LPEDAP: Localized Power Efficient Data Aggregation Tree Protocol for Wireless Sensor Networks

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Abstract

In wireless sensor networks, the sensors collects the data from the nearby environment and deliver it to the base station. This requires more power. The problem with the previous approaches is it acts in a centralized manner. To overcome this problem, a localized approach called LPEDAP is used. The approach for solving the aggregation and routing problem done in two phases are topology construction and aggregation/routing tree computation. The topology construction is done by LMST structure. Flooding based tree construction algorithm is used for obtaining the tree structure given a graph. After the parent node and children nodes for an individual sensor node are determined, the node can join the data gathering process. Parent node will wait until all the data from its child nodes and aggregate the data, and then, send the aggregated data to the base station. In addition to that, the route maintenance procedures will be executed when a sensor node is removed or a new node is added to the network.

Keywords

Wireless sensor networks, data aggregation, tree construction algorithms

I. Introduction

The design of wireless sensor networks depends on the application requirements. Environmental monitoring is an application where a region is sensed by sensor nodes and the sensed data are gathered at a base station (a sink) where further processing can be performed. The sensor nodes for such applications are usually designed to work in conditions where it may not be possible to recharge or replace the batteries of the nodes. This means that energy is a very precious resource for sensor nodes, and communication overhead is to be minimized. In order to reduce the communication overhead and energy consumption of sensors while gathering, the received data can be combined to reduce message size. A simple way of doing that is aggregating the data. An important problem studied here is finding an energyefficient routing scheme for gathering all data at the sinkperiodically so that the lifetime of the network is prolonged as much as possible. The lifetime can be expressed in terms of rounds where a round is the time period between two sensing activities of sensor nodes. There are several requirements for a routing scheme to be designed for this scenario. First, the algorithm should be distributed since it is extremely energy consuming to calculate the optimum paths in a dynamic network and inform others about the computed paths in a centralized manner. The algorithm must also be scalable. The message and time complexity of computing the routing paths must scale well with increasing number of nodes. Another desirable property is robustness, which means that the routing scheme should be resilient to node and link failures. The scheme should also support new node additions to the network, since not all nodes fail at the same time, and some nodes may need to be replaced. In other words, the routing scheme should be self-healing. The final and possibly the most important requirement for a routing scheme for wireless sensor networks is energy efficiency.

II. Related Work

A. Routing Protocols

There are also a number of protocols for data gathering with aggregation. Most of them are centralized approaches and assume that all the sensor nodes are in direct communication range of each other and the sink. Kalpakis et al. propose a linear programming solution to maximize the lifetime. The solution provides near-optimal results. However, their approach has high computational cost and must be applied in a central location. Heinzelman et al. propose a distributed two-level hierarchy called LEACH [4]. In this protocol, sensors randomly decide whether or not to become clusterheads. If not, they join the nearest clusterhead and transmit sensed data to it. Clusterheads aggregate collected data and transmit directly to the sink. The main Features of LEACH protocol consists of Local coordination among the sensors for cluster setup and operation.Randomized rotation of the cluster head for improved energy usage. Local data compression to reduce global communication.Since LEACH protocol relies on randomization; it is far from being optimal. Lindsey and Raghavendra proposed PEGASIS [10] protocol in which the sensors are organized into a chain by a centralized algorithm. They transmit to each other along the chain, aggregate received data, and last sensor in the chain transmits to the sink. Greedy algorithm is used for chain formation. Token passing approach is used by leader to start the data transmission from the ends of the chain. The cost is very small since the token size is very small. This approach is also not very efficient, since the transmission distances can be quite long and finding a minimum distance chain is NPcomplete (traveling salesman problem). Also, the delay is another problem for PEGASIS [10]. Tan and Korpeoglu showed that their protocol PEDAP [16], which routes the packets on the edges of an MST, improves the system lifetime dramatically. PEDAP protocol uses the link costs and computes the minimum energy cost tree by using Prim's MST algorithm. Also, PEDAP consumes the minimum amount of energy in a single round. Power-aware version of their protocol, which is called as PEDAP-PA [16]. This protocol provides near-optimal lifetime for the first node failure by sacrificing the lifetime for the last alive node. The idea behind PEDAP-PA is to use a power aware cost function for a link that considers the remaining energy of the sender. The PEDAP-PA algorithm simply finds the minimum spanning tree with these link costs. In order to balance the load, it recomputes the routing tree after a predefined number of rounds.

III. Proposed Work

To combine the energy-efficient features of the MST with the distributed nature of the shortest weighted path-based routing schemes, in order to efficiently and locally compute the routing

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paths that can also provide a superior network lifetime. The approach for solving the aggregation and routing problem consists of two phases: topology construction and aggregation/routing tree computation.

A. Topology Construction

In this phase, to constructs a sparse and efficient topology over the visibility graph of the network in a distributed manner. There are different alternatives for sparse topologies that can be efficient for energy-aware routing. Here neighbourhood structure called local MST (LMST) is used. LMST[11] is computed as follows: First, each node determines its one-hop neighbors and computes an MST for that set of nodes, based on the distance between nodes as the weight of the edges. After computing the MST of the neighbors, each node i selects the edges (eij) where node j is a direct neighbor of node i in its MST. The resulting structure is a directed graph. LMST needs a second message for informing about the LMST neighbors. This second message contains the local MST neighbors of the nodes, and hence, it is larger in size compared to the first message which contains only the location information. LMST structures are defined based on Euclidean distances; there can be used with other link cost functions as long as the functions are symmetric. An important advantage of using structures like LMST[11] is that they can be constructed very efficiently in a localized manner. Node deletions and additions do not globally change the structure. Only local changes in the structure are required and there can be efficiently computed when a node fails or when a new node is introduced to the network.

B. Routing tree computation

There are several methods for obtaining a tree structure (spanning all the nodes) given a graph. Here a flooding-based tree construction algorithm is used. A special route discovery packet is broadcasted by the sink and when a node receives that packet, it decides its parent according to the information in the packet. After selecting the parent, it rebroadcasts the packet. The SWP method tries to yield a tree that minimizes the cost of reaching the sink for each node.

The main goal in this phase is to find a sparse topology and set up the routes over it, which means determining the children and parent nodes for each node. At the end of this phase, a data aggregation tree rooted at sink is constructed. The pseudo code for this phase is given in Algorithm1.

Algorithm 1.Topology and Route Computation
1. Send HELLO message
2. Collect HELLO message for t_{hello}
3. Reset Parent (n, null)
4. Compute neighbours on the sparse topology
5. While ROUTE_DISCOVERY packet RD received in $t_{discovery}$ do
6. if update required for RD then
7. Update parent (n, source [RD])
8. Broadcast ROUTE_DISCOVERY
9. End if
10. End while
11. Inform n to construct its child list

Initially, the nodes and the sink are not aware about the environment. In the setup phase, all nodes and the sink broadcast HELLO messages, which include their location and remaining energy, using their maximum allowed transmit power. The remaining energy level is advertised only when dynamic (power-aware) protocols are used. Threshold time thello is given for waiting advertisements, which must be long enough to hear all possible advertisements. After receiving HELLO messages, all nodes are informed about their one-hop neighbors and their locations and energy levels. Each node can then locally compute its neighbors in the desired sparse topology. After finding its neighbors in the sparse topology, a node can join the distributed route computation process in order to find its parent and children on the aggregation tree. The route computation is done via a broadcasting process which starts at the sink node. The sink initiates a ROUTE-DISCOVERY packet in order to find and set up the routes from all sensor nodes toward itself. When a sensor node receives a ROUTE-DISCOVERY packet, it broadcasts the packet to all its neighbors on the computed topology if it updates its routing table. By this way, the routing tree rooted at the sink is established over the sparse topology. An important energy conserving feature of this algorithm is that the packet is sent with a power just enough for reaching all the neighbors on the sparse topology instead of using the maximum power. Each ROUTE-DISCOVERY packet has three fields: a sequenceID which is increased when a new discovery is initiated by the sink, an optional distance field which shows the cost of reaching the sink, and an optional neighbor list field which is the list of the neighbors of the sending node in the chosen topology. If the SWP on LMST[11] is used, which gives the best performance but have some overhead. But an important point to mention is that in this approach, since the LMST computation is combined with the route computation, no extra messages are used for negotiation among LMST neighbors. Only overhead is the size of the ROUTE-DISCOVERY packet. Upon receiving a new ROUTE DISCOVERY packet, the sensor node ignores the packet if it is not coming from a direct neighbor, in order to ensure using only the edges in the computed topology. After that, according to the routing strategy chosen, the node decides whether or not to update its parent. If SWP is chosen the node updates its parent only if the path using the sender node is advantageous in terms of total energy consumption. Regardless of the chosen strategy if the packet has a higher sequence ID, the node directly updates its parent. If the node decides to update its parent, it rebroadcasts the ROUTE-DISCOVERY packet with updated fields. If in the time threshold tdiscovery, no other route discovery packets are received, conclude that the route setup converged. At this step, each node can inform its parent, in order to construct the children list which will be used in data gathering phase. After this final step, the data aggregation tree is set up and stabilized. This means that each node knows from which neighbors it will receive data and to which node it will send the received data after aggregation.

C. Data Gathering

After the parent and children nodes for an individual sensor node are determined, the node can join the data gathering process. In data gathering phase, each sensor node periodically senses its nearby environment and generates the data to be sent to the sink. However, before sending it directly to the parent node, it will wait all the data from its child nodes and aggregate the data coming from them together with its own data, and then, send the aggregated data to the parent node. Thus, at the beginning of data gathering step, only leaf nodes can transmit their data to their corresponding parent nodes. At each step, the data are gathered upward in the tree and reaches the sink after h steps, where h is the height of the aggregation tree. The reason for waiting to receive data from child nodes is to use the advantage of the aggregation. In this way, each sensor only transmits once in a round, and as a result, saves its energy.

D. Route Maintenance

After setting up the routes, two events can cause a change in the routing plan: node failure and node addition. Node failures can be due to various reasons. However, the most critical reason is depletion of energy of a node. Previous approaches (e.g., [4], [10], [16]) did not discuss the node failure problem. In these approaches, however, a node failure in communication phase will cause a routing problem in which the descendants of the failed node cannot send their data until next setup phase. In order to prevent this, failures must be handled as soon as possible. The solution handles the case where failures are due to energy depletion. However, the idea behind the solution can be applied to other failure causes as well. Failure of a node due to energy depletion can be handled gracefully, since the node can predict that it will die soon due to energy limitation. Here Algorithm2 presents the route recovery algorithm. In this solution, when a node's energy reduces below a threshold value, the node broadcasts a BYE message using maximum allowed transmit power. All nodes receiving the BYE message will immediately update their local structure. This message is not required to be retransmitted since the node failures do not affect the structure globally. However, in this case, the nodes that cannot reach the sink because of the energy depletion of their ancestor must find a new cost-efficient path to send their packets. In this solution, this is handled in a localized manner as follows: The child nodes of the failed node that receive the BYE message reset their routing tables and enter the parent-discovery phase by broadcasting a special message PARENT-DISCOVERY to its neighbors on the structure. According to the receiver of that special message, if the sender is its own parent on the way to the sink, the receiver also resets its routing table and broadcasts the packet to its neighbors. In this way, all the nodes that should enter the parent-discovery phase will be reached. If the PARENT-DISCOVERY packet is received by a neighboring node of the sender and if it has a valid parent, the receiver constructs a new ROUTE-DISCOVERY packet as mentioned above and broadcasts it to the sender. It is worth to mention that the sequence ID in this new packet is not incremented; therefore, the update of the routing table takes place only when the newly received cost is smaller. After the route discovery phase converges, the new routes are set up and data gathering can continue.

Consider now the case of node additions. When a new node is deployed, it broadcasts a HELLO message. Its neighbors update their local structure upon receiving this message and also inform the new node about their existence and locations by replying a HELLO message so that the newly deployed node can also determine its neighbors. Nodes that update their local structure send back a ROUTEDISCOVERY packet including their costs to the newly deployed node. The new node selects the most efficient node as its parent and broadcasts this information by a new ROUTE-DISCOVERY packet. Since the sequence ID is again not incremented, the new packet is broadcasted throughout the network only when using the new node is advantageous

Algorithm 2.Route Recovery

```
n_old ← n
If BYE message B received then
   Remove source(B) from neighbour list
   Compute the sparse topology
   If source(B) = n then
      Reset parent (n ← null)
      Reset child list
      Broadcast PARENT_DISCOVERY message
      Enter route discovery phase
   End if
End if
If PARENT_DISCOVERY message PD received then
   If source(PD) = n then
      Reset parent (n ← null)
      Reset child list
      Broadcast PARENT_DISCOVERY message
      Enter route discovery phase
   Else
      If n ≠ null then
         Send ROUTE_DISCOVERY
      End if
   End if
End if
```

IV. Results

In a sensor networks consists of collection of nodes. Initially all the nodes have same energy level. The transmission ranges are different from the each other. All the nodes sense its nearby environment. Each node sends a hello message to all others nodes. Now each node knows its one hop neighbours nodes energy level. All the nodes starting to send the sensed data to the base station so the energy consumption of each node is high for transmission. The nodes deplete its energy quickly. This kind of transmission reduces the network lifetime so that can be avoided by using the proposed concept. Here the parent and child nodes are chosen based on its distance and its energy level. The parent node waits until collects the data from it's all the child nodes and then parent node aggregates the data and finally sends its aggregated data to the base station. So the sending of number of nodes and data to the base station may be reduced hence the lifetime of the network is increased.

The following snapshots are describing the results.

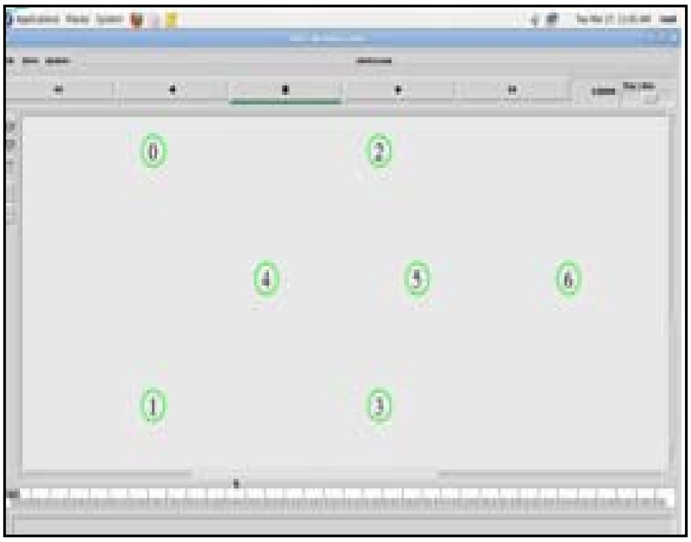

Fig. 1: Shows the Collection of Nodes in Sensor Networks

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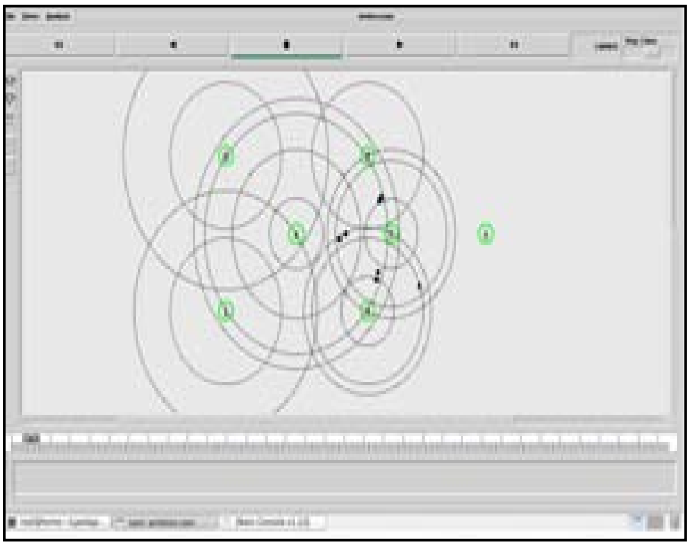

Fig. 2: Shows transmission range for each node.

Fig. 3: Packet data transfer from nodes to base station.

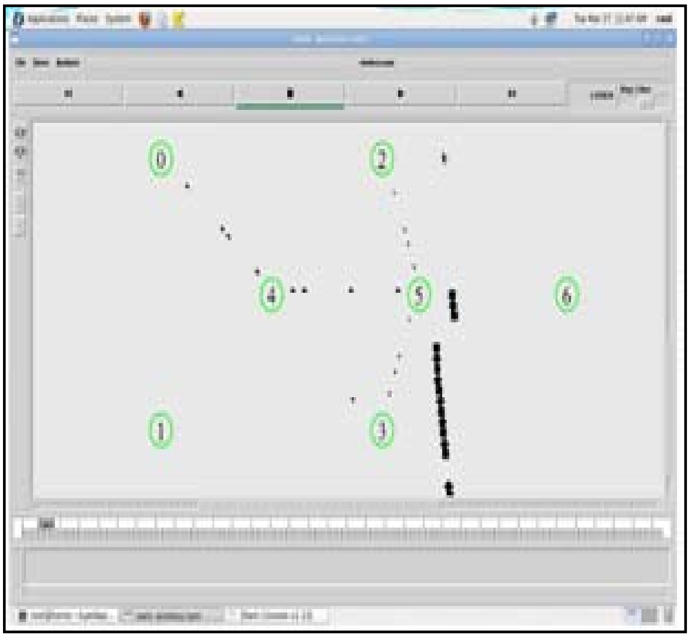

Fig.4 Bottleneck problem occurred at node5

Fig.4 Energy level of nodes is reduced

Fig.5 Nodes completely dry its energy.

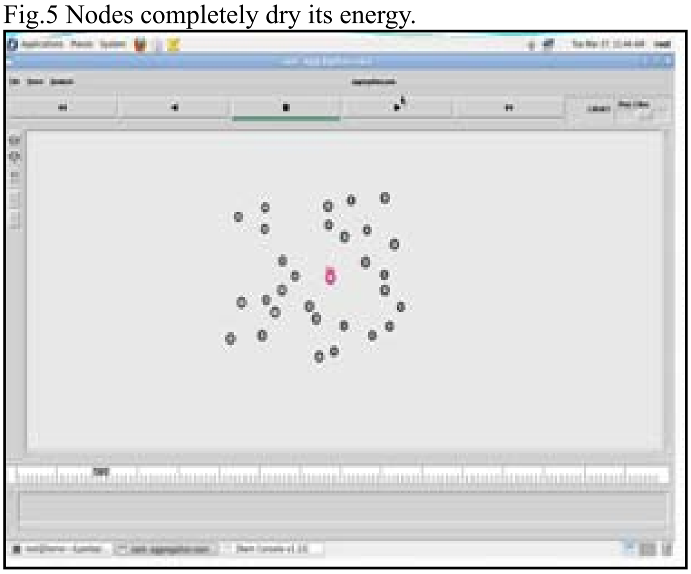

Fig. 6 Now parent, child nodes are selected.

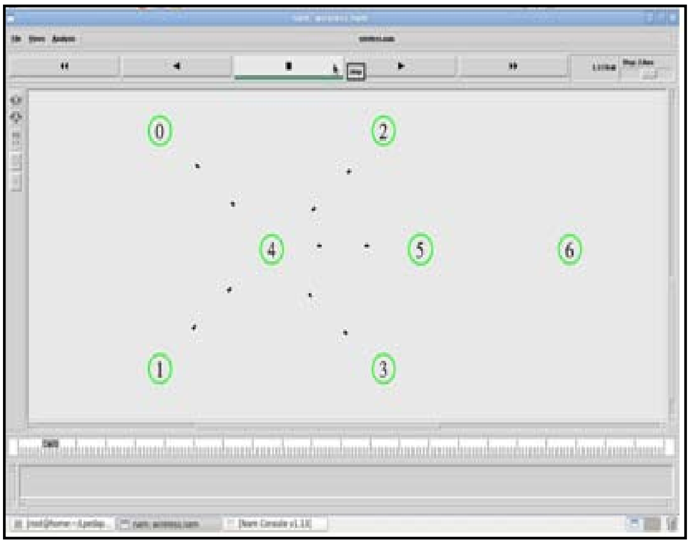

Fig. 7: Parent node Aggregates the data coming from its child nodes with its own data

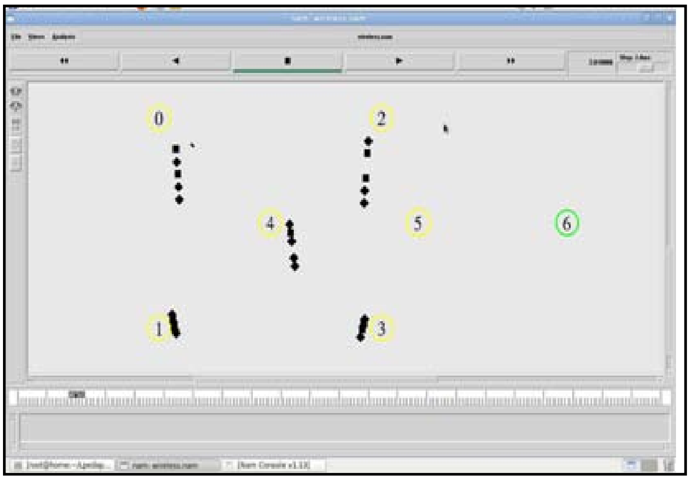

Fig.8 Nodes will depletes its energy slowly when compared to without data aggregation

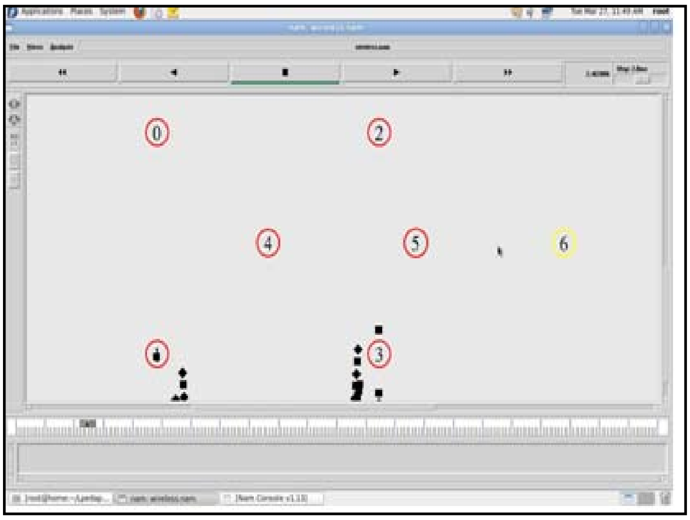

Fig.9 Nodes completely dry its energy at later time.

V. Conclusion

In this paper, presented a new energy-efficient routing approach that combines the desired properties of minimum spanning tree and shortest weighted path tree-based routing schemes. The proposed scheme uses the advantages of the powerful localized structures such as LMST and provides simple solutions to the known problems in route setup and maintenance because of its distributed nature. The proposed algorithm is robust, scalable, and self-organizing. The algorithm is appropriate for systems where all the nodes are not in direct communication range of each other.

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