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Survey on Data Gathering Approaches in Wireless Sensor Networks

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Abstract

Objective: To study the diverse data gathering approaches and issues involved in wireless sensor networks. **Method:** This study deals with traditional cluster architecture, challenges in clustering, bibliographical survey on numerous data gathering approaches based on the sink deployment such as cluster based data gathering, mobile element data gathering and its diversification. The most recent data and references have been further examined so as to concentrate key data and mapped into particular subsections. **Findings:** Based on the sink deployment, data gathering approaches are classified as static sink and mobile sink data gathering. In static sink data gathering approach, because of multi-hop communication, nodes near the sink depletes its energy very quickly. It makes the network unreachable. In Mobile Element (ME) data gathering, ME visits each sensor node in its transmission range and collects the information via single-hop communication. It results in delayed data gathering. It also gives packet loss due to smaller memory in the sensor node. Communication range and memory size of the sensor node, speed and traversal pattern of the mobile element play a vital role in determining the performance of wireless sensor network.

Keywords: Clustering, Data Gathering, Mobile Sink, Static Sink, Wireless Sensor Networks

1. Clustered Architecture

Clustering is the fundamental approaches for designing energy efficient, robust and highly scalable sensor networks. Clustered organization dramatically reduces the communication overhead, thereby minimizing energy consumption and interference among the sensor nodes. Furthermore, by aggregating the sensor's data at a designated node called the cluster head, the total amount of data to the base station can be shortened.

The key elements involved in the clustering Figure 1 are

- Cluster head
- Cluster member
- Base station

1.1 Cluster Head

In each cluster, one special node is elected as Cluster Head (CH). The role of CH is to collect the information from the sensor nodes called cluster members in the local sensing region and performs the aggregation operation in order to eliminate the redundant transmission. Finally, it transmits the fused information to the BS either via single-hop communication or multi-hop communication.

1.2 Cluster Head Election Strategies

- Probability based selection
- Random selection

In probability based CH election method, each and every sensor node is assigned with certain probability based on which CH election is carried out. In the random selection method, the CH is elected based on some certain conditions, such as energy level, proximity, connectivity etc.

1.2.1 Cluster Member

The role of the cluster member is to sense the environment

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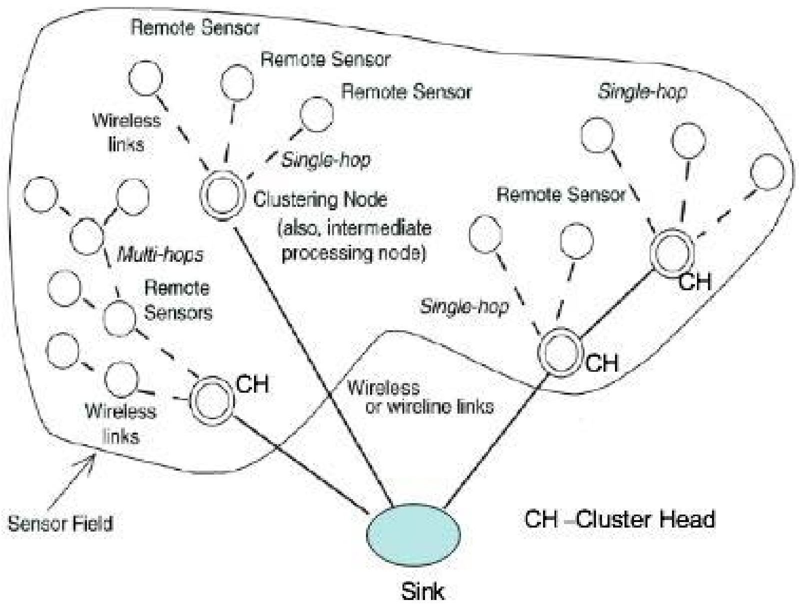

Figure 1. Clustered Architecture.

and deliver the information to the CH via either single-hop or multi-hop communication based on the Euclidean distance. The energy level of the cluster member is lower than that of the CH.

1.2.2 Base Station

The information gathered from the sensor nodes are finally relayed to the special node called Base Station (BS). It has enhanced capabilities than the simple sensor nodes, since they perform the complex operations.

1.3 Challenges in Clustering

The planning of clustering protocol is one of the major challenges for economical routing of packets. Some of the planning challenges in the clustering are listed below.

(i) Energy management

For wireless networks, the efficient use of this energy is vital. Hence, the clustering protocol tackles the problems of power management of sensors within the clustered networks.

(ii) Position estimation

The cluster head consumes energy, when the sensor node position is not identified by cluster head. The node may waste its energy in identifying the particular nodes for routing and, thereby the battery power drains, which raises the challenges to form energy potency and scalability issue of the cluster network crucial.

(iii) Cluster formation

The most important challenges in clustering is the Cluster Head (CH) selection and cluster formation. The design of the best cluster preserves the challenges of low message exchange and the total time complexity is independent of the application.

(iv) Data aggregation

The proven challenges of style of clustering protocol are able to support in solving the challenges of knowledge aggregation of the routings. The aggregation within the clustering creates an energy optimization for the facility management of sensor networks.

(v) Cluster size and cluster count

Cluster size and cluster density are very important factors considered while designing the WSN as it affects the network lifetime.

Cluster size is defined as the number of cluster members in a particular cluster. When the size of the cluster is small, energy consumption in intra-cluster communication is low and in inter-cluster communication is high, whereas when the size of the cluster is high, energy consumption in intra-cluster communication is high and in the inter-cluster communication is low. Hence, the calculation of optimum cluster size and its density are the greatest challenges.

2. Cluster based Data gathering Approaches

Low Energy Adaptive Clustering Hierarchy (LEACH)[1], is one in all the pioneering cluster based routing approaches for WSNs. The fundamental thought of LEACH has been a motivation for some consequent cluster based routing protocols. The main objective is to distribute the energy load evenly among the sensors in the network by the random rotation of the cluster head. It is a hierarchical, probabilistic, distributed, and a one hop protocol that works in rounds. Round is the time duration for which a node elects itself as CH and serves to other nodes.

Each round is alienated into two phases: i) cluster setup phase and ii) steady state phase. Cluster formation and cluster head selection are carried out in the set up phase. Data transmission is carried out in the steady state phase. LEACH creates clusters based on the Received Signal Strength (RSS) by employing a distributed algorithm, where every node creates autonomous decisions without any centralized control. At the time of cluster formation, each sensor node elects itself as a cluster head for the current round by generating the random number between 0 and 1. This generated number is compared with the threshold value. If the generated number is less than the threshold value, then it becomes the clustered head, else it becomes the cluster member.

$$T(\mathrm{n}) = \begin{cases} \dfrac{P}{1-P\left(\mathrm{rmod}\dfrac{1}{P}\right)}, if\ n \in G \\ 0 \quad , \quad else \end{cases} \tag{1}$$

where P denotes the desired percentage of CHs, r denotes the current round, and G is the set of nodes that have not been elected CHs in the last rounds. Once the cluster heads are elected, the remaining nodes are attached to the cluster head based on the RSS.

In[2] proposed a clustering technique which balances the load among the cluster by using special nodes called backup nodes. It is outfitted with high energy and high processing power and replaces the cluster head after the cluster reaches its threshold limit. This approach improves the network lifetime and provides high throughput. When the energy level of the CH reaches to the threshold value, the CH activates one of the sleeping nodes and makes it CH. This information about the new CH is sent to the entire cluster members and other CH also. The old CH becomes the general sensor node.

In[3] introduced an efficient cluster based power saving scheme for wireless sensor networks (SECA). The main objective is to extend the network lifetime by using uniform cluster location and balance the network load among the clusters. K-Means algorithm is used to partition the network into equal sized clusters. Cluster head is elected based on the both hybrid energy levels of the sensor node and the Euclidean distance between the sensor nodes.

In[4] proposed a clustering algorithm for non uniformly distributed sensor nodes in wireless sensor network for balancing energy consumption and improving the network lifetime. The distribution of the sensor node affects the lifetime of the individual nodes as well as the wireless sensor network because the nodes at different locations have a different energy loss due to the distance from the base station.

3. Mobile Element Data Gathering Approaches

Normally in static sink data gathering approach, sensor nodes transmit its data via multi hop communication, which makes the nodes around the sink deplete its energy very soon. Furthermore, long distance communication from CH nodes to farthest located static sink, and frequent re clustering increases the energy consumption.

To avoid energy hole problems[5,6] and to prolong the network lifetime, mobile sink was introduced. The mobile sink also plays a vital role in rectifying the load balance, path reconfiguration and congestion control related problems.

In[7] addressed the fundamental and significant challenges for Networked Info Mechanical Systems (NIMS). NIMS introduce an embedded networked sensor architecture exploiting infrastructure for constrained actuation. Precise, wide range actuation enables the NIMS systems design to address underlying problems related to traditional static sensor networks, including active reduction of sensing uncertainty and sustainable adaptation to environmental dynamics.

The following literature explains about some of the existing energy optimization methods using mobile sink.

3.1 Mobile Element in Delay Tolerant Application

In[8] had proposed mobile element data gathering approach, in which mobile element acted as a mechanical agent outfitted with a powerful transceiver and battery. It directly gathered the information from the sensors via single hop communication when traversing in its communication range and eventually delivered the collected information to the remote central.

In[9] had presented mobile element to gather the data from the sensor nodes effectively. Data collected from the sensor nodes by the Mobile Element (ME) without packet loss is known as the ME scheduling problem (MES), which visits every sensor node in its transmission range and collects the sensed data before the buffers are full.

In[10] have developed sensor networks with mobile sinks for delay tolerant applications like intelligent space applications with large latency tolerance or environmental applications. Due to the mobile sink, multi hop communication is converted into single hop. Also the node transmits data only when the sink reaches the vicinity of the nodal area.

In[11] analyzed heterogeneous sensor networks with energy rich mobile relays, where they can dynamically move around the network to relieve sensors that are heavily burdened by high network traffic, thus extending the node lifetime.

In[12] proposed an optimization algorithm to expand the network lifetime in delay tolerant applications. WSNs are projected to be deployed in inaccessible and hostile environments such as battlefields, dense jungles, etc.; dense deployment brings various problems, such as severe medium access control contentions and difficulties in network management. Here the sink will be attached to an unmanned vehicle which flies over few safe locations within a limited operation time. The nodes send the data to mobile sink when the sink, that reaches the favorable location until it keeps the data with them.

From the above approaches, the static sensors only send their data when the sink is close enough to them. The shortcoming of such proposals is that there would be a considerable delay in packet delivery, since a node needs to wait for the sink to approach it.

3.2 Mobile Element in Delay Constraint Applications

In several applications, where the delay is a constraint, techniques utilizing multiple mobile relays or multiple mobile sinks have been proposed are assuming one hop communications to these sinks or relays[13,14] introduced mobile agents, which collected the information from the nearby sensor nodes on behalf of the immobile sink. When the mobile agents visited the proximity of the sink, they forwarded the collected data to the sink. Here single hop communication was adopted and random walk model was used. This is not applicable for delay tolerant applications because it was assumed that the delay of the collected data was bounded.

The multi-hop, single sink alternative was also studied, by concentrating on developing algorithms for adaptive mobility in order to increase the network lifetime[15-17].

In[18] had proposed WSN model, in which the mobile sink can visit only a small number of locations, the lifetime was increased by optimizing schedule of sink visited and by routing of the traffic.

To reduce the delay, several methods have been proposed[19,20] where the data are sent to the mobile sink through multi hop communication. Transmission scheduling of packets through a single shared channel for mobile sink was developed[21].

In[22] suggested data collection of mobile agents from the cluster heads. The sensor nodes were grouped into clusters. The cluster heads were determined and the agent traveled through the cluster heads. The length of the mobile agent is reduced. So the energy consumption was reduced. However, the cluster head node's energy was drained drastically when compared to the other nodes.

3.3 Data Collection using Path Constraint Single Mobile Element

The movement of the mobile sink is predicted and also controlled when it is used[23].

The Vehicle Routing Problem (VRP) is defined as determining a route for a vehicle that diminishes the total travel cost to deliver cargo between a warehouse and the customers. Unlike Travelling Salesman Problem (TSP), VRP considers more than one vehicle and the sensor nodes can be visited more than once[24,25] .

In[26] used a linear programming problem to determine the movement of the mobile sink and the duration to park the mobile sink at each point along the path of the sink so as to prolong the lifetime of the WSN.

In[27] proposed multi-hop sensor networks with a path constrained mobile sink, where the Shortest Path Tree (SPT) is employed to choose the cluster heads and route data that may result in low energy efficiency for data collection.

The nodes must be aware of the movement of the sink in WSNs with a path predictable mobile sink routing protocol called MobiRoute, which is an energy consuming one[28]. Random sink trajectories were used to collect the data[29], where mobile sinks are mounted on some people or animals moving randomly.

In[30,31], offered a mixed integer linear programming problem formulation to attain the optimal travel path of the sink and the sojourn times in the sink stops for prolonging the lifetime of the system.

In[32] projected numerous heuristic solutions for the ME scheduling problem such as Earliest Deadline First (EDF), EDF with k-look ahead and Minimum Weighted Sum First (MWSF). In EDF, the sensor node with the earliest deadline is visited first. A inadequacy of this algorithm is that it relies exclusively on the deadline and supplementary factors are not considered. To augment this, EDF with k-lookahead has been presented, in which ME visits the sensor nodes based on the permutations of the k earliest deadline nodes. The permutation is selected in such a manner that none of the k nodes miss their deadline. For every visit, k nodes are looked ahead and the node for the next visit is selected based on the permuted value. The third algorithm is the MWSF, which considers the weights of the deadlines as well as the distance between the nodes in determining the visiting schedule. However the MWSF algorithm performance is considered to be the best, the incidence of the back and forth movement between distant away nodes is recurrent. The cost and the speed factors have been fixed as a constant in all the above problems.

Path constraint sink mobility was adopted in[33,34], single hop sensor networks to improve the energy efficiency, which may be infeasible due to the limits of the path location and communication power.

3.4 Data Collection using Path Constraint Multiple Mobile Element

Due to the path constraint, a single mobile sink with constant speed has limited the communication time to collect data from the sensor nodes that are deployed randomly, hence it is a challenging task to jointly improve the amount of data collected and reduce the energy consumption.

To conquer these drawbacks, multiple mobile sinks were presented, [35]proposed the data collection scheme called as Maximum Amount Shortest Path (MASP), that increases network throughput and improves energy by optimizing the assignment of sensor nodes with multiple sinks and used multi hop mode. They formulated Maximum Amount Shortest Path (MASP) problem as a 0-1 Integer Linear Programming (ILP) problem which aims to calculate the optimized mapping between members and sub sinks to maximize the network lifetime.

4. Conclusion

This study investigates various data gathering approaches in wireless sensor networks in various aspects. Communication distance, the energy level of the sensor node, data gathering speed, memory size of the sensor node, the traversal pattern of the mobile element determine the performance of the wireless sensor network *viz.* packet delivery ratio, lifetime of the sensor network, routing overhead, etc. It has been observed that many research avenues are open up for energy efficient data gathering in wireless sensor network.

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