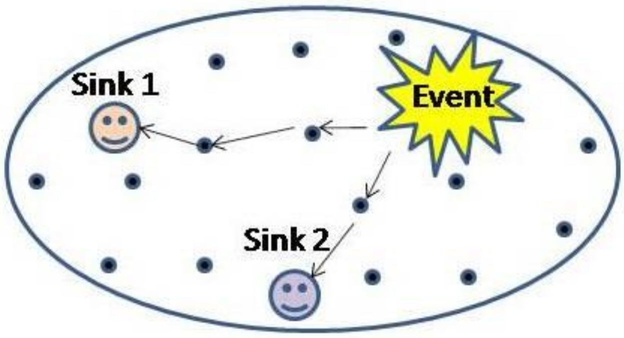

Figure 1: A sensor network example with source and sink

Unlike TTDD, In this scheme the grid is constructed only when no valid grid is present in the sensor field. The first source appearing in the sensor field initiates the grid construction process with its source id, its own location co-ordinates and a predefined radius (*d*) of the expected zone in the dissemination node location. The value d is used because it is not always possible to find the sensor nodes at the exact location estimated for the dissemination point. It restricts the flooding of messages over the sensor field as only those nodes which have distance from estimated dissemination point less than the value of *d* will reply to dissemination node. The expected zone is a circular region of radius ***d***. For handling the dissemination node failure, each sensor node which forwards a Grid Construction Message (GCM) for grid construction maintains a list of all sensor nodes that belong to the expected zone.

2. ENERGY-EFFICIENT GRID-BASED DATA DISSEMINATION SCHEME

2.1 Network Model
The following assumptions are used in this paper for network modeling:

- A vast field is covered by a large number of homogeneous sensor nodes which communicate with each other through radio signals.

- Each sensor node is aware of its own location co-ordinates in a two-dimensional sensor field (for example, using GPS signals).
- Sensor nodes are stationary and capable of storing some information regarding the neighboring nodes.
- Sinks send query packet to the source with the Source Id of the corresponding source node.
- Source nodes forward the data to the sink using the backward path followed by the query packet from sink.
- The grid is constructed by the source only when there is no already existing grid.

2.2 Grid Construction

We propose a grid construction scheme in which grid construction process is initiated by the source appearing in the sensor field only when on valid grid is present. The first source appearing in the sensor field will initiate the grid construction process similar to TTDD [4].

A source divides the entire sensor field into a grid of square sized cells of dimension $\alpha \times \alpha$. A source itself is at one crossing point of the grid. It propagates Grid Construction Message (GCM) to reach all other crossings, called *dissemination points*, on the grid. For a particular source at location $Ls = (x, y)$, dissemination points are located at $Lp = (xi, yj)$ such that:

$\{ xi = x + i\alpha, yj = y + j\alpha; i, j = \pm 0, \pm 1, \pm 2, \ldots \}$.

- The source node sends the calculated co-ordinates and a predefined distance (d) of the dissemination node from the crossing point with GCM.
- The distance d is the maximum limit of tolerance in the cell size as it is not always necessary that there will be a node at exact location of the calculated crossing point.
- Each node, on receiving the GCM, calculates its distance from the co-ordinates of the crossing point received with GCM.
- If the calculated distance is less than d, then the node replies to the sender dissemination node with its co-ordinates and the calculated distance d_i.
- The sender dissemination node arranges all the distances in ascending order and selects the node with the minimum distance that is the closest node from the crossing point.
- It sends the confirmation message to the selected node and designates it as the next dissemination node.
- The GCM message is *recursively* propagated in the entire sensor field so that each dissemination point on the grid is served by a dissemination node.

If a source or event appears in the sensor field and there is an already existing valid grid constructed by some other source in the sensor field, then the event source instead of initiating grid construction makes use of the already existing grid. The new source node finds out its nearest dissemination node and sends data announcement message with its own source id. This nearest dissemination node works as a proxy of the source node. The data and query forwarding process will be in the similar way as for the original source node which has constructed the grid.

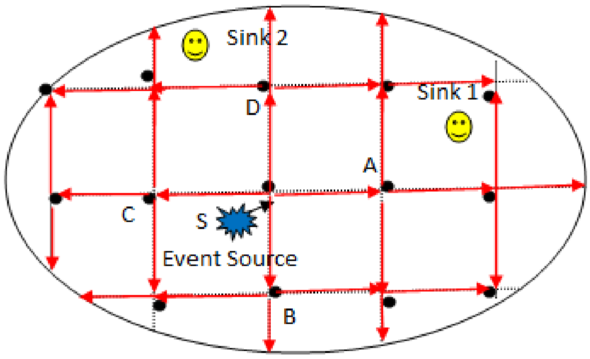

Figure 2: Grid construction by source S

In figure 2, It is shown that the source S initiate the grid construction process. A, B, C and D are the crossing points calculated by Source S. The neighboring nodes which are at the distance less than or equals to the predefined radius (d) of the expected zone from the calculated crossing points will reply to S with their respective distances from the crossing point. Now S will arrange all the received distances in ascending order and select the first one from the list. S will send the confirmation message to the selected node and that will be the dissemination node. When this node fails or dies then the second node from the list is selected as the dissemination node. In this way we have reduced the flooding of messages for selecting the alternate dissemination node.

2.3 Determining the Cell size

Cell size is determined by using the radio range R of sensor nodes and the limiting distance d. We can determine the cell size α with the help of figure 3.

AB = BC = CD = AD = α … (cell size)

AP = CQ = d … (radius of expected zone)

In triangle ABC, $\llcorner ABC = 90°$
So, AC = $\sqrt{2}\alpha$ (Applying Pythagoras Theorem)

Radio range of the node should be equals to PQ.
PQ = R … (Radio range)

So, QC + CA + AP = R

Or $d + \alpha\sqrt{2} + d = R$

Or $\alpha\sqrt{2} + 2d = R$

Or $\alpha\sqrt{2} = R - 2d$

Or $$\boldsymbol{\alpha = (R - 2d) / \sqrt{2}} \quad (1)$$

So from the above derivation it is clear that the cell size α should be equals to $(R - 2d) / \sqrt{2}$.

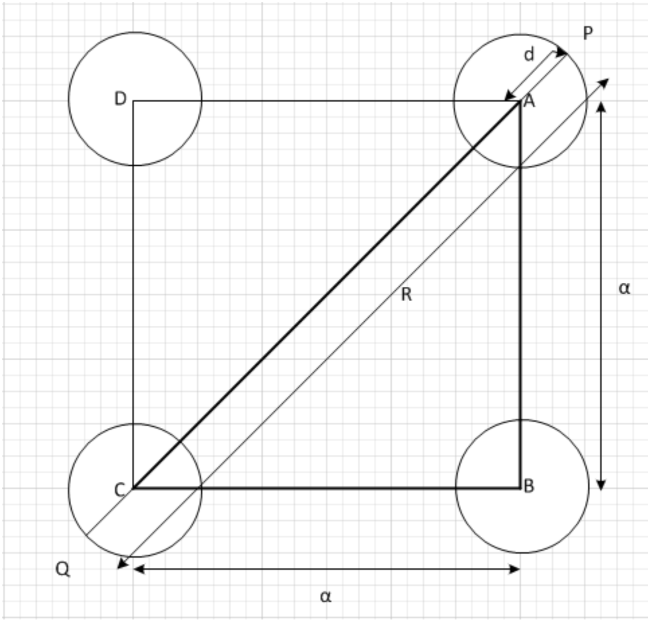

Figure 3: Cell size for grid construction

2.4 Determining the radius d of expected zone

We will construct a circular expected zone with radius d.
So πd^2 will be the area of the expected zone.
Let there are n sensor nodes deployed in the sensor field and the area of the region is A.
Then
Area of finding 1 sensor node = total number of sensors / total area

$$\pi d^2 = n / A$$

$$d = (n / \pi A)^{1/2}$$

We will take the upper bound (floor value) of the calculated value, so that there will be the probability of finding more than one sensor nodes in that area-

$$d = \lceil (n / \pi A)^{1/2} \rceil \quad (2)$$

2.5 Query forwarding

In this approach the query forwarding is based on the virtual grid infrastructure. Each data source has its own unique source id and the source id is known to all the dissemination nodes of the cell in which the data source is lying. The query from a sink includes the source id of the source of interested data. When a sink needs data, it floods a query within the local cell area. The query reaches to the local dissemination node of that cell. Now it is forwarded on the grid towards the source. Each dissemination node checks the Source Id in the query. If it matches with the id of its own source id, then the dissemination node forwards the desired data to the sink through the backward path traversed by the query. If a dissemination node receives queries for the same data from different sinks, then it aggregates all these queries and sends only one copy to its upstream dissemination node. Each node maintains the information about all the queries received by neighboring nodes and when it receives the data then it forwards the data to all the nodes from where it had received the query for that data item.

2.6 Query Forwarding from multiple sinks

We propose a query forwarding scheme (Figure 4) for data dissemination to mobile sinks in WSN. We assume that each dissemination node is aware of its own location (coordinates) as well as the location of all its neighboring dissemination nodes. When a sink wants to forward the query to a particular source, it generates a query packet with the source id, Source Sequence Number and (X_s, Y_s) coordinates of the source dissemination node. Now it forwards the query packet to all its neighbors. When a dissemination node receives the query packet, it compares its y coordinate with the y coordinates of the sender dissemination node. If it is closer than the previous sender dissemination node then it will forward the query packet, otherwise it will reject the query packet. When the Y coordinates of source node and the dissemination node is same then we will compare the X coordinates and only the node whose X coordinate is less than that of the previous sender node will forward the query until the source dissemination node is reached.

Algorithm for query forwarding

The algorithm for query forwarding is given below-

1) Update the query packet by including its own (X_i, Y_i) coordinates in the packet.

2) Forward the query to all its neighboring dissemination nodes with coordinates (X_j, Y_j).

3) While (Y_s =! Y_j)

a. On receiving a query packet, calculate $|Y_s-Y_i|$ and $|Y_s-Y_j|$ where Y_i is the Y coordinate of sender dissemination node from where the query is received and Y_j is the Y coordinate of the receiving dissemination node.

b. If $|Y_s-Y_i| > |Y_s-Y_j|$, then forward the query packet, otherwise discard.

4) If ($Y_s = Y_j$)

a. Then calculate $|X_s-X_i|$ and $|X_s-X_j|$ where X_i is the X coordinate of sender dissemination node from where the query is received and X_j is the X coordinate of the receiving dissemination node.

b. If $|X_s-X_i| > |X_s-X_j|$, then forward the query packet, otherwise discard.

If a node receives multiple query packets with same Source id and Source sequence number then it forwards only one query and stores the location of all the nodes from where it has received the duplicate queries. Thus it removes the probability of forwarding duplicate query packets.

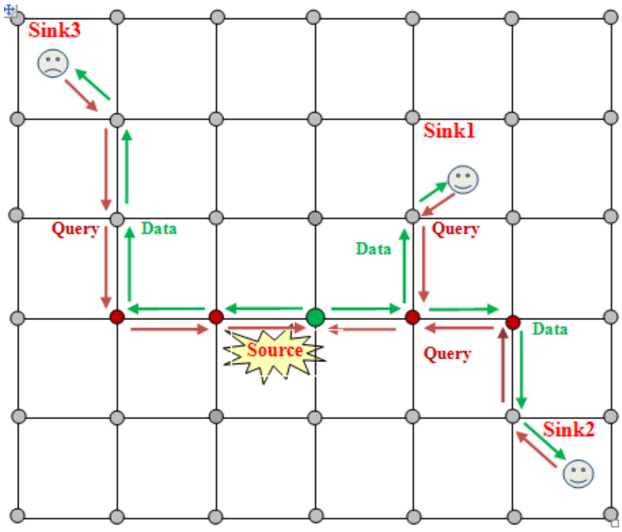

Figure 4: Query forwarding by multiple sinks located at different locations

2.7 Data Forwarding

Once the query is received by a dissemination node, it is forwarded to the data source. Data is forwarded to the sinks through the reverse path followed by the query. If a dissemination node had received queries from different neighboring nodes, it sends a data copy to each of them. Once the data arrive at a sink's local dissemination node, trajectory forwarding [4] is employed to further relay the data to the sink.

2.8 Handling Dissemination node failure

The most important feature of the proposed scheme is to handle the dissemination node failure problem without excessive flooding in the entire sensor field. This scheme makes use of the circular expected zone with radius d. But it does not rely on forwarding query when the dissemination node fails instead it makes use of the priority list of nodes which is maintained during the grid construction process. During the grid construction process, all the nodes belonging to the expected zone will send their location information to the neighboring node from which the query is received. A priority list is maintained by that node based on the closeness of the nodes with the estimated crossing point. Thus the nearest node is selected as the dissemination node and the information about the remaining nodes is stored in the priority list on the basis of their closeness. When a dissemination node fails then its upstream dissemination node selects the next node from the priority list as the dissemination node and sends the small message to that node to find out whether it is alive or not. If that node sends the confirmation signal then it will be the alternate dissemination node otherwise the process is repeated with the next node in the priority list. In this way the proposed scheme reduces the energy consumption and handles the dissemination node failure problem in an efficient way.

3. PERFORMANCE EVALUATION

In this section we evaluate the performance of our EGDD approach. Energy Efficiency is the major concern of EGDD scheme so we have analyzed for energy only. The energy consumption is defined as the total energy consumed in the network during communication (transmitting and receiving) excluding the idle. Figure 5 and figure 5 plot the total energy consumption according to number of sinks and sources. We simulate this experiment with two cases of number difference for sinks and sources respectively.

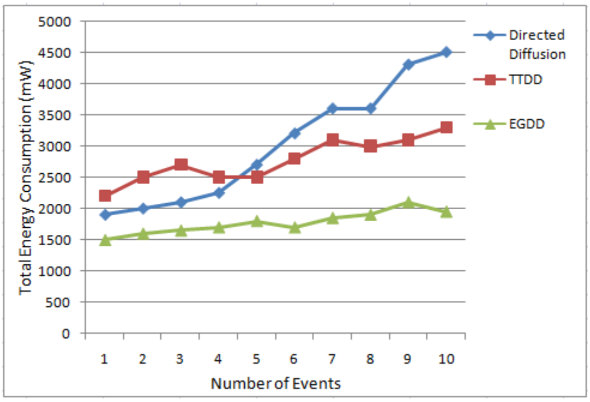

Figure 5: Total energy consumption with different number of event sources

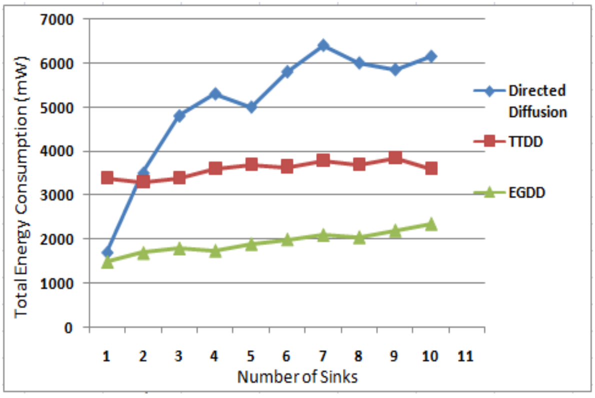

Figure 5: Total energy consumption with different number of sinks

4. CONCLUSION

In this paper we have proposed an energy efficient data dissemination scheme which makes use of virtual grid infrastructure for query and data forwarding. EGDD is an energy-efficient scheme for addressing the issues of dissemination node failure and excessive flooding of packets in WSNs. It introduces a query forwarding scheme for multiple sinks which are located at different geographical locations. The proposed data dissemination scheme determines the cell size on the basis of the area of the sensor field and the number of nodes deployed in the area. EGDD reduces energy consumption due to query flooding by multiple sinks located at different geographical locations. Theoretical analysis and simulation result shows that the proposed scheme is energy efficient for multiple sinks and multiple sources.

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