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A Cluster-Tree based Data Dissemination Routing Protocol

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Abstract

Immobile sensor nodes are deployed in the gigantic area and formed a network, known as the Wireless Sensor Network (WSN). Mobile sink is a resource opulence node, whose duty is to receive the data from all the sensor nodes. Energy efficiency and network lifetime is the prime concern of the WSNs. In this paper, we propose a Cluster Tree based Data Dissemination (CTDD) routing protocol. Theoretical analysis evince that the CTDD protocol is more energy efficient, sturdy protocol with relatively less delay than another protocol because in CTDD there will be no issue of frequent tree re-construction for load balancing.

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Keywords: Cluster Based Routing; Energy Efficiency; Mobile Sink; Tree Based Routing; Wireless Sensor Networks.

1. Introduction

Wireless sensor network predominantly includes sensor nodes, a processor, batteries, radios and mobile sink. The operation of sensor node includes sensing the physical world data, processing those data and relaying the data into the entire network. Applications of WSNs include habitat monitoring, area monitoring, water quality monitoring, landslide detection, health care monitoring, earth sensing, precision agriculture, automation, disaster detection etc.[1–4] The advantage of WSNs includes flexibility, low-cost and centralized monitoring, etc.[5,6]

Sink aggregates all those data and forward it to the user through the Internet. The sink is movable or mobile in the case of WSN that makes the network dynamic. The energy consumption of the sensor nodes, which are nearest to the sink node, is much more than other nodes in WSNs. Because of more energy consumption, the nearest nodes died prior to the other nodes. This problem is known as an energy-hole problem. The mobility of the sink overcomes the energy-hole problem. Energy efficiency and lifetime of the network is the prime concern of any WSN. The sensor network requires routing techniques for increasing the efficiency of any sensor nodes. Wireless sensor network includes many types of routing techniques. Network structure based routing techniques and Protocol based Routing techniques are the two main categories of WSN[7]. In this proposed work, the network is divided into equal sizes virtual grids, then the cluster is formed within the grids, and at last the tree structure is formed over the clusters. Only cluster heads are included in the formation phase of tree structure, i.e. all cluster heads are treated as a vertex of a tree structure in the wireless sensor network.

The subsequent section of the paper is organized as follows: section 2 delineates the related work, section 3 delineates the protocol description, section 4 includes the theoretical analysis part, and finally section 5 concludes the entire paper.

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2. Related Work

2.1 Cluster based routing

For routing purpose, cluster based protocol is used that is based upon LEACH[8] algorithm. The cluster based routing protocol (CBRP)[9] uses the probability function for selecting the cluster head (CH). In the setup phase of this protocol, each node creates a random value of probability and also computes the value of the threshold level[10]. The maximum threshold value node is selected as cluster head. By the help of *join-REQ* packet to all cluster nodes are connected with corresponding cluster heads. At the end of setup phase cluster head knows about all its cluster members. In the steady phase of this protocol, the cluster head communicates with a base station (BS) and send collected data to the BS.

2.2 Tree based routing

Tree based routing is the part of hierarchical routing protocol. The Tree Based Routing Protocol (TBRP)[7] forms the tree structure in the whole network area. Each sensor node calculates its distance and levels from the base station (BS). After assigning the levels, *join-REQ* is used for attachment of all the nodes from one level to other levels. Once the tree is formed according to the levels, the data are sent from lower level nodes, i.e. from child nodes to its upper level nodes, i.e. to parent node and finally data reaches to the root node. The root node provides TDMA schedule to all its child nodes and in that time intervals child node forwards their data to root node and at last root node forwards the whole aggregated data to the BS.

2.3 Cluster and tree based routing

The General Self-Organized Tree Based Energy-Balancing Routing GSTEB[11] protocol is basically based on clustering and tree based routing concepts. In the GSTEB protocol, firstly cluster is formed in wireless sensor network and then tree structure is formed by including all cluster heads (CHs) as a vertex of a tree. Fuzzy logic[12] is used for the cluster head election procedure because fuzzy logic is useful for evaluating the energy level of each and every sensor node. After the formation of clusters, each cluster head finds its location by using GPS (Global Partitioning System) and its distances from the base station. All the distance are organized in ascending order by any of the sorting techniques, the minimum distance value node becomes a root node of the tree and second minimum value node become a left child of the root node and similarly the third minimum distance node become a right child of the root node and so on. According to the distance values the nodes are arranged in the form of tree structure.

All above defined routing protocols are less energy efficient because of few reasons like tree reconstruction, network delay, less throughput etc. The proposed protocol CTDD is constructed by following efficient features like less end to end delay, more throughput and energy efficiency.

3. Network Model

The proposed protocol assumes that all sensor nodes are homogeneous in nature and deployed randomly in the network area of 100 meter^2 diameters. All sensor nodes have equal radio range having its minimum (Min_R) and maximum (Max_R) values. Sensor network environment includes some basic assumptions such as:

- Every node has ability to convey the message from one node to another node as well as to mobile sink.
- The movement of the mobile sink is randomly in the case of wireless sensor network.
- All sensor nodes are immobile in nature as well as all are energy constrained.

3.1 Cluster-tree based data dissemination protocol

Cluster-Tree Based Data Dissemination (CTDD) protocol is the coalition of two schemes, one is a cluster formation in the entire network and the other is the tree structure formation over the clusters. In CTDD protocol, the entire

network is virtually divided into a number of grids and then, according to the numbers and sizes of the grid structure the clusters are formed within the virtual grid and cover entire sensor nodes of the network. The cluster formation procedure includes cluster head (CH) election process and bonding process between cluster heads and its corresponding cluster nodes (CNs). After the cluster formation, the cluster heads are treated as vertex for tree formation. The tree formation procedure includes the adjustment of all cluster heads in the form of parent-child relationship and finding the neighbor node information. The main objective of CTDD protocol is to make sensor nodes more energy efficient by excluding the tree re-construction concept of the load balancing phase. For load balancing, cluster head is re-elected only when cluster head losses their energy from a certain threshold value. Apart from energy efficiency constraint, CTDD protocol reduces the latency delay and increases the network lifetime. The CTDD protocol consists of five phases such as: grid construction, cluster formation, tree construction, sink management and load balancing.

3.1.1 Grid construction phase

Grid construction phase is the initial phase of CTDD protocol in which the virtual grid is constructed on the whole network area as shown in Fig. 1. Because of the homogeneous nature of sensor nodes, the whole network is divided into equal size grid. As delineate in Algorithm 1, the network area is defined by two parameters known as width and height. Network area is divided into equal size cell by following operations:

- Cell Range is defined by a range, which lies between the minimum (Min_R) and Maximum (Max_R) radio range of sensor nodes.
- In the case of width, a virtual line is drawn along height according to the Cell Range and also provides the numbers to each cell.
- Similarly, in the case of height, the virtual line is drawn along the width according to the Cell Range and also provides the number to each cell.
- Finally the whole network is divided into equal size cell or a grid.

Data structure of any network area:
Min Range (Min_R): Minimum radio range of sensor node.
Max Range (Max_R): Maximum radio range of sensor node.
N_Cell: Number of each and every cell, initialized to 0.
Width: Width of network area.
Height: Height of network area.
Cell_Range: Range of Particular cell.
Grid Construction Procedure:

```
1.  Begin
2.  Cell_Range ← Min_R <= Sensor Node Range <=Max_R
3.  for each i initialized to 0, repeat
4.          if ( i <= Width) then,
5.          Virtual line created at i position along height.
6.          N_Cell ← N_Cell + i.
7.          Cell_Range + i.
8.  end for.
9.  for each j initialized to 0, repeat
10.         if ( j <= Height) then,
11.         Virtual line created at j position along width.
12.         N_Cell ← N_Cell + j.
13.         Cell_Range + j.
14. end for.
15. end.
```

Algorithm 1. Grid construction procedure

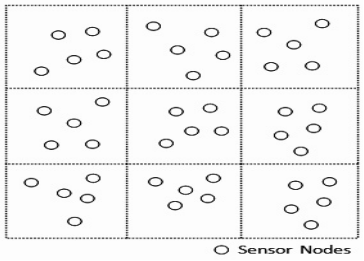

Fig. 1. Grid construction phase.

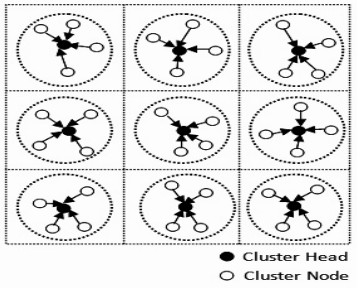

Fig. 2. Cluster formation phase.

Data structure of any cluster:
Cluster Head (CH): Sensor nodes with better threshold energy
Cluster Nodes (CN): All the nodes of any cluster, except CH.
C_MSG: It is a message, used for broadcasting purpose.
Cell_Center (C): Mid of each and every cluster.
$parent\_node_x$: parent node of x, initialized to ø.
$child\_node_y$: child node of y, initialized to ø.
N: Number of sensor nodes.
Cluster Head Election Procedure:

1. **Begin**
2. **for** each cluster i , **repeat**
3. C ← Center point of Cluster.
4. CH_i ← Select_Min-dist (C, N).
5. br_1 < C_MSG, CH_i_id, N_Cell_i > // Broadcast.
6. While receiving C_MSG by any CN.
7. **if** (CN ε N_Cell_i) **then**,
8. $parent\_node_{CN}$ ← CH_i_id.
9. **end if.**
10. br_1 < C_REPLY, CN_id, CH_i_id > //Reply
11. While receiving C_REPLY by CH_i_id.
12. **if** (CH_i_id ε N_Cell_i) **then**,
13. $child\_node_{CHi\_id}$ ← CN_id.
14. **end if.**
15. **end for.**
16. **end.**

Algorithm 2. Cluster formation procedure

Data structure for tree construction:
T_MSG: It is a message used for tree construction purpose.
$parent\_node_i$: parent node of i, initialized to ø.
$child\_node_j$: child node of j, initialized to ø.
Tree Construction Procedure:

1. **Begin**
2. **any** CH initiates the tree construction procedure.
3. **if** ($initiator\_node_x$==TRUE) **then**,
4. $parent\_node_x$ ← id_x.
5. br_1 < T_MSG, id_x, $parent\_node_x$ > //Broadcast.
6. **end if.**
7. **any** CH_y receives T_MSG from any CH_x
8. **if** (id_y == $parent\_node_x$) **then**,
9. $child\_node_{(y)}$ ← $child\_node_{(y)} \cup id_x$.
10. **else**
11. **if** ($parent\_selected_y$ == FALSE) **then**,
12. $parent\_node_y$ ← id_x
13. $parent\_selected_y$ = TRUE
14. br_1 < T_MSG, id_y , $parent\_node_y$ > //Reply
15. **else**
16. Drop the packet.
17. **end if.**
18. **end if.**
19. **end**

Algorithm 3. Tree construction procedure

3.1.2 Cluster formation phase

Cluster formation phase is initiated by grid formation phase in which the clusters are formed after the formation of the grid or cell. Cluster head (CH) and cluster nodes (CNs) are two different categories of sensor nodes which are represented in Fig. 2 by filled and unfilled bubbles respectively. Cluster head is having better threshold energy value than cluster nodes. As delineate in Algorithm 2, the cluster formation phase includes following operations:

- Initially the nodes having same energy level so that the node which is nearest to cell center is elected as cluster head. C_MSG is broadcasted by cluster head in the cluster formation phase. The format of C_MSG is <CMSG, CH_id, N_Cell>, here CH_id is the cluster head *id* and N_Cell denotes the cell number in which cluster head belongs.
- If any cluster node gets the C_MSG, it sends C_REPLY back to the corresponding cluster head, here cluster head becomes a parent node and a cluster node becomes a child node.

3.1.3 Tree construction phase

In this phase, the tree structure is constructed with cluster heads as a vertex of the tree. Any cluster head that provokes the tree construction procedure by broadcasting T_MSG is known as initiator node. The tree construction phase delineates in Algorithm 3 and also evince in Fig. 3. The following operations are included in the procedure of tree construction:

- Initiator node (say x) broadcasts T_MSG with the format <T_MSG, id_x, $parent\_node_x$>. Initially, the $parent\_node_x$ is the node (x) itself. If any other cluster head (say y) receives T_MSG then it checks whether it is $parent\_node_x$ or $child\_node_x$.

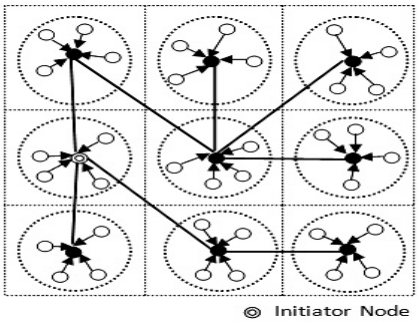

Fig. 3. Tree construction phase.

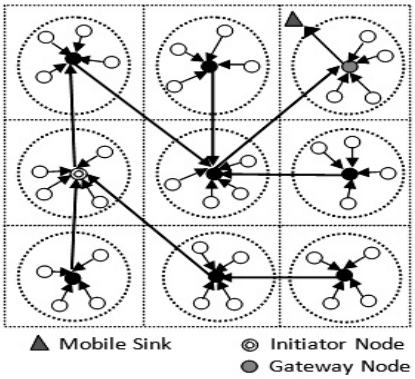

Fig. 4. Sink management phase.

Data structure for sink management:
Gateway Node (GN): The node nearest to the sink.
Sink: Mobile Base Station or Sink.
Sink_Loc: Sink location information.
S_MSG: It is a message, used for sink management purpose.
Sink Management Procedure:

1. **Begin**
2. br_1 < S_MSG, Sink_id, Sink_Loc > // Broadcast
3. While receiving S_MSG by any node i
4. br_1 < S_MSG, id_i, Sink_id > // Reply
5. **if** (Gateway_Selected == FALSE) **then**,
6. GN ← id_i
7. Gateway_Selected = TRUE.
8. $next\text{-}hop_{GN}$ ← Sink
9. **end if**.
10. **if** ($Status_i$ == CH) **then**,
11. **for** all cluster heads (CH_x), **repeat**
12. **if** ($parent\_node_x$ || $child\_node_x$ == TRUE) **then**,
13. br_1 < CH_x_id, $parent\_node_x$, $child\_node_x$ > // Broadcast
14. While receiving parent and child information by any node y.
15. **if** (id_y == $parent\_node_x$) **then**,
16. $next\text{-}hop_y$ ← $child\_node_y$.
17. **if** (id_y == $child\_node_x$) **then**,
18. $next\text{-}hop_y$ ← $parent\_node_y$
19. **end for**
20. **else** // ($Status_i \neq CH$)
21. CH ← $parent\_node_i$
22. **goto** Step (11).
23. **end if**.
24. **end.**

Algorithm 4. Sink management procedure.

- If the cluster head (y) is the $parent\_node_x$ then it includes cluster head (x) into its child node list. Otherwise cluster head (y) sends reply of T_MSG and now cluster head (y) becomes a $child\_node_x$.

3.1.4 Sink management phase

When sink moves from one location to another, sink management is required in the network. In the sink management phase the concept of gateway node (GN) comes into existence. The node which is nearest to the sink is known as gateway node. Sink management is delineated in Algorithm 4 and also evince in Fig. 4. Sink management phase includes following operations:

- Sink broadcast S_MSG in the whole network with the format of <S_MSG, sink_id, sink_loc>.
- If any node which is nearest to the sink receives S_MSG, then it sends replies back to the sink and become a gateway node. The next_hop of gateway node is sink. For defining data transmission path next_hop is used.
- The gateway node is either cluster head or cluster node. If it is CH then, it broadcasts its *id*, the parent node information and the child node information to any other CH *via* a tree structure. The receiver CH checks whether it is a parent node or child node of the sender's CH. If it is a parent node, then next_hop will be the $child\_node_{receiver}$ and if receiver CH is child node then next_hop will be $parent\_node_{receiver}$.
- If the gateway node is any cluster node, then firstly it selects the parent node to corresponding CH and then above process continues for managing the next_hop in the network.

3.1.5 Load balancing phase

When the cluster head's energy level reaches below to the threshold value of energy then, new cluster head (new_CH) is elected by selecting the maximum energy level node from the cluster. The new elected CH broadcasts the information to the rest of the nodes in the cluster. If any cluster node receives the message from new_CH then it selects new_CH as a parent node and sends replies back to the new_CH and the CN becomes a child node of new_CH. In this way only load balancing phase includes the new cluster head election procedure not tree reconstruction procedure.

4. Theoretical Analysis

According to theoretical analysis, the proposed protocol CTDD is more energy efficient protocol with relatively less delay than CBRP[9] and TBRP[7] because unlike CBRP and TBRP, there is no issue of frequent selection of cluster heads by probability function as well as frequent tree re-construction for load balancing. In GSTEB[10] protocol, the sorting techniques are required for arranging the sensor nodes as a vertex of a tree and also required Euclidean distance calculation for calculating the sensor node distances from BS, that increases the delay in the network and decreases the network lifetime. CTDD protocol overcomes the problem of network delay because in CTDD protocol tree is fixed in nature, i.e. no concept of tree re-construction. For load balancing, only cluster head is elected whenever it is required and elected new cluster head informs via LB_MSG to all its neighbor cluster nodes as well as to its parent or child cluster head about the new selection of cluster head.

5. Conclusion

The CTDD routing protocol is an energy efficient protocol with relatively less delay, this superiority increases the network lifetime. A CTDD routing protocol is a coalition of two concepts, i.e. cluster formation concept and tree formation concept of wireless sensor network, so CTDD routing protocol is much more reliable protocol than any other cluster based or tree based routing protocol.

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