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A Survey on Algorithms for Cluster Head Selection in WSN

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Abstract— **Wireless Sensor Network is a resource constraint network, in which all sensor nodes have limited resources. In order to save resources and energy data must be aggregated to reduce the amount of traffic in the network. Data aggregation has to done with the help of clustering scheme. Clusters reduce the localized traffic by means of grouping sensor nodes and compress the data together and then transmit only compact data to base station. Therefore optimal cluster head selection is important to maximize the lifetime of the network by utilizing the limited energy in an efficient manner. Various algorithms are proposed for the selection of cluster head for maximizing the network life time. This paper is focused on the survey of such algorithms.**

***Index Terms*— Cluster, Hierarchical Cluster, Cluster Head Selection, Energy factor.**

I. Introduction

Wireless Sensor Network [1],[2],[3] (WSN) consists of autonomous sensors to monitor physical or ecological conditions, such as temperature, sound, pressure, etc. and to cooperatively bypass their data through the network to a main location. The development of wireless sensor networks was motivated by military applications such as battlefield supervision; today such networks are used in many manufacturing and consumer applications, such as process monitoring and control, health monitoring [4], etc.

Sensor nodes can be imagined as small computers, extremely basic in terms of their interfaces and their components. They usually consist of a processing unit with limited computational power and limited memory. Every sensor node has a power source typically in the form of a battery. The base stations may have one or more components of the WSN with infinite computational, energy and communication resources. They act as a gateway between sensor nodes and the end user as they typically forward data from the WSN on to a server.

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II. Clustering in WSN

Hierarchical clustering is the efficient way [5] to utilize the energy in an efficient manner. Grouping of sensors that performing similar tasks are known as clusters. In hierarchical cluster, it contains Cluster Head, Regular Nodes and Base Station. After the cluster head is selected, it collects the data from all of its member nodes and aggregates it in order to eliminate the redundancy. Thus it limits the amount of data transmission to Base Station, hence remaining energy level is increased and network lifetime is maximized. There are several key attributes [6] which must be carefully considered, while designing the clusters in WSN:

A. Clustering Parameters

1) Number of Clusters

It may be varied according to the CH selection algorithms. In some cases this count will be the predestined one.

2) Intra-cluster Communication

Communication between the regular node and CH may be one-hop communication or multi-hop communication.

3) Nodes and CH Mobility

Cluster formation is dynamically changed in the case of sensor nodes are in mobility.

4) Node Type and Roles

Nodes may be in homogeneous or heterogeneous nature. In homogeneous, all sensor nodes have same capabilities such as same energy level, configurations. In heterogeneous, nodes are varied in configurations.

5) Cluster Head Selection

CHs are elected from the deployed nodes based on the criteria such as residual energy, connectivity, communication cost and mobility.CH selection may be in deterministic or probalistic manner.

6) Multiple Levels

In very large networks, multi level clustering approach is used to achieve better energy distribution.

7) Overlapping

Most of the protocols do not support for overlapping of different clusters.

B. Issues to be Considered in Clustering

To create an organizational structure among sensor nodes in WSN, it has the ability to deploy them in an ad hoc manner, as it is not feasible to organize these nodes into groups' pre -deployment. For this reason, there has been an large amount of research in ways of creating these organizational structures(or clusters).The clustering phenomenon, plays an important role in not just organization of the network, but can dramatically affect network performance. There are several key limitations in WSNs, that clustering schemes must consider.

1) Limited Energy

Unlike energetic designs, wireless sensor nodes are "off-grid", meaning that they have limited energy storage and the efficient use of this energy will be vital in determining the range of suitable applications for these networks. The limited energy in sensor nodes must be considered as proper clustering can reduce the overall energy usage in a network.

2) Network Lifetime:

The energy limitation on nodes results in a limited network lifetime for nodes in a network. Proper clustering should attempt to reduce the energy usage, and hereby increase network lifetime.

3) Limited Abilities:

The small physical size and small amount of stored energy in a sensor node limit many abilities of nodes in terms of processing and communication abilities. A good clustering algorithm should make use of shared resources within an organizational structure, while taking into account the limitation on individual node abilities.

4) Application Dependency:

Often a given application will heavily rely on cluster organization. When designing a clustering algorithm, application robustness must be considered as a good clustering algorithm should be able to adapt to a variety of application requirements.

III. CLUSTERING ALGORITHMS BASED ON WITHOUT ENERGY CONSIDERATION

A. LEACH Protocol [Low Energy Adaptive Clustering Hierarchy]

LEACH protocol organizes the nodes by themselves. Regular nodes in cluster send data to Cluster Head (CH). Cluster Head aggregates the data and sends to base Station. In LEACH [7] Cluster Head Selection is based on the desired percentage of CHs for the network and number of times the node has been a CH so far. Each node should select a random number between the interval 0 &1. If the generated random number is less than threshold then the node becomes a CH for current round. Threshold is obtained by using the following formula:

$$T(n) = \{ P/1\text{-}P*(r \bmod 1/P) \quad , \text{if } n \in G$$

Where, P is the desired percentage of clusters; r denotes the current round; G denotes set of nodes that have not been CHs in the last 1/P rounds. Cluster Head Selection, Cluster Formation and Data Communication are taken place at a time instant is known as rounds. Each round has two phases: Set-up Phase & Steady State Phase. During Set-up Phase Cluster Head announces its election by sending advertisement message to all other nodes in order to form the cluster. During Steady State Phase each CH creates TDMA schedule for their members to transmit their data and it also tells when it to transmit. Nodes can send data during their allocated period. Radio of regular nodes is turned off until their scheduled time reached. Thus the energy is saved. Finally CH aggregates all data and **sends** to Base Station. Problems in Leach are i) CH selection is random and it does not consider about energy consumption of nodes. Therefore there may be a chance for CH will die earlier than other nodes. When CH dies, the cluster will become useless. ii) It cannot cover large area and CHs are not uniformly distributed. iii) It cannot be able to address the schedulability and predictability measures.

B. Adaptive Contention Window Based Cluster Head Election Mechanism [ACW]

In this [8] all sensor nodes randomly pick up a back off value from the contention window based on uniform distribution. The node which has minimal back off value can become Cluster Head. Back off means, during transmission if the node detects an idle channel, it transmits a frame. If collision occurs, then the node has to wait for a random amount of time and starts all over again. By using this mechanism, cluster head distribution becomes uniform. Probability of Cluster Head Selection is high compared to LEACH. This also suffers by the same problem of LEACH because this mechanism also not considers the energy consumption of nodes. If the initial length of the contention window is not properly set, then it leads to lower probability of success in the selection of Cluster Head. By this algorithm, it is possible to select the CH better than LEACH but this mechanism does not focus on predictability.

C. Clustering and In Network Processing Routing Algorithm: CIPRA

In this, cluster formation and routing tree construction are carried out simultaneously so that they reduce their energy required to organize a multi-hop routing tree of sensed data. Here data aggregation is performed by each and every node. Thus it reduces the amount of transmission. Cluster Head Selection is based on the total number of sensors and its unique ID. Cluster Head is obtained by using the formula **i mod N** for every round. If other nodes are not able to obtain the elected message, then they have to rerun the CH selection. Once CH is selected, routing tree is constructed then data transmission will take place [9].Here each node consumes an amount of energy to receive message from several tentative parent nodes. In CIPRA, sensor nodes can **be** able to dynamically adjust radio transmission energy in order to adapt the topology changes. But CIPRA technique can select only one CH at a time to reduce energy requirement. To select multiple CHs, residual energy should be considered. Even CIPRA can adopt the dynamic changes; it is very difficult to predict the life time bounds of network.

IV. CLUSTERING ALGORITHMS BASED ON ENERGY CONSIDERATION

A. Energy Residue Aware (ERA) Algorithm

In this algorithm, CH election is same as that of LEACH. But it differs from cluster formation that is association between cluster head and other nodes. After the CH is elected according to LEACH, CH estimates their residual energy [10] and broadcast this information to all other nodes. Residual energy of CH is calculated by subtracting the remaining energy of CH in current round from energy requirement for transmitting data to base station. All other regular nodes calculate their residual energy by subtracting their remaining energy in current round from energy requirement for transferring data to every CH. After this they associate with one CH according to the sum of maximum energy residue path. Thus it maximizes the network lifetime by balancing the energy consumption of the network. In LEACH, regular nodes choose their cluster head according to shortest distance; due to this there will be a chance for dying CH in earlier. Compared to LEACH, ERA prolongs network life time by balancing the energy consumption of nodes. ERA ensures optimal CH selection, prolongs network life time but it does not focus on predictability of network.

B. LEACH – C Algorithm [LEACH – Centralized]

In this, Cluster Head Selection depends on the current location of the node and residual energy [11]. During setup phase, each node sends its current location and residual energy to base station. Base station estimates the average energy from the collected energy information. It finds that which node‘s energy level is higher than average energy level; and those nodes will be selected as Cluster Head. After selection, base station broadcasts the message along with selected Cluster Head’s ID to all nodes. Node whose ID is matched with the ID containing in the message becomes CH. In LEACH –C, CHs are dispersed throughout the network because it is based on location & residual energy. Here the problem is, base station is responsible for calculating average energy level; in case any one of the node fails to communicate with base station due to far away from base station then the successful probability of CH selection is less. LEACH – C considers the energy level of network but not focuses on predictability of network.

C. Efficient Cluster Head Selection Scheme For Data Aggregation [EECHSSDA]

EECHSSDA [12] overcomes the problem of LEACH- C. Cluster Head Selection is same as that of LEACH-C. With decrease in energy level at CH, it selects Associate CH (ACH). If CHs energy is going to drain, ACH acts as a CH. For ACH selection, the node which has higher energy level after the energy of CH is less than average energy acts as an ACH. Due to this ACH,, no need to select the CH periodically.Hence it reduces load overhead, energy consumption and no need to select CH periodically. EECHSSDA ensures to obtain optimal cluster head, energy efficiency, but not addresses any schedulability bounds of network; hence it does not focus on predictability.

D. Hybrid Energy- Efficient Distributed Clustering [HEED]

HEED [13] is a hierarchical, distributed, clustering scheme. It allows single hop communication within each cluster and allows multi-hop communication between CHs and base station.CH selection depends on residual energy and intra cluster communication cost. Residual energy is used to set the initial set of cluster heads. Intra cluster communication cost is used for deciding to join a cluster or not. This cost value is based on node’s proximity or node’s degree to the neighbor. Each sensor node estimates CH_{prob} value for becoming a CH as follows :

$$CH_{prob}=C_{prob} * Er_{esidual}/E_{max}$$

This probability value should not **be** beyond the threshold value P_{min}; P_{min} is inversely proportional to E_{max}. This algorithm consists of constant number of iterations. Every node goes through this iteration until it finds a CH that it will be the node with least communication cost. At the end of iteration every node doubles the CH_{prob} value. Iteration will be terminated if CH_{prob} value reaches 1.Two types of CH status that a sensor node announces to its neighbors; i) Node becomes a tentative CH with CH_{prob} less than 1; ii) Node becomes permanently becomes a CH if its CH_{prob} reaches 1. At the end final CHs are considered as CHs, and tentative CH becomes regular nodes. In this, if two nodes are within the transmission range of each other, then the probability of selecting CH will be small. But in HEED, synchronization is required and energy consumption is significant if CHs are far away. It also requires knowledge of entire network to determine the intra cluster communication cost; in practical it is very difficult to calculate the cost. So it is very difficult to obtain the network lifetime bounds to ensure predictability.

E. Probabilistic Clustering Algorithm

This algorithm is the extended version of HEED[14]. This algorithm is used to generate a small number of CH in relatively few rounds, especially in sparse networks. It has three phases: i) Core Head Selection ii) Cluster Head selection iii) Finalize CH. During Core Head Selection each node checks whether its cost is least among its neighbors. If it is true, then it will set itself as Core Head; otherwise select the neighbor node with least cost as Core Head. During Cluster Head Selection other than Core Heads are involved. CH selection procedure is same as of HEED. During final round, final CHs are considered as CHs, and tentative CH becomes regular nodes. In this, every regular node must have one neighboring final CH with the highest priority as its CH; otherwise it will be considered as an uncovered one. All uncovered nodes run the Core Head Selection procedure in order to select some extra CHs. Here also obtain the predictability bounds of network is difficult.

F. High Energy First Algorithm [HEF]

HEF is used to obtain the optimal Cluster Head, maximize the network life time & schedulability bounds also derived under IOCH [15]. Here the Cluster Head is elected based on maximum residual energy. After each round, energy consumption of CH and regular nodes **are** calculated. From this calculated value, those nodes contain higher residual energy will be selected as CH. Cluster formation is similar to LEACH. HEF algorithm is based on residual energy, at different rounds nodes have maximum energy will be selected as CH. So the drain rate of the nodes will be linear and packet delivery rate is increased. At the end of each round, utilization of energy is better and hence network lifetime is prolonged in higher level compared to other algorithms. It also supports for deriving life time bounds for performing schedulability test to ensure predictability of the nodes. This prediction is very much helpful for real time WSN.

V. COMPARISON OF ALGORITHMS

From this survey, it is observed that, clustering algorithms without energy awareness, CH cannot be rotated, and loads cannot be shared. Therefore it is difficult for sensors to choose the most appropriate cluster heads to maximize their network lifetime, and hot-spot CH sensors die quickly. Clustering algorithms with energy awareness does not address the schedulability analysis. In this predictability of optimality is in stochastic nature. It does not guarantee that the hard network lifetime constraints can be met.

TABLE I
COMPARISON OF CLUSTER HEAD SELECTION ALGORITHMS

Clustering Approach	**CHs Selection**	**CHs Rotation**	**Energy Factor**	**Prolong Network lifetime**	**Predictability**
LEACH	Prob/ random	Yes	No	Yes	No
ACW	Backoff	Yes	No	Yes	No
CIPRA	ID-Based	Yes	No	Yes	No
ERA	Prob/ random	Yes	Yes	Yes	No
LEACH - C	Average Energy	Yes	Yes	Yes	No
EECHSSDA	Average Energy	Yes	Yes	Yes	No
HEED	Prob/ Energy	Yes	Yes	Yes	No
Extended HEED	Prob/ Energy	Yes	Yes	Yes	No
HEF	Residual Energy	Yes	Yes	Yes	Yes

VI. CONCLUSION

To maximize the network life time optimal cluster head selection is important. CHs require more energy than all other nodes because they perform processing, sensing, communication and aggregation. In case, the cluster head dies in earlier, then the entire network becomes useless; since the CH cannot communicate with Base Station. To obtain optimal cluster head, CH should be elected based on the residual energy of each and every node. Therefore energy efficiency is maximized & network lifetime is also prolonged.

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