Rotating Energy Efficient Clustering for Heterogeneous Devices (REECHD)

Matteo Micheletti
Computer Science Department
University of Camerino
Camerino, IT
matteo.micheletti@unicam.it

Leonardo Mostarda
Computer Science Department
University of Camerino
Camerino, IT
leonardo.mostarda@unicam.it

Andrea Piermarteri
Computer Science Department
University of Camerino
Camerino, IT
andrea.piermarteri@unicam.it

***Abstract*—Wireless sensor networks (WSNs) are an essential part of the Internet of Things (IoT). They provide a virtual layer where is possible to collect information about the physical world. WSN devices can be battery powered, produce a large volume of data and have heterogeneous hardware such as computational power, memory, and communication capabilities. Gathering data from battery powered heterogeneous devices in an energy efficient way is a challenging research area. Clustering is one of the solutions which has been proposed by researchers. In this paper we propose a novel Rotating Energy Efficient Clustering for Heterogeneous Devices (REECHD). Our experiments show that REECHD improves the network lifetime when compared to the state of art clustering protocols for heterogeneous WSNs.**

***Index Terms*—Wireless Sensor and Actuator Networks; Internet of Things; Clustering Protocols; Routing; Energy Efficiency.**

I. Introduction

The Internet of Things (IoT) is a makeup of interrelated smart objects, wireless devices and people that have autonomous capabilities to communicate data over the network [9]. The term IoT was first coined by Kevin Ashton in 2002 and in Forbes Magazine saying as, “We need an internet for things, a standardised way for computers to understand the real world” [12]. Various studies predict that more than 20 billion devices will be connected to the internet by 2020 [9] generating a market size of 267 Billion dollars. IoT main applications [2] include transportation, smart homes, smart supply chain, smart cities, connected cars, smart industry, and smart retails.

Wireless sensor networks (WSNs) provide a virtual layer which can collect information about the physical world. WSN devices can produce a large volume of data and can have heterogeneous features such as computational power, memory, and communication capabilities. When devices are battery powered, gathering data from them in an energy efficient way is a challenging research area [10]. Clustering is a possible solution proposed by the researchers. This organises the devices into sets (clusters). Each cluster has a cluster head (CH) that gathers data from its nodes (intra-cluster communication) and communicates with other CHs in order to report data to a centralised base station (BS) (inter-cluster communication). Quite a few clustering protocols have been proposed [11] [8]. Some protocols are based on equal-sized clusters while others use clusters of unequal size. Some others make use of rotation techniques to reduce the amount of cluster head elections. Most of the clustering approaches have their roots on the homogeneous WSN field which assumes devices with homogeneous capabilities [13] [10]. Cluster head selection is usually based on the node residual energy. Few approaches may consider the node transmission rate for cluster formation.

In this paper, we propose a Rotating Energy Efficient Clustering for Heterogeneous Devices (REECHD). We assume heterogeneous WSNs that are composed of nodes with different transmission rates and different energy levels. REECHD introduces a novel leader election protocol which, not only considers the node residual energy, but also the node induced work. This is estimated by using the node transmission rate. REECHD also introduces the concept of intra-traffic limit rate (ITLR). This defines a limit on the intra-traffic communication that all WSN clusters must comply with. ITLR can be used to improve energy efficiency.

Our experiments compare REECHD with well-known protocols for homogeneous WSNs such as Low-Energy Adaptive Clustering Hierarchy (LEACH) [5], Hybrid Energy-Efficient Distributed Clustering (HEED) [17], Unequal clustering algorithm based on HEED (UHEED) [4], HEED with rotations (ER-HEED) [15]. We also consider protocols from the heterogeneous WSN field such as FMUC [8]. Our simulation results show that REECHD performs better under various network conditions.

The rest of the article is organised as follows: Section II reviews the state of art of clustering for homogeneous and heterogeneous WSNs; Section III details the REECHD election and its novel contribution as well as the algorithm for cluster formation; Section IV describes the network model and the simulation results; finally, Section V concludes the article and outlines future work.

II. Related Works

A great deal of literature and research articles are available on clustering protocols. In this section, we focus on existing prominent clustering protocols for homogeneous and heterogeneous WSNs. We consider clustering approaches having equal and unequal size clustering, rotation and non rotation, single hop and multi-hop.

A. Clustering protocols for homogeneous WSNs

Low Energy Adaptive Clustering Hierarchy (LEACH) [5] is one of the pioneering routing protocols that introduced the idea of clustering into the field of WSNs. Unlike most of the clustering protocols, which use the node residual energy for cluster election, LEACH uses a probabilistic function. All cluster heads can directly communicate with BS, i.e., multi-hop communication never takes place. Once a node has been elected as a CH it cannot take the same role in the next cluster election. LEACH proposes a randomised rotation of CHs and data aggregation at each CH.

HEED [17] clustering protocol produces clusters of equal size, i.e., each cluster has the same radius. The HEED algorithm is composed of the following two phases: (i) clustering, and (ii) network operation. During the clustering phase, CHs get elected based on the residual energy, and member nodes join the closest CH[1]. During the network operation phase data messages get delivered from the members to the BS. Clustering and network operation phases are repeated over time. HEED generally prevents two nodes within the same transmission range from becoming CHs. As reported in [17], sensor nodes close to the BS deplete their energy faster with respect to nodes that are farther away. This problem is referred to as hot spot problem. In fact, while all CHs will have the same amount of average intra-traffic communication (i.e., the traffic inside a cluster) CHs close to the BS have a higher inter-cluster communication (i.e., relay traffic amongst CHs).

Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC) [2] is an equal size clustering based protocol for WSNs. It optimises intra-cluster communication by introducing multi-hop transmission within the clusters. All sensor nodes execute DWEHC individually to decide whether to be a cluster head or a member node. DWEHC clustering formation phase is based on HEED topology. Resultant clusters arrangement is well-balanced and leads to enhance network lifetime.

Voluminous literature have been developed on devising energy efficient unequal size clustering protocols for WSNs.

Energy Efficient Unequal Clustering (EEUC) algorithm [7] for WSNs is one of the first approach that had been conceived. EEUC is based on the idea that a larger cluster size should be used when the CH resides in zones farthest from BS whereas zones nearest to BS should be populated with a considerable amount of smaller clusters. This approach would minimise excessive overhead burden on cluster heads nearest to BS and should alleviate the energy hole or hot spot problem.

Unequal clustering algorithm based on HEED (UHEED) [4] is an unequal size clustering based protocol for WSNs. UHEED incorporates the idea of EEUC protocol into HEED in order to build unequal size clusters. The size of a cluster CH depends on its distance from the BS. The farther away CH is from the BS, the larger its competition radius is. In other words, clusters that are farther away from the BS have a larger radius with respect to clusters nearer to the BS. UHEED reduces the hot spot problem and increases network lifetime when compared to HEED and LEACH.

Rotated Unequal HEED (RUHEED) [1] uses an unequal size clustering based approach that not only improves the hot spot problem but also enhances the network lifetime. RUHEED is composed of three stages that are CH election; clusters formation; and CH rotation. HEED is used to elect CHs based on its residual energy and communication cost. EEUC concept, which is based on the sensor node distance from the BS, is used in order to establish unequal sized clusters. During CH rotation phase, current CH selects the member nodes with the highest energy and directly designates it as the next cluster head. Rotation strategy avoids re-clustering of the network thus network lifetime is improved. Re-clustering of the network takes place when any of the sensor nodes drain its entire energy. RUHEED preserves energy and minimises the number of cluster election and cluster formation phases.

ER-HEED [15] is a clustering protocol that enhances performance of HEED by introducing CHs role rotation inside clusters. ER-HEED is composed of three stages that are cluster head election, cluster formation using HEED and cluster head rotation. Like RUHEED, CHs nominate the next CHs that have the highest residual energies. This concept of CH selection within the cluster member nodes reduces the number of cluster elections. HEED based cluster head election is performed only when any of the sensor nodes depletes its energy completely. ER-HEED performance in terms of first node dies measure criteria is far superior to RUHEED, HEED and UHEED.

B. Clustering protocols for Heterogeneous WSNs

While WSNs have homogeneous nodes, heterogeneous WSNs introduce nodes that can have differences in the following features: (i) energy level; (ii) data rate; (iii) transmission range; (iv) aggregation performance; (v) processing capabilities. Heterogeneity affects significantly the network lifetime and lessens network response time [16]. In this section we describe various clustering algorithms that have been devised for heterogeneous wireless sensor networks. Different protocols can make different assumptions about the heterogeneity of the WSNs.

DEEC (distributed energy-efficient clustering algorithm for heterogeneous WSNs) [11] is an equal size clustering protocol. DEEC cluster head election is based on a probability that is calculated by considering the ratio of the residual sensor node energy and the network average energy. The CH role is rotated among sensor nodes on the basis of their residual energies. This ensures a uniform energy consumption over the entire network. Sensor nodes that have the highest residual and highest initial energies will be more likely selected as cluster heads. BS broadcasts the network average energy information to all wireless sensor network nodes.

Distributed energy balance clustering Protocol for heterogeneous WSNs (DEBC) [3] is a clustering protocol for heterogeneous WSNs. DEBC assumes that sensor nodes have heterogeneous energy levels. The cluster head election is based on the sensor node residual energy. Sensor nodes that have

[1]Communication costs can be considered to elect or join a CH.

the highest initial energy and the highest residual energies are highly probable to be selected as cluster heads. The simulation results shows that the performance of DEBC is superior to LEACH and SEP [14].

Energy efficient heterogeneous clustered scheme for wireless sensor networks (EEHC) [6] is a clustering protocol for heterogeneous WSNs. In EEHC, a percentage of sensor nodes are equipped with various levels of battery capacity. EEHC aims at enhancing network efficiency and reliability. Like DEEC and DEBC, the cluster head election probability of EEHC depends on sensor node residual energies.

A stable election protocol for clustered heterogeneous wireless sensor networks (SEP) [14] is a heterogeneous protocol and intents to enhance network lifetime according to the first node dies network lifetime measure. SEP assumes two different types of nodes that are normal and advanced sensor nodes. CH election is based on sensor node initial and residual energies. Simulation results show that SEP prolongs network lifetime and average throughput.

FMUC (feedback mechanismbased unequal clustering) [8] is a feedback mechanism based unequal heterogeneous protocol. FMUC is specifically designed to avoid the energy hole problem when balancing the energy load in application-based WSNs. Initially, FMUC divides the network into layers which are computed analytically. A mathematical model is used in order to uniform the ratio of the energy consumption and the total initial energy of each layer. Each cluster will belong to the one of the layers. The size of each cluster is calculated by considering the ratio of the energy consumption of each layer. Clusters send their sizes as a feedback to the sink which broadcasts the collected values into the network. All nodes of the WSN receives the feedback values but only the cluster heads change their competition radius according to received values.

III. REECHD CLUSTERING PROTOCOL

In this section we describe the leader election novelty introduced by REECHD as well as the REECHD cluster formation and rotation algorithms.

A. Low-rate-high-energy node depletion problem

Cluster head selection is usually based on the node residual energy, i.e., the node with the highest energy is usually selected as CH. This selection strategy can cause a quick energy depletion when nodes have a variable transmission rate. More precisely, nodes that have high energy and low rate can quickly deplete their energy. We refer to this problem as the low-rate-high-energy node depletion problem. Figure 1 shows an example of the low-rate-high-energy node depletion problem. There are the following three nodes: (i) 1 that has the highest rate (e.g., 100 bits per second) and lowest energy; (ii) 2 and 3 that have the lowest rate (e.g., 3 bit per second) and the highest energy. The colour represents the residual energy, more precisely, green nodes have more energy left when compared to yellow ones which have more energy than orange nodes. A clustering approach which elects nodes with the highest residual energy can elect the node 3 as cluster head. This selection creates the cluster shown in the left side of Figure 1 where the total amount of intra-cluster transmission is 103 bits per second. Over the time, the nodes 3 and 2 would be selected as cluster heads in alternation till their energy is the same as the node 1 (see right side of Figure 1). This causes a rapid depletion of the total energy of the cluster. In the next Section we show how REECHD faces the low-rate-high-energy node depletion problem by introducing node rate in the leader election algorithm.

B. REECHD leader election probability

REECHD is an equal size clustering protocol for heterogeneous WSNs that uses rotation in order to prolong the network lifetime. The novelty of REECHD is in its probabilistic election process and the use of intra-traffic limit.

The probabilistic election considers node residual energy and the node work. This is estimated by considering the node transmission rate. This probabilistic election mitigates the low-rate-high-energy node depletion problem. More precisely, every time a new leader election process takes place a node set its probability of becoming cluster head according to the following function:

$$CH_{prob} = max(\frac{C_{prob}}{K}(\frac{E_{residual}}{E_{max}} + IW^{-1}), P_{min}) \quad (1)$$

$$IW = \frac{D_{Rmax}}{D_R} \quad (2)$$

where K is a constant (i.e. 2) s.t. the value of CH_{prob} is always between 0 and 1, and C_{prob} is a predefined initial probability (e.g., 5%) that sets the initial percentage of cluster heads among all WSN nodes. This is used to limit the initial CH announcements, and does not impact the final clustering. In addition, the CH_{prob} value of a node is not allowed to fall below a certain threshold P_{min} (e.g., 10^{-4}), that is selected to be inversely proportional to E_{max} s.t. the algorithm terminates in $N_{iter} = O(1)$ iterations [17]. $E_{residual}$ is the residual energy of the node, E_{max} is the maximum energy of the node (it equal to a fully charged battery), IW is the node induced work rate. This estimates the energy the node spends and induces on other nodes when it plays the CH role. Thus, a node with higher induced work should have less probability to be elected. In this paper we estimate the node induced work by using the eq. (2) where D_R is the average transmission rate of the node, D_{Rmax} is the highest transmission rate of the WSN (it corresponds to the rate of the node which has the highest transmission rate in the WSN). A node with lower transmission rate has a higher induced work when compared with a node with higher transmission rate. In fact, the selection of a node with lower transmission rate generates more intra-traffic communication (see Section III-A for details) thus a faster depletion of the total amount of the cluster energy. It is worth mentioning that the node induced work could be further refined by considering further sources of energy consumption such as the energy the node spends to run the sensor hardware or the inter-traffic the node can potentially generates. Generally speaking, the node induced work can contain the energy the node spends to run its circuitry and the inter-traffic induced on other CHs when it is selected as cluster head.

The use of the REECHD probability CH_{prob} solves the low-rate-high-energy node depletion problem that is described in Section III-A. Figure 2 shows the application of the REECHD election strategy to the case study scenario of Section III-A. Node 1 has a higher probability of being elected as CH with respect to nodes 2 and 3 since REECHD considers node residual energy but also the node induced work rate. The selection of 1 as CH creates the cluster shown in the left side of Figure 2 where the total amount of intra-cluster transmission is 6. This is much less when compared with the 103 intra-cluster transmissions of the energy-based leader election approach of Section III-A. The right-side Figure 2 shows the energy left when several runs of election processes and intra-cluster communications are performed by using REECHD. The energy left is much more when compared with the right-side of Figure 1 which shows the energy left when the energy based election approach of Section III-A is used.

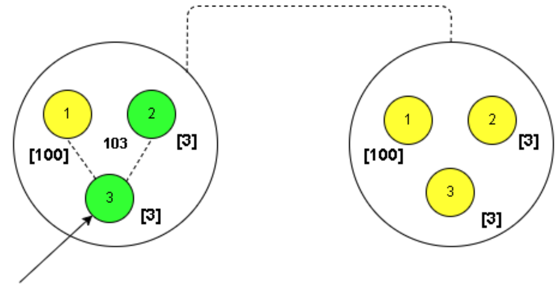

Fig. 1. Low-rate-high-energy node depletion problem

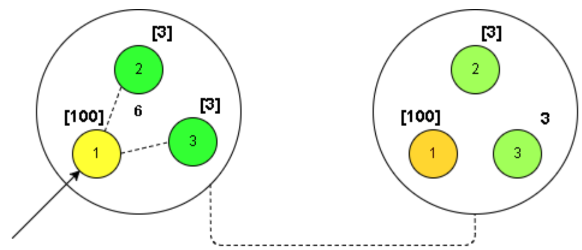

Fig. 2. REECHD applied to low-rate-high-energy case

C. REECHD intra-traffic rate limit

The intra-traffic rate limit (ITRL) defines a rate that each CH must use during cluster formation. More precisely, each CH must make sure that the sum of transmission rates of its member nodes is less than the ITRL. This is defined by the following equation:

$$\sum_{i=1}^{|member\_set|} sending\_rate(n_i) < ITRL$$

where *member_set* is the set of member nodes that compose a cluster, $|member\_set|$ is the cardinality of *member_set*, n_i is a node that belongs to *member_set* and $sending\_rate(n_i)$ is the transmission rate of the node n_i. We can define a lower and upper bound for the ITLR:

$$\left[0, \sum_{i=1}^{|WSN\_nodes|} sending\_rate(n_i)\right]$$

where $|WSN\_nodes|$ is the number of WSN nodes. We have a flat routing (i.e., each node of the WSN is cluster head and has no member nodes) when the ITLR is equal to zero. We have one single cluster that contains all nodes when the ITRL is the sum of all node sending rates.

The ITLR is a quite useful means to control the number of clusters inside the WSN. Low ITLR values can generate more clusters than high ITLR values. More clusters can lead to lower intra-traffic communication at the cost of higher inter-traffic communication. As we see in Section IV-B the choice of the ITLR depends on the aggregation rate. We emphases that the use of the ITLR is also useful when nodes are not uniformly deployed since denser area can get a higher number of clusters. This allows the balance the intra-cluster communication thus balancing the energy consumption and prolonging the WSN lifetime.

D. REECHD algorithm

REECHD is an equal size clustering protocol which uses rotation in order to reduce the number of elections. This reduces the energy consumption thus improving the WSN lifetime. Members nodes can directly communicate with their cluster heads. This is often referred to as 1-hop communication [17].

REECHD is composed of the following main phases:

- *cluster head election:* a node becomes cluster head according to the probability that has been described in Section III-B.
- *cluster formation:* each node attempts to join the lest cost CH. This may decide to refuse a join when the intra-traffic communication limit is reached.
- *cluster iteration:* a node iterates the cluster head election and formation phases when it receives an *unjoin* message from all reachable CHs. These phases are iterated a predefined number of times after which the node elects itself as CH. This strategy ensures the cluster election terminates in $O(1)$ number of interactions.
- *rotation phase:* the current CH designates the next CH directly by using the equation (1)[2]. More precisely the current CH calculates the probability CH_{prob} of each member node and chooses the one with the highest CH_{prob} as the next CH. The new CH is elected without the need of performing any election protocol.
- *operation phase:* during this phase member nodes send data to their CHs which report data to the BS;

Cluster head election, formation and iteration are performed at the beginning and anytime a node dies. When no node dies

[2]It is assumed that each data packet received by the CH contains energy information of its member nodes. This is needed in order to calculate CH_{prob}.

```
1  Initialisation ()
2      iterations = 0
3      max_iterations = n
4      set_parameter(ITLR)
5
6  Cluster_head_election()
7      cluster_head_set = tentative_CH_set = member_set = ∅
8      neighbours ← {node | node is alive, within my radius and
9       not inside a cluster}
10     E_prob = E_residual / E_max
11
12     DR_prob = DR / DR_max
13
14     CH_prob = max((C_prob / 2) * (E_prob + DR_prob), P_min)
15
16     iterations = iterations + 1
17
18     Repeat
19         if(tentative_CH_set ≠ ∅)
20             CH = least_cost(neighbours)
21             if(CH = myself)
22                 if(CH_prob = 1)
23                     broadcast_election_msg(neighbours)
24                     add_to(final_CH_set)
25                 else
26                     broadcast_tentative_msg(neighbours)
27                     add_to(tentative_CH_set)
28         else if(CH_prob = 1)
29             broadcast_election_msg(neighbours)
30             add_to(final_CH_set)
31         else if(CH_prob >= random(0,1)) f
32             broadcast_tentative_msg(neighbours)
33             add_to(tentative_CH_set)
34
35         previous_prob = CH_prob
36         CH_prob = min(CH_prob * 2, 1)
37     Until previous_prob = 1
```

Fig. 3. REECHD cluster election

the rotation and network operation phases are performed in alternation.

1) REECHD cluster head election: Figure 3 outlines the cluster head election algorithm that each node executes. Let B denote the node executing the algorithm then the election can be summarised as follows:

- B populates its neighbours set (lines $8-9$). This contains all nodes within its competition radius that are alive and do not belong to any other cluster. B will compete with nodes inside the neighbours set in order to become CH.
- B computes its probability CH_{prob} of becoming cluster head (lines $10-14$).
- When some nodes are attempting to become cluster head, the $tentative\_CH\_set$ is not empty (line 19). In this case B selects the least cost CH from $tentative\_CH\_set$. When the selected CH is the node itself it can broadcast either an election message or a tentative message. The former is broadcast when the CH_{prob} has reached 1 while the latter when the CH_{prob} is less than 1. We have experimented various cost functions such as selecting the closest CH or selecting the CH which has the largest member-set. In the presented simulation results we use the first approach.
- When no nodes proposed as CH and CH_{prob} is equal to one (lines $28-30$) B proposes itself as cluster head;
- When no nodes proposed as CH and CH_{prob} is less than one (lines $31-33$) B decides whether or not to become tentative CH by considering its probability CH_{prob};
- at the end of each repeat cycle the probability is doubled (line 36). This ensures that REECHD terminates in $O(1)$ number of steps.

2) Cluster formation: Figure 4 outlines the cluster formation algorithm that each node executes. The cluster formation can be summarised as follows:

- B sends a broadcast election message when it is cluster head (line 5). After the broadcast, B performs the $member\_selection$ procedure by using the $join\_set$ and the $ITRL$ parameters (line 6). B uses the $join\_set$ to store all nodes that requested a $join$. The $ITLR$ defines the maximum intra-traffic communication B can receive (see section III-C for details). The $member\_selection$ procedure returns the node set $member\_set$. This contains all nodes B selected as cluster members. We recall that the intra-traffic communication generated by the $member\_set$ nodes must be less than the $ITRL$ (see sectionIII-C for details). Various member selection strategies can be adopted. For instance a random pick can be performed until $ITLR$ is reached (this is the strategy we used in the presented simulation results). The member nodes can be selected starting from the highest rate node until the $ITLR$ is reached. The member nodes can be selected so that the total rate is less than or equal to $ITLR$ and is as large as possible.
- B sends an $unjoin$ message to all nodes that are not included in the $member\_set$ (line 8).
- B tries to join one after another all reachable CHs (from the $least\_cost$ to the $worst\_cost$) when is not CH. B will join the first CH that replies with a join message (lines $10-16$). After the join the nodes terminate the cluster formation procedure.
- B repeats the cluster head election when it is not CH and is not able to join any CH. The cluster head election can be repeated a maximum number of times (i.e., $max\_iterations$)

3) Cluster rotation: Figure 5 outlines the algorithm a CH performs when rotation takes place. The member node with the highest CH_{prob} is selected and designated as a new CH. When no node is found no rotation takes place.

REECHD generally prevents two nodes within the same transmission range from becoming CHs when the ITLR has high values. Cluster overlapping increases as the value of the ITLR decreases. REECHD election and cluster formation terminates in $O(1)$ steps.

IV. REECHD Network Model and Simulation Results

In this section, we describe our network model and discuss the simulation results.

A. Network Model

The network model can be summarised as follows,

- Nodes are not mobile and uniformly distributed in a two dimensional field;

```
Cluster_formation()

    if(myself ∈ final_CH_set)
        join_set = ∅
        broadcast_election_msg(neighbours)
        member_set = member_selection(join_set, ITRL)
        send(member_set, join)
        send(join_set − member_set, unjoin)
    else
        while(final_CH_set ≠ ∅)
            CH = least_cost(final_CH_set)
            final_CH_set = final_CH_set − CH
            join(CH)
            if(join_msg_received)
                return
        end while

        if(iterations ≤ max_iterations)
            Cluster_head_election()
        else
            broadcast_election_msg(neighbours)
```

Fig. 4. REECHD cluster formation

```
 Rotation()
    max = 0
    next_CH = null

    cluster_members ← {node | node is in the cluster of this CH}

    for each node n in cluster_members
        E_prob_n = E_residual_n / E_max_n

        DR_prob_n = DR_n / DR_max_n

        CH_prob_n = max((C_prob / 2) * (E_prob_n + DR_prob_n), P_min)

        if ( max < CH_prob_n )
            max = CH_prob_n
            next_CH = n

    if (next_CH != null)
        broadcast_designate_msg(next_CH)
    else
        do not rotate
```

Fig. 5. REECHD rotation algorithm

- Nodes can have different initial energy (this is often referred to as energy heterogeneity);
- Nodes have the same processing and aggregation capabilities;
- Nodes have different data transmission rates within a defined maximum and minimum data rate (this is often referred to as data rate heterogeneity);
- Nodes have a unique IDs;
- Nodes can transmit at various power levels depending on the distance of the receivers;

The BS resides outside the sensing field, is not mobile and has no energy constraints. The BS has higher processing and communication capabilities when compared to normal sensor nodes. Each CH can aggregate the intra-traffic messages (one message from each cluster member) in order to reduce the amount of bits that are forwarded to the BS. Inter-traffic is not aggregated that is a CH forwards (towards the BS) messages received from other CHs with no aggregation.

We use a network operation model that has been adopted in quite a few papers such as LEACH, HEED, RUHEED, FMUC and so on. We recall that a clustering protocol usually includes the following phases: (i) cluster election and formation; (ii) network operation phase; (iii) rotation (if any); (iv) re-election and formation. During the data network operation phase a TDMA is composed of the following two activities: (i) each member node sends one variable size message to its cluster head; (ii) all CHs data reaches the BS. In other words, a TDMA starts from the collection of data from the member nodes and ends when all the data reaches the base station. A round is composed of multiple TDMAs.

We define two types of WSN nodes that are homogeneous and heterogeneous. Homogeneous nodes have an initial energy of 0.5 joules and send messages of 1000 bits. Heterogeneous nodes have an initial energy that falls within the interval $[0.2, 0.8]$ joules and send messages of a size that falls within the interval $[100, 1900]$ bits. We define the heterogeneity level as the ratio between the number of the heterogeneous nodes and all WSN nodes. For instance an heterogeneous level of 20% means that 20% of the WSN nodes are heterogeneous. Table I summarises all network parameters.

For simulation purposes we define the aggregation rate (AR) which is a number between 0 and 1. This is is used to calculate the inter-traffic message size that is generated by the CH as follows:

$$MIN\left(\sum_{i=1}^{|cluster\_set|} sending\_rate(n_i) * (1 - AR), min\_msg\_size\right) \tag{3}$$

where $cluster\_set$ is the set of nodes that compose a cluster (inlcuding the CH), $|cluster\_set|$ is its cardinality, n_i is a node that belongs to $cluster\_set$, $sending\_rate(n_i)$ is the transmission rate of the node n_i, AR is the aggregation rate and min_msg_size is a constant that denotes the minimum size of message that is forwarded by a CH. When the aggregation rate (AR) is zero a CH packs all messages received by the members (during a TDMA) and forwards them to the next hope. In this case no aggregation takes place. When the aggregation rate is 1 the CH aggregates all messages received by the members in a TDMA by producing a message with a minimum size. In this paper we set this minimum size to 100, that is the minimum rate of a node. A more refined min_msg_size value could consider the node with the smaller (greater) rate inside the cluster or the average rate.

The adopted radio model utilises free space and multi path channel model. The assumed network grid size is 100 by 100 meters and BS is placed at position (175, 50). The simulation parameters are outlined in Table I. Transceiver circuitry of a sensor node consumes $E_{elec} = 50nJ/bit$. Sensor node amplification energy E_a depends on the distance between sender and receiver. When $d < d_0 = 75m$, E_a becomes $E_{fs} = 10pJ/bit/m^2$ and when $d \geq d_0 = 75m$, E_a reduces to $E_{mf} = 0.0013pJ/bit/m^4$. The transmission and reception

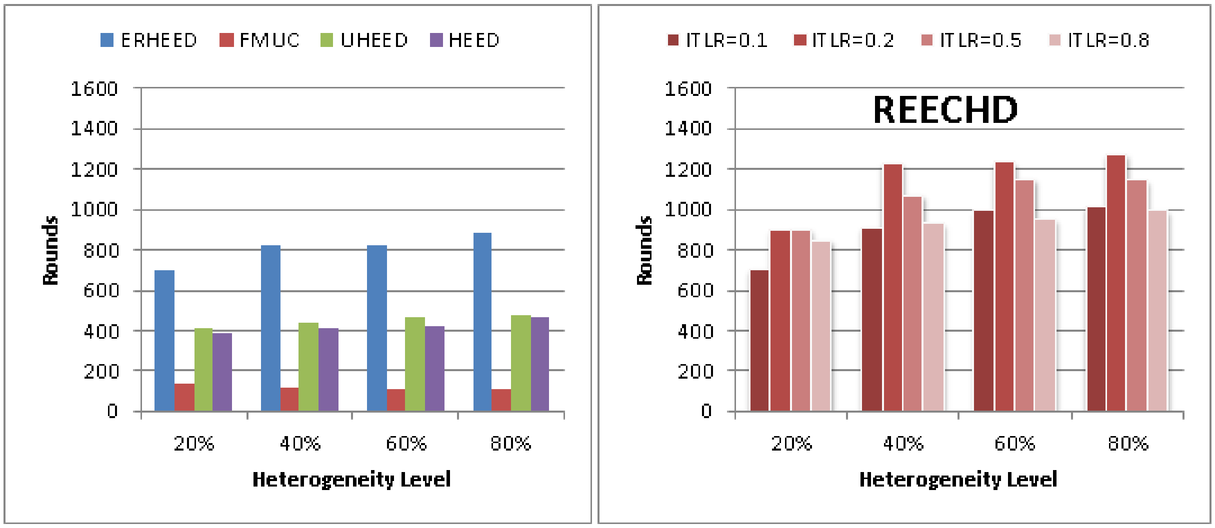

Fig. 6. Lifetime measure=FND; aggregation=50%; Heterogeneity level= 20%,40%,60%,80%; Intra Traffic Limit Rate= 0.1,0.2,0.5,0.8

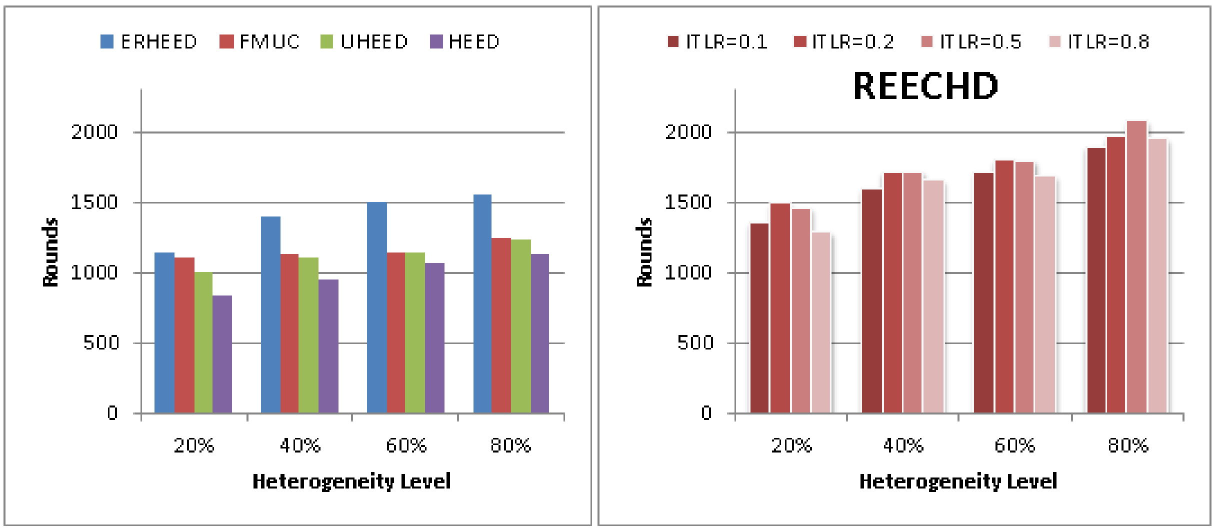

Fig. 7. Lifetime measure=HND; aggregation=50%; Heterogeneity level= 20%,40%,60%,80%; Intra Traffic Limit Rate= 0.1,0.2,0.5,0.8

energy consumed in sending and receiving a data packet k (bits) over distance d, can be be computed [5] as:

$$E_{Tx} = k(E_{elec} + E_a d^n) \tag{4}$$

$$E_{Rx} = k(E_{elec}) \tag{5}$$

B. Simulation Results and Analysis

We performed extensive simulations in order to compare the energy efficiency of REECHD, UHEED, HEED, ERHEED and FMUC clustering protocols. We consider a WSN that is composed of 200 nodes and a grid size of 100 by 100 meters. We varied the heterogeneity level from 20% to 80%, the node competition radius R_0 from 30 to 50 meters, and we set the aggregation to 50%. We also defined the ITLR percentage by multiplying the maximum ITLR value by a number between zero and one. We have used an ITLR percentage of 0.1,0.2,0.5 and 0.8.

Each simulation result is an average of hundred runs. We simulated all clustering protocols by using our Java simulator

TABLE I
Simulation parameters

Simulation parameters	
Parameters	Values
Network grid	$From(0,0)to(100,100)$
BS	$(175,50)$
E_{elec}	$50nJ/bit$
E_{fs}	$10pJ/bit/m^2$
E_{mp}	$0.0013pJ/bit/m^4$
R_0	$30m, 35m, 40m, 45m, 50m$
Control parameter UHEED	$c = 0.5$
Number of nodes	200

and a Matlab one. We made sure that both simulators gave always the same results. We have also validated our simulators by using various case studies we found in literature [17], [4], [1], [11] and [8].

Figure 6 shows the lifetime of the network for different heterogeneity levels until the first node dies (FND). More precisely, the left graph of Figure 6 shows network lifetime for ERHEED, FMUC, UHEED and HEED protocols. These are run for an increasing heterogeneity level, and radius from 30m to 50m. We display the lifetime that is related to the radius that produced the highest number of rounds. The protocol lifetime increases as the heterogeneity level approaches 80%. The right graph of Figure 6 shows the network lifetime for REECHD protocol. For each heterogeneity level, we show the network lifetime for different ITLR percentages. The most energy efficient results are achieved when the ITLR percentage is equal to 0.2. Figure 7 shows the results for half of the nodes die (HND) lifetime measure.

By looking at the Figures 6 and 7 we can observe that REECHD outperforms all other clustering protocols for both HND and FND lifetime measures.

Is it worth mentioning that REECHD outperforms FMUC [8], a protocol that have been conceived in the heterogeneous WSN context. We used the same simulation settings of FMUC [8] which outperforms the EEUC and DEBUC protocols. Thus REECHD outperforms both EEUC and DEBUC.

V. Conclusions

In this paper we present a Rotating Energy Efficient Clustering for Heterogeneous Devices (REECHD). This is a novel equal size clustering protocol that uses rotation. REECHD combines in a novel way node residual energy and node induced work in order to operate leader election and rotation. The cluster head selection strategy reduces the intra-traffic communication thus prolonging the network lifetime. REECHD also introduces the concept of intra-traffic limit rate (ITLR). This defines a limit on the intra-traffic communication that all WSN clusters must comply with. ITLR can be used to tune the number of clusters and prolonging the WSN lifetime. REECHD is more energy efficient when compared with well-known clustering protocols for homogeneous WSNs that are HEED, UHEED, ERHEED. REECHD also outperforms various clustering protocols that have been conceived in the heterogeneous WSN context that are FMUC, EEUC and DEBUC. In future work, we plan to implement a variation of REECHD which uses unequal size clustering. We plan to experiment various member selection strategies for cluster formation such as Knapsack. Finally we plan to study euristics to find the best ITLR under various WSN settings.

References

[1] N. Aierken, R. Gagliardi, L. Mostarda, and Z. Ullah. Ruheed-rotated unequal clustering algorithm for wireless sensor networks. In *29th IEEE International Conference on Advanced Information Networking and Applications Workshops, AINA 2015 Workshops, Gwangju, South Korea, March 24-27, 2015*, pages 170–174, 2015.

[2] P. Ding, J. Holliday, and A. Celik. Distributed energy-efficient hierarchical clustering for wireless sensor networks. In *Proceedings of the First IEEE International Conference on Distributed Computing in Sensor Systems*, DCOSS'05, pages 322–339, Berlin, Heidelberg, 2005. Springer-Verlag.

[3] C. Duan and H. Fan. A distributed energy balance clustering protocol for heterogeneous wireless sensor networks. In *2007 International Conference on Wireless Communications, Networking and Mobile Computing*, pages 2469–2473, Sept 2007.

[4] E. Ever, R. Luchmun, L. Mostarda, A. Navarra, and P. Shah. Uheed - an unequal clustering algorithm for wireless sensor networks. In *SENSORNETS*, 2012.

[5] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan. Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd Hawaii International Conference on System Sciences-Volume 8 - Volume 8*, HICSS '00, pages 8020–, Washington, DC, USA, 2000. IEEE Computer Society.

[6] D. Kumar, T. C. Aseri, and R. Patel. Eehc: Energy efficient heterogeneous clustered scheme for wireless sensor networks. *Computer Communications*, 32(4):662 – 667, 2009.

[7] P. Liu, T. l. Huang, X. y. Zhou, and G. x. Wu. An improved energy efficient unequal clustering algorithm of wireless sensor network. In *2010 International Conference on Intelligent Computing and Integrated Systems*, pages 930–933, Oct 2010.

[8] T. Liu, J. Peng, J. Yang, G. Chen, and W. Xu. Avoidance of energy hole problem based on feedback mechanism for heterogeneous sensor networks. *International Journal of Distributed Sensor Networks*, 13(6):1550147717713625, 2017.

[9] F. Mattern and C. Floerkemeier. *From the Internet of Computers to the Internet of Things*, pages 242–259. Springer Berlin Heidelberg, Berlin, Heidelberg, 2010.

[10] D. Miorandi, S. Sicari, F. D. Pellegrini, and I. Chlamtac. Internet of things: Vision, applications and research challenges. *Ad Hoc Networks*, 10(7):1497 – 1516, 2012.

[11] L. Qing, Q. Zhu, and M. Wang. Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. *Computer Communications*, 29(12):2230 – 2237, 2006.

[12] C. F. M. Schoenberger. The internet of things., 2002.

[13] A. R. Sfar, E. Natalizio, Y. Challal, and Z. Chtourou. A roadmap for security challenges in internet of things. *Digital Communications and Networks*, 2017.

[14] G. Smaragdakis, I. Matta, and A. Bestavros. SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor networks. In *Second International Workshop on Sensor and Actor Network Protocols and Applications (SANPA 2004)*, Boston, MA, August 2004.

[15] Z. Ullah, L. Mostarda, R. Gagliardi, D. Cacciagrano, and F. Corradini. A comparison of heed based clustering algorithms – introducing er-heed. In *2016 IEEE 30th International Conference on Advanced Information Networking and Applications (AINA)*, pages 339–345, March 2016.

[16] M. Yarvis, N. Kushalnagar, H. Singh, A. Rangarajan, Y. Liu, and S. Singh. Exploiting heterogeneity in sensor networks. In *Proceedings IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies.*, volume 2, pages 878–890 vol. 2, March 2005.

[17] O. Younis and S. Fahmy. Heed: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on Mobile Computing*, 3(4):366–379, Oct. 2004.