RUHEED- Rotated Unequal Clustering Algorithm For Wireless Sensor Networks

Nueraili Aierken, Roberto Gagliardi, Leonardo Mostarda, Zaib Ullah
Computer Science Division
University of Camerino, Camerino, Italy
Email: {nueraili.aierken,roberto.gagliardi,leonardo.mostarda,zaibullah.zaibullah}@unicam.it

***Abstract*—Prolonging the network lifetime, scalability and balancing are very important requirements when implementing a wireless sensor network (WSN). Clustering is a technique that has been widely applied for achieving these goals. However, there exists the energy hole problem which causes an unbalanced energy consumption in equally formed clusters. More specifically, nodes near the base station (BS) die very quickly since they, not only transmit their own data, but also forwards the rest of the network data. In this article, we propose a rotated unequal clustering protocol RUHEED in order to mitigate the energy hole problem. Our experiments show that RUHEED improves the network lifetime when compared to other clustering protocols.**

***Keywords*-Wireless sensor networks; clustering protocols; energy efficiency;**

I. Introduction

A wireless sensor network (WSN) is composed of spatially distributed sensor nodes with limited memory, processing, communication and energy capabilities [2], [3], [4] and a Base Station (BS). Sensor nodes sense the environment, process the data and transmit it to a nearby node until they reach the BS [1]. The role of a base station is to collect all data received from the various sensors, analyse them and ultimately make decisions. WSNs can be classified as continuous or event-based [5], [6]. In the first case readings are collected and reported periodically irrespective of the changes involved. In the second case a report is sent only when a specific event happens. Depending on the application, sensor node deployment can be either deterministic or random, stationary or mobile, homogeneous or heterogeneous [7].

The energy efficiency challenge is very important when building WSNs since nodes are often equipped with a non-renewable source of energy. Thus WSNs have a bounded lifetime [8], [9]. Clustering is one of the solutions proposed by the researchers. Clustering organizes the WSN into sets (clusters). A sensor from each set is elected as cluster head (CH). A CH coordinates and aggregates data of nodes within its cluster (intra-cluster communication). CHs communicate with each other and/or with an external base station (BS) (inter-cluster communication) on behalf of their nodes. When equal size clustering [12], [11] is used, the energy hole problem can take place [10] where nodes close to the base station die earlier. In fact, they are burdened with heavy relay traffic from the rest of the network (intra-cluster communication) in addition to their own intra-cluster traffic (inter-cluster communication). A quit common solution to the energy hole problem is unequal clustering [10], [14], [17], [18] where clusters far away from the BS will have a larger size when compared to clusters closer to the BS. By creating unequal sized clusters, the amount of intra-cluster traffic is considerably reduced for the CHs nearer to the BS.

In this paper, we present Rotated Unequal Clustering Protocol (RUHEED) that enhances the Unequal Clustering Algorithm (UHEED) [10] with the addition of rotation for cluster head election. More precisely, RUHEED does not always perform a full leader election protocol but CHs are rotated among the member nodes of the same cluster. This rotation is based on the highest residual energy. We compared RHEED with LEACH, HEED and UHEED. RUHEED outperforms all the mentioned clustering protocols when the first-node dies and half-nodes die network lifetime measures are considered.

Section II details RUHEED and Section III discusses the network model, the simulation parameters and the results. Section IV compares the presented work with existing related works in this area. Finally, Section V provides a conclusion and outlines future work.

II. RUHEED- Rotated Unequal Clustering Algorithm

The RUHEED protocol is an enhancement of the UHEED [10] that is based on HEED. Because of this evolutionary order in the following we first sketch HEED, afterwards we discuss UHEED and we conclude with the enhancement offered by RUHEED.

A. HEED

HEED is a clustering protocol that periodically selects cluster heads. The selection is based on different parameters such as residual energy, node degree, node proximity to its neighbors and so on. A periodical and careful change of cluster heads can balance load among clusters prolonging the network lifetime. HEED election is composed of three main phases that are initializing, iterative and final.

The initializing phase assigns to each node the probability of becoming a tentative cluster head. This is done according to the following formula (see [12] for details about the formula):

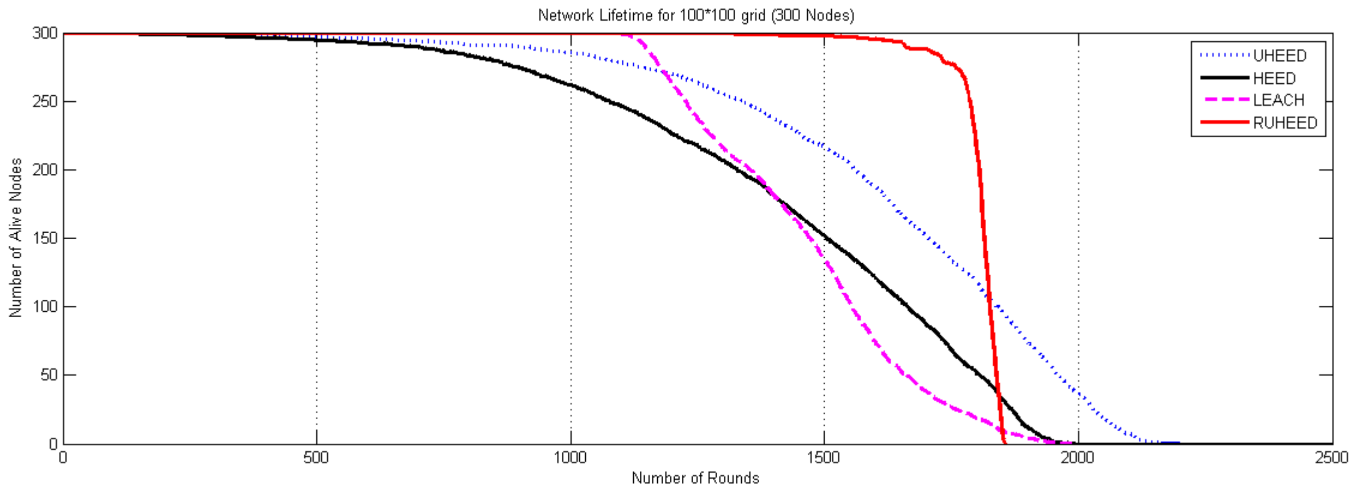

Figure 1. Comparison of LEACH, HEED, UHEED and RUHEED for a competition radius of 50

$$CH_{prob} = C_{prob} * \frac{E_{residual}}{E_{max}} \quad (1)$$

where C_{prob} is the initial probability (i.e., a predefined value), $E_{residual}$ is the residual energy and E_{max} is the maximum energy of the sensor nodes.

In the iterative phase neighbor tentative cluster heads compete in order to become cluster heads. The best in terms of residual energy and/or node degree and/or node proximity is selected. In the final phase a non-cluster-head node joins the nearest cluster head or announce itself to be cluster head (when it does not detect any surround cluster head).

The size of a cluster is independent of the distance of its cluster head from the base station. In multi hop transmission, sensor nodes closer to the BS deplete their energy faster than distant sensor nodes due to high inter-cluster relay traffic. This reduces the overall network lifetime. Unequal clustering protocol has been devised in order to alleviate this problem.

B. UHEED

UHEED [10] is an unequal clustering protocol that combines HEED [12] and EEUC [18]. More precisely, it uses the leader election algorithm that is defined in HEED and each cluster head computes the competition radius by using the formula defined by EEUC [18]. This is described as follows (see [18] for a full description):

$$R_{comp} = (1 - c(\frac{d_{max} - d(s_i, BS)}{d_{max} - d_{min}}))R^o_{comp} \quad (2)$$

R^o_{comp} is a predefined competition radius that is the maximum transmission radius of a sensor node. The constant c is a coefficient having values between 0 and 1, d_{max} and d_{min} are the maximum and minimum distances of sensor nodes from the BS, $d(s_i, BS)$ is the distance of the sensor s_i from the base station.

UHEED creates unequal sized clusters based on the distance of the CH from the BS. The farther away a cluster head is from the BS, the larger will be its competition radius and hence the cluster size will be bigger compared to those clusters formed nearer to the BS. By creating unequal sized clusters, the amount of intra-cluster traffic is considerably reduced for the CHs nearer to the BS. Thus energy hole problem discussed for HEED is mitigated. Although UHEED improves the HEED protocol, enhancements can still be made. Energy can be saved with the introduction of cluster head rotation. More precisely, the election phase is sometimes replaced by a designation phase where the old cluster head directly elects a new one.

C. RUHEED

RUHEED improves UHEED with the introduction of rotation [19]. RUHEED is composed of three phases that are cluster head election, cluster formation and rotation. In the cluster head election phase HEED algorithm is used. In the cluster formation phase the competition radius formula of EEUC [14] is used. In the rotation phase the CH elects one of its cluster members as the new cluster head without performing any election protocol. The new cluster head is selected based on the highest residual energy. The rotation phase is performed until one of the WSN nodes completely deplete its energy. When this happens the BS will inform all nodes to perform a new cluster head election and cluster formation phase (as defined by HEED).The advantage of RUHEED is to reduce the number of cluster head election and cluster formation phases thus reducing the number of control messages. It is assumed that each data packet received by the CH contains energy information of the sender node.

RUHEED can be summarised as follows:

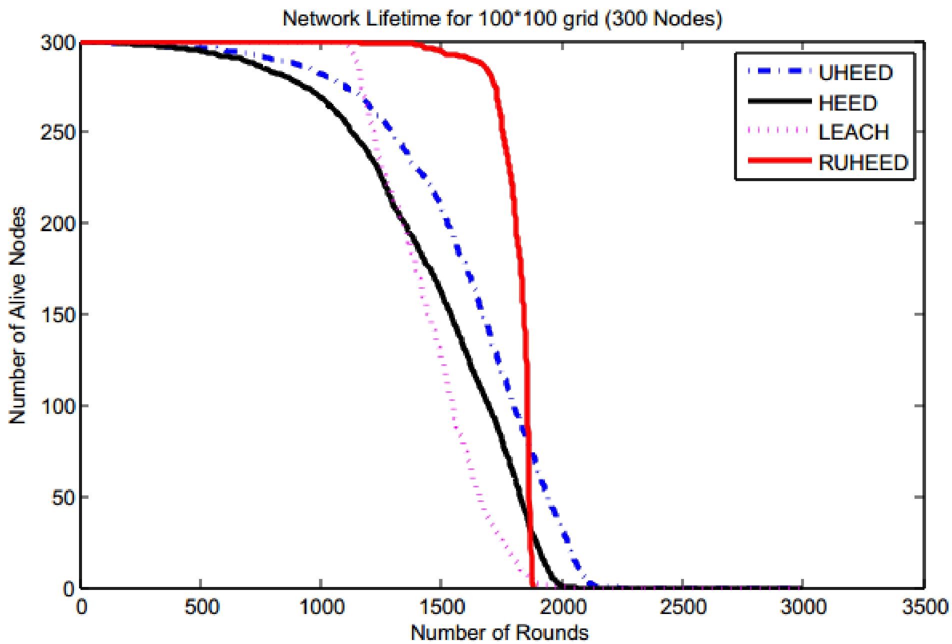

Figure 2. Comparison of LEACH, HEED, UHEED and RUHEED for a competition radius of 45

1) In the clustering phase, sensor nodes select their CHs like in HEED.
2) In the rotation phase, based on the highest residual energy of member nodes, next CHs are selected in their corresponding clusters and there is no need of re-clustering until any of the nodes deplete completely its energy.
3) When any of the node dies re-clustering is performed by repeating step 1.

III. RUHEED Network Model and simulation results

In this section we present the network model and the simulation results.

A. Network Model

Sensor nodes are uniformly deployed in a two dimensional field with the following assumptions:

- All sensor nodes have the same initial energy (homogeneous), same data communication and processing capabilities;
- Each node is identified with a unique ID;
- Nodes can transmit at various power levels depending on the distance of the receivers;
- Nodes are not mobile that is they remain stationary
- Nodes are equally distributed in the field.

The BS is located away from the sensing field with no energy constraints. It is considered to be a node with enhanced communication and computation capabilities. The BS is stationary. The data captured in a cluster is highly correlated, therefore it can be aggregated before being transmitted to the base station. CHs aggregate data during intra-cluster communication and forward to the BS via multi-hop. We use the network operation model that is presented in [12]. This is composed of multiple rounds. A round starts by triggering the cluster election and formation phases. When the clusters have been formed, the network starts a data exchange phase. This includes intra-cluster communication where each sensor node sends one message to its CH and inter-cluster communication where each aggregated data is sent by the CH to the BS (multi-hop data transmission among cluster heads is performed). The round ends when all aggregated data sent by the CHs reach the base station using 5 TDMA frames.

The radio model employed uses both the free space and the multi-path channel model and assumes error-free communication links. The simulation parameters are those used in [12] and are summarised in Table 1. The network field (in the table referred to as network grid) is 100 metres by 100 metres. The position of the base station is $(50, 175)$. A sensor spends $E_{elec} = 50nJ/bit$ to run the transceiver circuitry. The energy spent by the amplifier E_a will depend on the distance d between the sender and the receiver. More precisely $E_a = E_{fs} = 10pJ/bit/m^2$ when $d < d_0 = 75m$ (in this case a free space model is assumed) while $E_a = E_{mf} = 0.0013pJ/bit/m^4$ when $d \geq d_0 = 75m$ (in this case a multipath model is assumed). The transmission energy E_{T_x} spent to send a packet can be calculated by using the following formula (see [11] for details):

$$E_{T_x} = (E_{elec} \times k) + (E_a \times k \times d^n), \quad (3)$$

where k specifies the number of bits that are sent, d is the distance of the receiver and $n = 2$ for the free space model and $n = 4$ for the multipath model

The amount of energy E_{R_x} spent to receive a k-bit size message can calculated as follows (see [11] for details):

$$E_{R_x} = (E_{elec} \times k) \quad (4)$$

Table1

Parameters	Values
Network grid	$From(0, 0)to(100, 100)$
BS/Sink	$(50, 175)$
E_{elec}	$50nJ/bit$
E_{fs}	$10pJ/bit/m^2$
E_{mp}	$0.0013pJ/bit/m^4$
Threshold Distance (do)	$75m$
R^0_{comp} (competition radius)	$50m$
Data Packet Size	$2000bits$
Initial Energy	$2J$

B. *Simulation Study and Results*

We have simulated the RUHEED clustering algorithm by using a grid with dimension of 100 by 100 meters and by considering 300 sensor nodes uniformly deployed with continuous data collection capacity. Each experiment result is obtained for an average of 50 run and 5 TDMA frame is used for LEACH, HEED, UHEED and RUHEED. Network lifetime of RUHEED is evaluated by running simulations with different predefined competition radius (see Section II for the definition) that are 45 and 50.

Figure 1 compares RUHEED, UHEED, HEED and LEACH for a competition radius of 50. We can clearly see that RUHEED outperforms all the clustering approaches when the first node dies is considered. In fact while in RUHEED the first node dies in about 1500 rounds, in LEACH is about 1200 rounds, UHEED AND HEED about 200 rounds. If we consider half nodes die RHUEED still outperforms all the clustering approaches. The situation is completely different when we consider the last node dies in which case RUHEED perform the worst.

Figure 2 shows that the same conclusion can be reached when the competition radius is equal to 45.

IV. Literature Review

A lot of literature is available on equal and unequal size clustering techniques for wireless sensor networks. In the following we first introduce some work on equal clustering protocols then we discuss some unequal size protocols. We conclude the section with protocols that take advantage of the rotation approach.

Low Energy Adaptive Clustering Hierarchy (LEACH) [11] is one of the primary adaptive hierarchical clustering algorithm. This algorithm maintains uniform energy and load distribution among nodes over rounds. Each round consists of clustering and steady state phases. In the former phase, a WSN is organised into clusters, each cluster has its cluster head and the rest of the nodes are known as cluster members. In LEACH, cluster head election happens probabilistically rather than based on residual energy of sensor nodes [10] and data transmission between CHs and BS takes place using single hop communication. LEACH proposed randomized rotation of CH in the network and data compression at the cluster head. Once a node has been elected as a cluster head it cannot take the same role in the next round.

Hybrid Energy Efficient Distributed (HEED) [12] uses both energy and communication cost in order to perform cluster head election. HEED basics goals are to enhance network lifetime, to spawn well-distributed CHs, to shorten control overhead and to complete the network clustering phase in a constant number of iterations. The residual energy of nodes and intra cluster communication cost play a significant part in CH selection. HEED also sets a fixed number of power levels to establish cluster size, inter-cluster communication and break ties among various nodes using average minimal reachable power (AMRP) criteria. Like LEACH, steady state phase of HEED must be greater than clustering phase.

Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC) [13] proposes an optimization of the in intra-cluster topology of the HEED protocol. This optimization produces more balanced, equal sized clusters thus resulting in a better network lifetime. Like HEED, every node execute DWEHC protocol independently until and unless may not decide its status of either member node or CH.

Extensive studies have been carried out on designing unequal sized clustering protocols. Energy Efficient Unequal Clustering (EEUC) protocol [14] is based on the idea that sensor nodes should join the unequal cluster and generates smaller unequal clusters near to BS. Thus CHs nearer to the BS lives longer and avoid energy holes in the WSN.

In the unequal layered clustering approach (ULCA) [15], author partitions the WSN into layers. The layers nearer to the base station are of smaller size when compared to the layers away from the base station. Cluster heads of middle layers retains more energy for inter-cluster data relay traffic [10]. ULCA performance is better than the EEUC in terms of network lifetime.

In [16] the authors present an energy-driven unequal clustering (EDUC). This protocol introduces unequal clustering and energy-driven robust CH rotation. This balances the energy utilization of CHs and enhances network lifetime.

Energy aware fuzzy unequal clustering algorithm (EAUCF) [17] determines the cluster size by using sensor nodes residual energy and distance from BS using fuzzy logic. This idea offers more energy to nodes nears BS and the performance of this protocol is better than the LEACH, CHEF and EEUC.

In [18] the authors describe an improved energy efficient unequal clustering (IEEUC) protocol. This computes competition radius using node degree. Cluster heads that are closer to the base station have less number of member nodes in comparison to farthest one. Thus, CHs near to the BS have more residual energy for inter-cluster data transmission.

In [10] the authors introduce Unequal Clustering Algorithm (UHEED). This combines the unequal clustering size of EEUC and the leader election algorithm proposed in HEED. Smaller clusters are created near to the BS and larger clusters are created at the farthest distance. UHEED outperforms LEACH, HEED and EEUC.

V. Conclusion

In this article, we proposed RUHEED a novel unequal WSN clustering protocol that is based on UHEED. RUHEED improves UHEED with the introduction of rotation [19]. This reduces the number of cluster head election and cluster formation phases thus reducing the number of control messages. RUHEED outperforms HEED, UHEED and LEACH clustering protocols when the first node dies and half-node die network lifetime measures are considered. In future work, we plan to investigate RUHEED dependency on various values of the competence radius, different network grid sizes and various number of nodes.

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