A COMPARATIVE STUDY OF CLUSTERHEAD SELECTION ALGORITHMS IN WIRELESS SENSOR NETWORKS

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ABSTRACT

In Wireless Sensor Network, sensor nodes life time is the most critical parameter. Many researches on these lifetime extension are motivated by LEACH scheme, which by allowing rotation of cluster head role among the sensor nodes tries to distribute the energy consumption over all nodes in the network. Selection of clusterhead for such rotation greatly affects the energy efficiency of the network. Different communication protocols and algorithms are investigated to find ways to reduce power consumption. In this paper brief survey is taken from many proposals, which suggests different clusterhead selection strategies and a global view is presented. Comparison of their costs of clusterhead selection in different rounds, transmission method and other effects like cluster formation, distribution of clusterheads and creation of clusters shows a need of a combined strategy for better results.

Keywords

Wireless Sensor Network, cluster-head (CH), LEACH

1. INTRODUCTION

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion pollutants at different locations.

Wireless sensor networks consist of hundreds to thousands of low-power multi functioning sensor nodes, operating in an unattended environment with limited computational and sensing capabilities. In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller and an energy source, usually a battery. These inexpensive and power-efficient sensor nodes works together to form a network for monitoring the target region.

Through the co-operation of sensor nodes, the WSNs collect and send various kinds of message about the monitored environment (e.g. temperature, humidity, etc.) to the sink (base) node, which processes the information and reports it to the user.

The development of wireless sensor networks was originally motivated by military applications such as battlefield surveillance [2]. Recent developments in this technology have

made these sensor nodes available in a wide range of applications in military and national security, environmental monitoring, and many other fields.

Wireless sensor networks have the following characteristics:

- ✓ It includes two kinds of nodes:
 - 1. *Sensor nodes* with limited energy can sense their own residual energy and have the same architecture;
 - 2. One *Base Station (BS)* without energy restriction is far away from the area of sensor nodes.
- ✓ All sensor nodes are immobile. They use the direct transmission or multi-hop transmission to communicate with the BS.
- \checkmark Sensor nodes sense environment at a fixed rate and always have data to send to the BS.
- ✓ Sensor nodes can revise the transmission power of wireless transmitter according to the distance.
- ✓ Cluster head perform data aggregation and BS receives compressed data.
- ✓ The lifespan of WSN is the total amount of time before the first sensor node runs out of power.

In this paper Wireless Sensor Networks, sensor node and its characteristics are introduced in first section. Clustering concepts are introduced in the second section. In Section 3 brief survey results with different parameters are given and concluded in section 4.

2. CLUSTERING

2.1 Cluster Formation

Sensor nodes typically use irreplaceable power with the limited capacity, the node's capacity of computing, communicating, and storage is very limited, which requires WSN protocols need to conserve energy as the main objective of maximizing the network lifetime. An energy-efficient communication protocol LEACH, has been introduced [16] which employs a hierarchical clustering done based on information received by the BS. The BS periodically changes both the cluster membership and the cluster-head (CH) to conserve energy.

The CH collects and aggregates information from sensors in its own cluster and passes on information to the BS. By rotating the cluster-head randomly, energy consumption is expected to be uniformly distributed. However, LEACH possibly chooses too many cluster heads at a time or randomly selects the cluster heads far away from the BS without considering nodes' residual energy. As a result, some cluster heads drain their energy early thus reducing the lifespan of WSN.

In each round of the cluster formation, network needs to follow the two steps to select clusterhead and transfer the aggregated data. (*i*) Set-Up Phase, which is again subdivided in to Advertisement, Cluster Set-Up & Schedule Creation phases. (ii) Steady-State Phase, which provides data transmission using Time Division Multiple Access (TDMA).

The election of cluster head node in LEACH [16] has some deficiencies such as,

- ✓ Some very big clusters and very small clusters may exist in the network at the same time.
- \checkmark Unreasonable cluster head selection while the nodes have different energy.
- ✓ Cluster member nodes deplete energy after cluster head was dead.
- \checkmark The algorithm does not take into account the location of nodes.

✓ Ignores residual energy, geographic location and other information, which may easily lead to cluster head node will rapidly fail.

Motivated from this, so many clustering proposals are reported in the literature, suggesting different strategies of clusterhead selection and its role rotation.



Fig. 1. The LEACH clustering communication hierarchy for WSNs.

To have a global view of these strategies of clusterhead selection, their necessary characterization on a common platform raises following questions.

- ✓ Who initiates the clusterhead selection?
- ✓ Which parameters decide the role of a sensor node?
- ✓ Which sensor nodes shall be selected as clusterheads?
- ✓ Does it require re-initiation of cluster formation process?
- ✓ Are the selected clusterheads evenly distributed?
- ✓ Does it guarantee creation of balanced clusters?
- ✓ Which method is suitable for large network, Single-hop or Multi-hop?

2.2 WSNs Topologies

WSN topologies are classified into four types of models as shown in Fig. 2. In the single-hop models (Fig. 2(a) and Fig. 2(b)), all sensor nodes transmit their data to the sink node directly. These architectures are infeasible in large-scale areas because transmission cost becomes expensive in terms of energy consumption and in the worst case, the sink node may be unreachable.

In the multi-hop models, we can consider the flat model (Fig. 2 (c)) and the clustering model (Fig. 2(d)). In the multi-hop flat model, because all nodes should share the same information such as routing tables, overhead and energy consumption can be increased. On the other hand, in the multi-hop clustering model, sensor nodes can maintain low overhead and energy consumption because particular cluster heads aggregate data and transmit them to the sink node. Additionally, wireless medium is shared and managed by individual nodes in the multi-hop flat model, which results in low efficiency in the resource usage. In the multi-hop clustering model, resources can be allocated orthogonally to each cluster to reduce collisions between clusters and be reused cluster by cluster. As a result, the multi-hop clustering model is appropriate for the sensor network deployed in remote large-scale areas.

2.3 Clustering Strategies – Classification

While improving the limitations of LEACH, many clustering proposals for increasing network lifetime are reported suggesting different strategies of clusterhead selection and its role rotation among the sensor nodes, using different parameters. Based on these parameters, these strategies of clusterhead selection may broadly be categorized as *deterministic, adaptive* and *combined metric (hybrid)*.

In *deterministic schemes* special attributes of the sensor node such as their identification number (Node ID), number of neighbours they have (Node degree) and in *adaptive schemes* the resource information like remnant energy, energy dissipated during last round, initial energy of the nodes are used to decide their role during different data gathering rounds.

Based on who initiates the clusterhead selection, the adaptive schemes may be categorized as base station assisted or self organized (Probabilistic). Based on the parameters considered for deciding the role of a sensor node, the probabilistic schemes may further be classified as fixed parameter or resource adaptive.



Fig 2. Classification of WSN Topologies

Few proposals, reported, use combination of deterministic and adaptive approaches and may be termed as combined metric (hybrid) schemes.

3. COMPARISON OF VARIOUS CLUSTERHEAD SELECTION STRATEGIES

Comparison of various clusterhead selection strategies in terms of their assistance considered in clusterhead selection (CSA), parameters used, required re-clustering (RC), required cluster formation (FC), even or fair distribution of clusterheads (DCH), and creation of balanced clusters (BCC) seems to be meaningful, to have their broader understanding.

3.1 Deterministic Schemes

In a communication range, sensor nodes first satisfying the fixed node degree criterion select themselves as clusterheads. To decide on the clusterhead role, during each round, all sensor nodes broadcast hello message to their neighbours and the nodes first receiving as many as pre-defined number of these broadcasts declare themselves as clusterheads and broadcast a cluster setup. Existence of exactly one clusterhead is ensured in a communication range by not allowing the sensor nodes receiving the setup broadcast to broadcast again. The sensor nodes receiving the setup broadcast then send the joining requests and the clusterhead after receiving these requests confirms the joining, prepares and distributes the time schedule for its cluster members.

ACE-C [7], for even distribution of sensor nodes and to avoid re-clustering during each round, select clusterheads for each round based on node ID's. Initially all sensor nodes are assigned ID's from 0 to N-l (N is the number of nodes in the network). Depending on the number of clusterheads (C) required for each round the necessary number of nodes (with ID's from 0 to C-l) are selected as clusterheads for first round. For next round the nodes with ID's from C to 2C-1 are selected as clusterheads. To distribute the clusterheads evenly over the network, ACE-L [4] uses location information, provided in the form of reference points, to decide the clusterhead during each round.

Based on number of clusterheads required equal number of reference points is fixed, a priori. The nearest among these points is used as a main reference point (MRP) by the sensor nodes. Nodes with same MRP values contend for the role and the one with minimum delay elects itself as a clusterhead for current round The nodes receiving the selection beacon from this clusterhead leave the competition and join it as cluster members. However both ACE-C and ACE-L needs clusters to be formed after each role rotation of clusterhead.

Deterministic clusterhead selection strategies discussed in this section are compared, below in Table 1 with respect to their requirements of clusterhead selection and the associated after effects.

Scheme	CSA	Parameters	RC	DCH	BCC
ACE-C [4]	Sensor nodes (Self organized)	Node ID	NO	NO	NO
ACE-L [4]		Reference Point (MRP)	YES	YES	YES
RCLB [5]		Number of CHs range	YES	YES	NO

Table 1: Comparison of Deterministic Schemes

3.2 Base Station Assisted Adaptive Schemes

The base station, based on the node deployment information either priori available or collected from the sensor nodes, clusters the network and informs it to these nodes. The clusterheads are either elected by the base station or selected by the sensor nodes.

Particularly in LMSSC [6], the network is first partitioned into clusters by the base station and appropriate number of clusterheads are decided by evaluating a node metric which is defined, for any sensor node, as a ratio of its residual energy to the aggregate of sum

of squared distances from a concerned sensor node to every other sensor node in the cluster and its squared distance to the base station.

All sensor nodes communicate their position information and energy level to the base station in LEACH-C [7] and provide the necessary information to calculate the average node energy. Sensor nodes with remaining energy below this value are restricted from becoming clusterhead during current round. Base station finds the predefined number of clusterheads and divides the network into clusters, so as to minimize the energy required for non clusterhead members to transmit their data to the clusterhead. However formation of clusters with equal number of nodes in each of them is not guaranteed with this scheme.

To avoid re-clustering, LEACH-F [9] uses a stable cluster and rotating clusterhead concept in which cluster once formed is maintained stable, throughout the network lifetime. Only the responsibility of cluster data gathering is rotated within the nodes in the cluster. Initially the clusterheads are selected and clusters are formed using LEACH-C algorithm.

Other base station assisted schemes are Controlled Density Aware Clustering Protocol (CBCDACP) [10] where the base station centrally performs the cluster formation task, Two-Tier Data Dissemination approach [11] that provides scalable and efficient data delivery with location aware, FZ-LEACH [12] that forming Far-Zone which is a group of sensor nodes which are placed at locations where their energies are less than a threshold, In Adaptive Cluster Head Election and Two-hop LEACH protocol (ACHTHLEACH) [13], Nodes are tagged as near nodes or far nodes according to the distances to the BS. The near nodes belong to one cluster while the far nodes are divided into different clusters by the Greedy K-means algorithm. The cluster head is shifted and the node with the maximal residual energy in each cluster is elected.

In document [14] a cluster head election called Grid Sectoring base-on distribution of load balancing and energy consumption over both uniform and non-uniform deployment were presented and in Optimal Placement of Cluster-heads (OPC) algorithm [15], the key future is handling the load near the sink is to vary the density and the transmission range of the cluster-heads based on the distance between cluster-heads and the sink.

Base station assisted schemes are compared with respect to different features of their clusterhead selection, below in Table 2. It should be noted that the base station is responsible for re-clustering in most of these schemes and the sensor nodes do not perform the computations for selecting the clusterheads.

3.3 Fixed parameter probabilistic schemes

In these schemes, clusterheads are selected for initial and subsequent data gathering rounds by evaluating an expression involving some probabilistic requirements, utilizing fixed parameters like number of clusterheads and round number.

In LEACH, clusterhead role is rotated among all sensor nodes by re-clustering the network after specific number of data gathering cycles called *round*. During each round, a fixed percentage of total network nodes are selected as clusterheads which then start cluster formation process by advertising their selection to the non clusterhead nodes that on receipt of these equal transmit power advertises, from different clusterheads, join one with highest received signal strength. Each node in the network chooses a random number between 0 and 1 and if this number is less than the evaluated adaptive threshold, selects itself as clusterhead for the current round.

In LEACH, during some round, it is possible that none of the node selects itself as clusterhead and all the nodes have to act as forced clusterheads. To improve upon, such a round is treated as cancelled in power efficient communication protocol [17] and a fresh clusterhead selection is carried out, independent of the current round.

Scheme	CSA	Parameters	RC	DCH	BCC
LMSSC[6]		Residual energy, CH to SN and CH to BS distances	NO	YES	YES
LEACH-C [7]	Base station	Position information and energy level "	NO	NO	NO
BCDCP [8]		Position information and energy level	NO	YES	YES
LEACH-F [9]		Position information	NO	NO	YES
CBCDACP) [10]		Min distance b/n node to base	NO	YES	YES
TTDD[11] FZ- LEACH[12]		Location aware	NO	YES	YES
[13], [14], [15]		Optimal placement	NO	NO	YES

 Table 2. Comparison of base station assisted schemes

ERA [18] suggests an improvement in cluster formation phase in which the non clusterhead nodes while deciding the clusterhead to join select a path with maximum sum of residues. The strategy proposed in [19] uses CDMA codes from cluster set up whereas LEACH uses them during data gathering. The TDMA schedule is distributed immediately after confirming joining, on receipt of joining request from a node, to avoid collision during node's reply to clusterhead advertise, to achieve the energy efficiency. RRCH in [22] in which, initial clusterhead selection and cluster formation is carried out following LEACH algorithm and TB-LEACH [23] suggests to select constant number of clusterheads, the partition of clusterhead is balanced and uniform.

Following Table 3 summarizes, various features associated with, the clusterhead selection and role rotation strategies discussed in this section.

Scheme	CSA	Parameters	RC	CF	DCH	BCC
LEACH [16], [17],[18], [19], [20], [21], [23]	Sensor nodes	Number of clusterheads, round number	YES	YES	NO	NO
RRCH[22]			NO	NO	NO	NO

Table 3: Comparison of fixed parameter probabilistic schemes

3.4 Resource adaptive probabilistic schemes

In resource adaptive schemes, information about the available node resources is utilized, while selecting clusterheads for the subsequent rounds.

The scheme suggested in [24] calculates the threshold considering residual energy, energy dissipated during current round and average node energy as additional parameters and makes the clusterhead selection strategy energy adaptive. The nodes in the network take decision about their clusterhead role carrying out a process similar to LEACH but with a resource adaptive threshold value. LEACH-B [25], Energy-LEACH [26] and scheme in [27] also adapt the LEACH threshold using different energy values.

In HEED [28], sensor nodes use residual energy as a criterion to decide on their role as a clusterhead and make up their mind setting the probability to a value expressed in terms of residual energy, maximum energy and the optimum percentage of clusterheads required for a particular data gathering round which is not allowed to fall below a minimum pre-defined threshold. In schemes [30], power optimized LEACH [31], ALEACH [32], EAMC [33], EAP [34], CEFCHS [35], FRCA [36], LEACH-M [37] are suggests that node's remaining energy or residual energy as the main constrain to select a node as clusterhead.

The clusterhead selection strategies discussed in this section are summarized in Table 4, below.

Scheme	CSA	Parameters	RC	CF	DCH	BCC
[24]		Energies – residual, in last round.	YES	YES	NO	NO
LEACH- B [25]		Energy	YES	YES	NO	NO
Energy- LEACH [26]	Sensor nodes (Self organized)	Energy	YES	YES	NO	NO
[27]	organizedy	Remnant Energy	YES	YES	NO	NO
HEED [28]		Energies- residual and optimum percentage of CH	YES	YES	NO	NO
LEACH- ET [29]		Threshold	YES	YES	NO	NO
[30] to [37]		Residual energy in the range	YES	YES	YES	YES

Table 4: Comparison of resource adaptive probabilistic schemes

3.5 Clusterhead Selection in Hybrid Clustering (Combined Metric) Schemes

In cluster based data gathering literature, some hybrid approaches are suggested combining clustering with, one or more of the, other architectures and increased energy efficiency is claimed. In M-LEACH [38] that adjusting the nodes, Threshold function, when

non cluster-heads choose optimal cluster-head, they consider comprehensive nodes' residual energy and distance to base-station, then compare their performance, the simulation results show that the new strategy of cluster-heads election achieve great advance in sensor and in ACAER [39] which periodically selects cluster nodes according to their coverage rate and residual energy.

The EAMC [40] can reduce the number of relays used for data transmission by minimizing the amount of the nodes in the root tree (that is cluster-head). Unequal Cluster-based Routing (UCR) [41] protocol groups the nodes into clusters of unequal sizes. Cluster heads closer to the base station have smaller cluster sizes than those farther from the base station, thus they can preserve some energy for the inter-cluster data forwarding and [42] using decision tree algorithm to select the best node as a cluster head.

Gradual Cluster head election Algorithm (GCA) [43] which gradually elects cluster heads according to the proximity to neighbour nodes and the residual energy level and one-hop neighbour information (GCA-ON), which elects cluster heads based on Er and the relative location information of sensor nodes. LEACH-improve [44] consider both energy and coverage together.



Fig. 3. An overview of the UCR protocol

Particularly, Concentric Clustering Scheme proposed in PEGASIS [45] extend chain formation approach to clustering architecture for data gathering in wireless sensor networks. In concentric clustering scheme, each node in the sensor network assigns itself a layer number, based on the received signal strength (RSSS) of the control message from the base station. The nodes with same layer numbers form a chain in their respective layers and one of these nodes is selected as a head node (clusterhead) for that layer. The role of head node is rotated among the nodes in the same layer.

Scheme	CSA	Parameters	RC	CF	DCH	BCC
M-LEACH[24]		Threshold, location	NO	YES	YES	YES
ACAER [39], EAMC [40], UCR [41]*, [42], GCA [43], LEACH-imp [44]	Sensor nodes (Self organized)	Coverage rate and residual energy	NO	YES	NO	YES
PEGASIS [45]	Base station	RSSS	NO	NO	YES	YES

 Table 5: Comparison of Hybrid Clustering Schemes

*- Additional parameter unequal cluster size

4. CONCLUSION

In this paper, different clustering schemes are classified and discussed with special emphasis on their clusterhead selection strategies. They are compared with respect to their requirement of (1) clustering during each round for selecting the clusterheads, (2) cluster formation required after each rotation of role of clusterhead, (3) distribution of clusterheads over the network, (4) creation of balanced clusters, (5) parameters used and (6) the assistance considered to highlight the effect of clusterhead selection strategy on the performance of these schemes. This survey also answers all the questions raised at starting stage about the clustering and clusterhead selection sections. The use of these parameters for this comparison is justified by reasoning the effects of clusterhead selection and its role rotation on the energy efficiency of the network. For multi-hop data forwarding, from clusterhead to base station, distance between the forwarding clusterhead and intermediate clusterhead shall be maintained approximately same, during different data gathering rounds, to ensure equal amount of energy consumption due to their data forwarding to or towards the base station. Finally it is concluded from the survey that, still it is needed to find more scalable, energy efficient and stable clustering scheme, for data gathering in wireless sensor networks.

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