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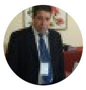

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A New Energy Efficient Cluster based Protocol for Wireless Sensor Networks

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Abstract: In Wireless Sensor Networks (WSNs), clustering techniques are usually used as a key effective solution to reduce energy consumption and prolong the network lifetime. Despite many works on clustering in WSNs, this issue is still, however, in its infancy as most existing solutions suffer from long and iterative clustering cycles. In an attempt to fill in this gap, we propose a new cluster-based protocol, referred to as Load-balancing Cluster Based Protocol (LCP) that introduces a new inter-cluster approach to increase network lifetime. This new protocol rotates continuously the election of the Cluster Head (CH) election in each cluster, and selects the node with the highest residual energy in each round. Extensive simulation experiments show that our proposed approach effectively balances energy consumer among all sensor nodes and increases network lifetime compared to other clustering protocols.

Keywords: ***WSNs; Distribyted clustering; Network lifetime; Routing.***

I. INTRODUCTION

The Wireless Sensor Network (WSN) technology has been one of the major avenues of networking and Internet of Things (IoT) due to their potential role in digitising smart physical environments [1]. A WSN is typically composed of a large number of low-power sensor nodes that can be either densely or sparsely deployed in harsh and extreme environments, such as wild remote areas, natural habitats, and regions with access risk. On one hand, sensor nodes are usually battery-powered with limited operating time, and therefore they are highly sensitive to failure [2] [3]. On the other hand, the design of an energy andefficient protocols to prolonging the network lifetime is a challenging task due to the unique nature and strong networking contraints of wireless sensor networks [4].

The research community proposed different routing protocols to optimise the routing process in WSNs. Typically, the routing protocols for WSNs fall into three main categories : flat routing, location based routing, and hierarchical routing [5]. In flat routing, all nodes have the same functionality and they work together to sense and route [6] . Location based routing protocols rely on the position information of each node to discover and build optimal routing paths [7]. Compared to the two previous categories, in hierarchical routing approaches, the sensing field is subdivided into a set of administrative domains called clusters [8]. Each cluster has an organised leader or a root node called the Cluster Head (CH). The primary aim of the CH is to collect data from attached and associated downstream nodes and forward it to the best next well-known hierarchical upper level upstream neighbour node. The data is forwareded in a hop-by-hop manner until it reaches the Base Station (BS). The BS can then send the data, using a wired or wireless Internet connection, to an end user located outside the sensing field [9][10].

Several cluster based and energy efficient protocols have been proposed in the literature [11]. These approaches attempt to minimise energy consumption by reducing the transmission of redundant data. Clustering approaches focus primarly on the communication process during cluster organisation and CH election and neglect the effect of information processing on energy consumption. Hybrid Energy-Efficient Distributed (HEED) is one of the clustering protocols that uses both energy and communication costs to select CHs in a probabilistic manner. This protocol uses different inter-cluster approach in order to reduce energy consumption and to prolong the network lifetime [12].

In this paper, we present a new energy-aware distributed and dynamic clustering protocol, namely A Load-balancing Cluster Based Protocol (LCP). LCP addresses load balancing issues in cluster-based routing approaches. Given that cluster-based protocols require regular re-clustering for balanced energy consumption, repeated re-clustering of the whole network increases network overhead, and consequently decreases the network operation time. The proposed model, however, provides a pre-defined interval of time at the beginning of every round to select the CH. This delays the frequency of re-clustering message coming from the BS. If they do not receive a re-clustering message, the CHs will continue to rotate the leadership among them within the same cluster by electing the node with the highest energy each round. The performance evaluation of LCP is examined in depth and compared to HEED [12], LEACH [13] and R-HEED [14]. Obtained results demonstrate that LCP enhances the network lifetime by 15%.

The rest of the paper is organised as follows. In Section II, we review a set of up-to-date clustering algorithms proposed for WSNs. Section III presents the features of the new LCP protcol. Section IV presents a detailed description of the simulation environment and the simulation results. Finally, section V reviews the entire study and offers conclusions and recommendations for future work.

II. RELATED WORK

Different cluster-based approaches have been proposed by the research community to address the challenging issues of WSNs. Some of these approaches are as follows:

A. *Low Energy Adaptive Clustering Hierarchy (LEACH)*

Heinzelman, et al. proposed the first well-known clustering LEACH protocol [13]. This protocol was targeted at prolonging the lifetime of WSNs and reducing the energy consumption of sensor nodes. From an algorithmic point of view, LEACH is a hierarchical, probabilistic, distributed and single-hop protocol. It forms clusters based on the strength of received signal, while CH nodes act as default gateways to the BS, as illustrated in Fig. 1. In LEACH protocol, nodes make autonomous decisions without relying on a centralised third party entity. In addition, all node have an equal opportunity to become CHs. Initially a node decides to be a CH by generating a random number between 0 - 1 and comparing it with a threshold value T (n), calculated using Equation (1).

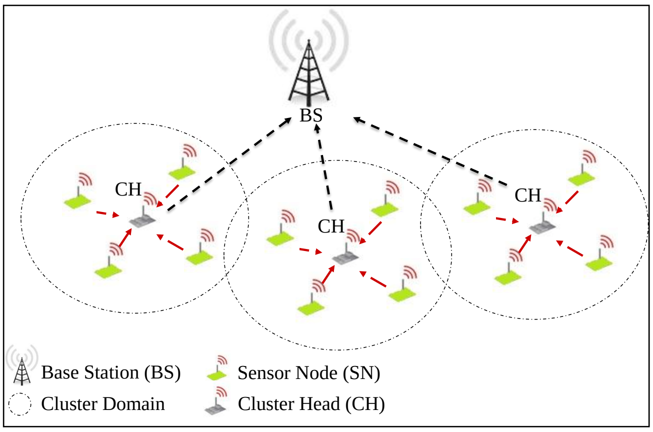

Fig. 1. Basic LEACH topology [11]

Nodes with a random number lower than T (n) then become CHs. Each elected CH broadcasts an advertisement to non-CHs to form a cluster. A non-CH chooses a CH that can be reached expending the least energy for communication.

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left(r \bmod \dfrac{1}{P}\right)} & if\ n \in G \\ 0 \end{cases} \quad (1)$$

Where ***p*** is the desired percentage of nodes to be CH; r is the current round; G is the set of nodes that have not been cluster heads during the last 1/P rounds.

Generally, LEACH provides a good model for energy consumption while providing an equal probability for node to be elected CHs. Once chosen as a CH, a sensor node cannot be reselected in a subsequent round. Moreover, LEACH avoids unnecessary collisions between CHs because it uses the Time Division Multiple Access (TDMA) protocol. Despite its generally good performance, LEACH also has some clear limitations. It uses single-hop communication which limits its scalability. In addition, the probabilistic election mechanism of CHs may lead to either high concentrations of CHs in one part of the network, or to orphan nodes (nodes without CHs in their neighbourhood.

B. *LEACH-Centralised (LEACH-C)*

To address the shortcomings of LEACH with respect to determining each CH's location and number rounds,a centralised version of LEACH, called LEACH-C was proposed [15]. In the new version, the BS decides which sensor nodes are eligible to become CHs and form a cluster. Each node transmits its location and energy level to the BS, which in return calculates the average energy level for the network and eliminates the nodes with remaining energy levels below this average, to form the set of CHs for that round. The centralised algorithm ensures that the energy load is equally distributed among all nodes by selecting a predefined number of CHs and dividing the network into optimum and equal sized clusters. However, the construction of clusters with an equal number of nodes in each cluster is not guaranteed in this protocol, and it is not always possible for nodes distant from the BS to send information about their status.

C. *Hybrid Energy-Efficient Distributed (HEED)*

O. Younis et al. [12] introduced HEED clustering protocol. In this protocol, the authors enhanced LEACH protocol by introducing two basic parameters to elect the CHs. The first main parameter concerns the remaining energy of each node, and the second parameter is the intra-cluster "communication cost". For example, the cost can be a function of neighbour proximity or cluster density, that can calculated using Equation (2). Thus, unlike LEACH, in HEED the CH nodes are not selected randomly. Only sensors with high levels of remaining energy can become CH nodes. In addition, when two nodes are within each other's cluster range, the probability of both becoming cluster heads is negligible. In comparison to LEACH, in HEED, the CHs are well distributed throughout the network. However, this protocol cannot fix the cluster count in each round. In addition, the energy consumption is not balanced, because more CHs could be generated more than expected, which creates massive overheads due to multiple election rounds.

$$CH_{prob} = C_{prob} \times \frac{E_{residual}}{E_{max}} \quad (2)$$

Where: C_{prob} is an initial percentage of cluster heads among all n nodes, $E_{residual}$ is the estimated current energy of the node, E_{max} is the referenced maximum energy (corresponding to a fully charged battery).

D. *Distributed Energy-Efficient Clustering (DEEC)*

Li Qing et al. [16] proposed the DEEC algorithm for WSN to improve HEED performances. In DEEC, the CHs are selected with a probability based on the residual energy of each node and the average energy of the network. The authors of this algorithm assumed that nodes would have different amounts of energy. With the adaptive values, the sensor nodes determine their role probabilistically in each round. The main drawback of DEEC is that each node demands global knowledge from the network, which increases the overheads.

E. Rotated Hybrid, Energy-Efficient and Distributed (R-HEED)

W. Mardini et al. [14] introduced R-HEED. With this protocol, the authors improved the performance of HEED by applying different inter-cluster approach. The new approach conducts a setup phase according to certain rules and schedule. At the beginning of every round, the CHs delay for a pre-defined period of time to await a re-clustering message from the BS. If they do not receive a re-clustering message, they continue rotating the cluster head within the same cluster. However, randomly rotating the CH does not take into account energy consumption.

F. Distributed weight based energy efficient hierarchical clustering protocol (DWEHC)

P Ding et al. [18] proposed a new protocol called DWEHC that improves HEED performances. Their primary aim was to to improve energy efficiency by creating balanced cluster sizes and improving intra cluster topology. Each sensor node begins broadcasting its (x, y) coordinates to search for its neighbour. After finding neighbouring nodes in its area, each node calculates its weight. Weight is the only parameter calculated locally and used for CH election; it is represented by W_{weight} in DWEHC as defined by Eduation 3.The node with the largest weight is selected as a CH and the remaining nodes become child nodes. At this stage, the nodes are considered first level members because they have a direct link to the CH. As the child nodes are further divided into levels (level 1, level 2, etc.) the total number of levels is seen to depend on the cluster range and the minimum CH energy. Like HEED, DWEHC is a fully distributed clustering protocol with a more balanced CH distribution. In addition, its clustering process does not rely on network size. However, this protocol cannot increase its energy efficiency give its inter-cluster communication function and the large control message overheads.

$$W_{weight(s)} = \left(\sum_{u \in N_{\alpha,c}(s)} \frac{(R-d)}{6R} \right) \times \frac{E_{residual}(s)}{E_{initial}(s)} \quad (3)$$

Where: R is the cluster range, d is the distance from node s to neighbouring node; $E_{residual(s)}$ is the residual energy in the nodes; $E_{initial(s)}$ is the initial energy in the nodes.

G. Power-Efficient and Adaptive Clustering Hierarchy (PEACH)

The majority of existing clustering protocols consume large amounts of energy, incurred by cluster formation overheads and fixed-level clustering. This is especially true when sensor nodes are densely deployed. To address this problem, Sangho Yi et al. [17] introduced PEACH protocol to minimise energy consumption of each node, and prolong the network lifetime. With PEACH protocol, a node becomes a CH when it receives a packet destined for the node itself. When the packet is destined for a different node, the node that received the packet joins the destination node cluster. Simulation results showed that PEACH consumes lower energy and prolonges the network lifetime comparative to the LEACH, and HEED protocols [Reference]. However, the network is not very scalable, because all the nodes must have global knowledge of the network.

III. THE LCP CLUSTERING PROTOCOL

The proposed scheme builds on the success of the HEED protocol. The clustering phase of the HEED protocol has been modified to make it more energy-efficient. The modified version is named A Load-balancing Cluster Based Protocol (LCP). In LCP, the clustering operation is divided into several rounds, each round has two phases: the setup and the steady-state phase. LCP is similar to HEED in terms of the following features:

- The elected CHs sent advertisement message only to 1- hop neighbours.
- The clustering procedure ends in O(1) iterations.
- Each node belongs only to one cluster and can communicate directly with its CH.
- During the clustering process, the node can be either a tentative_CH or a final_CH, or it can be covered.
- At the end of setup phase, CHs form a network backbone; therefore, the packets are routed from the CHs to the BS in a multi hop fashion over CHs.
- The steady state phase for both the protocols is alike, and CH election is done as part of an iterative process.

The setup phase is divided into four phases: the initialisation phase, the main processing phase, the finalisation phase and the rotation phase. The following steps describe the proposed phases, which are illustrated in Fig. 2.

1) Initialization phase: At the beginning of this phase, neighbours' information must be updated. After this update, each node then computes its cost, but does not broadcast it, because costs are exchanged through the cluster head message. The protocol sets an initial percentage of CHs among all sensor nodes, C_{prob}, and each sensor node establishes its probability of becoming a CH, setting its CH_{prob} according to HEED.

2) Main Processing phase: In this phase every node is subject to a delay time, in which it can decide whether the node will become a tentative_CH or not. If the node will not become a tentative CH during the main processing, then it declares itself to be a final_CH, by sending a cluster_head_msg (NodeID, tentative_CH, cost) to all the nodes within radio range.

3) Finalize phase: During this phase, each sensor node makes a final decision concerning its status. If the node is not a final_CH, and has received at least one cluster_head_msg (NodeID, final_CH, cost), it elects the final_CH with the least cost to join it. If the node is not a final_CH and has not heard any cluster_head_msg (NodeID, final_CH, cost), it elects itself to be the final_CH, and announces this to the nodes in its cluster range.

I. Initializ phase:

$S_{nbr} \longleftarrow \{\upsilon : \upsilon$ lies within my cluster range$\}$

$CH_{prob} \longleftarrow \max(C_{prob} * (E_{reidual}/E_{max}), P_{min})$

is_final_CH$\longleftarrow$ *False*

Node Wait for delay time

II. Repeat phase:

If $((S_{CH} \longleftarrow \{\upsilon : \upsilon$ is a cluster head$\}) \neq \emptyset)$

my _cluster_ head$\longleftarrow$ least_cost(S_{CH})

If (my_cluster_head=NodeID)

If (CH_{prob}=1)

cluster_head_msg(NodeID,final_CH,cost)

is_final_CH$\longleftarrow$ *TRUE*

Else

cluster_head_msg (NodeID, tentative_CH, cost)

Elseif (CH_{prob} = 1)

cluster_head_msg (NodeID,final_CH, cost)

is_final_CH$\longleftarrow$ *TRUE*

E***lseif*** Random(0,1) $\leq CH_{prob}$

cluster_head_msg(NodeID,tentative_CH,cost)

$CH_{previous} \longleftarrow CH_{prob}$

$CH_{prob} \longleftarrow \min(CH_{prob} \times 2, 1)$

Until $CH_{previous} = 1$

III. Finalize phase:

If (is_final_CH = FALSE)

If ((SCH $\longleftarrow \{\upsilon : \upsilon$ is a final_cluster_head$\}) \neq \emptyset)$

my_cluster_head $\longleftarrow$ least_cost(S_{CH})

Join_cluster (cluster_head_ID, NodeID)

Else Cluster_head_msg(NodeID,final_CH, cost)

Else Cluster_head_msg(NodeID, final_CH, cost)

IV.Rotate phase:

If $((S_{Cmber} \longleftarrow \{\upsilon : \upsilon$ is a cluster member$\}) \neq \emptyset)$

NodeID $\longleftarrow$ highest_nergy(S_{Cmber})

Cluster_head_msg(NodeID,final_CH)

Fig. 2. A Load-balancing Cluster Based Protocol algorithm.

4) Rotation phase: After constructing the clusters in the first round, and before entering the steady-state phase, every CH constructs a turn schedule for its members, informing every member when it must be a CH. The turns are sorted based on residual energy in the sensor node. The node with the highest residual energy will be the first candidate to become a CH for next round. Therefore, in the setup phase in the next round it is not necessary to re-elect a CH as in HEED. Nodes in the cluster take turns to be the CH. The nodes within the same cluster in subsequent rounds continue rotating the CH role between them, by selecting the node with the highest residual energy every round. When the first cluster finishes the rotating process, it sends a re-clustering message to the BS via multi-hop route. When the BS receives a re-clustering message from at least one CH, it re-broadcasts the re-clustering message to all the nodes in its network. After all nodes have received the re-clustering message they proceed to step I, See Rotate phase in Fig. 3.

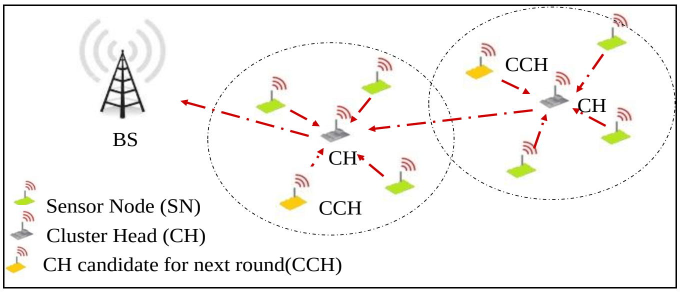

Fig.3. A Load-balancing Cluster Based Protocol Rotate phase.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the LCP mechanism by using open source Castalia simulator [19]. We consider a sensor network, composed of (100-350) sensor nodes, which are randomly deployed in a playground of 200m×200m square region. All sensor nodes are fixed and homogeneous and with limited stored energy. Nodes are not equipped with GPS-capable antennae. The BS is placed at the center of the sensor field. The energy consumption for each sensor node is calculated by data transmission and aggregation per round. The energy efficiency of LCP is compared against LEACH, HEED, R-HEED. Simulation parameters are given in Table I.

TABLE I. PARAMETER SETTINGS

Parameter	Value
Deployment field	200 x 200 m
Data packet size	200 bytes
Control packet	25 bytes
Number of nodes	100 – 350
Initial cluster radius (*RC*)	25m
Sink position	(0,0)
Initial energy	25J
Threshold distance (*d0*)	75m
Deployment method	Uniform, Random
Rotated time (T_r)	20 Sec
Radio model	CC2420

The residual energy metric, which is the average energy remaining in all nodes at a specific round, and the network lifetime metric are used to evaluate the performance of the protocols being compared. Some WSN applications require that each node should work to ensure the network has good coverage. Thus, the network lifetime metric for these applications should be measured according to the lifetime of the shortest-living node. Other applications require that only a specific percentage of nodes should remain alive to achieve the network objectives [17]. Hence, in our simulation, the network lifetime is measured by following three different metrics.

1- First Node Dies (FND): this is the time elapsed in rounds until at least one of the nodes has consumed all available energy.

2- Half Nodes Die (HND): this is the time elapsed in rounds until half of the nodes have depleted their entire energy store.

3- Last Node Dies (LND): this is the time elapsed in rounds until all the nodes have exhausted their entire energy supply.

Here the term ‘round’ refers to the time elapsed in seconds before a network re-clustering event occurs. There is no difference between the round concepts in HEED and LCP, in terms of time. The round time in HEED and LCP is measured in seconds, minutes or hours. In our simulation, we specified a round time of 20 seconds.

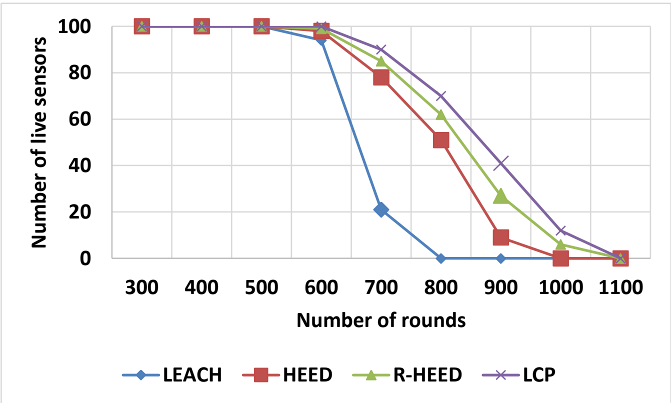

Fig.4. Number of alive sensors vs. numbers of rounds for LEACH, HEED, R-HEED and LCP.

Fig. 4 . demonstrates the total number of nodes remaining alive following the simulation round. LCP increases the network lifetime compared to its peers. Fig. 5. demonstrates the relationship between the remaining energy and the number of nodes. It is evident that LCP consumes the least amount of energy. Furthermore, how the increasing number of the nodes affects the lifetime of each protocol has been evaluated. Fig.6 demonstrates the network lifetime; which is the time elapsed until the first node dies, when the number of nodes varies between 150, 200, 250, 300 and 350.

Similar comparisons are conducted to determine the number of rounds before half of the nodes die, and the number of rounds before the last node dies, as depicted in Figs.7 and 8 accordingly. All the protocols improve the network lifetime when the number of nodes increases. Figs 6, 7 & 8 show that in all three cases LCP performs better than the rest of the protocols. This improvement is due to the process of rotating the cluster heads within the same group (cluster).

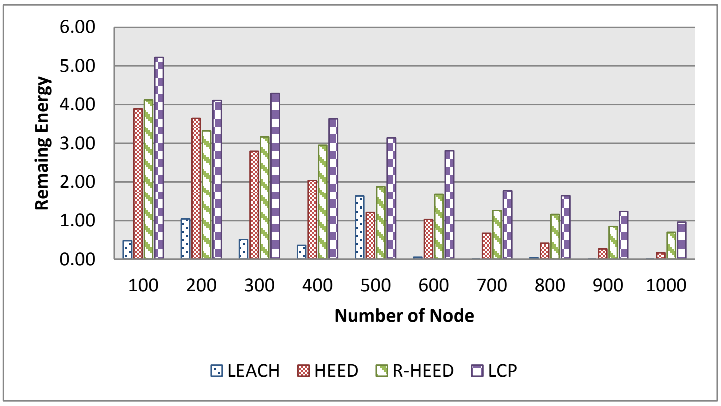

Fig.5. Total remaining energy in LCP in comparison with HEED, R-HEED.

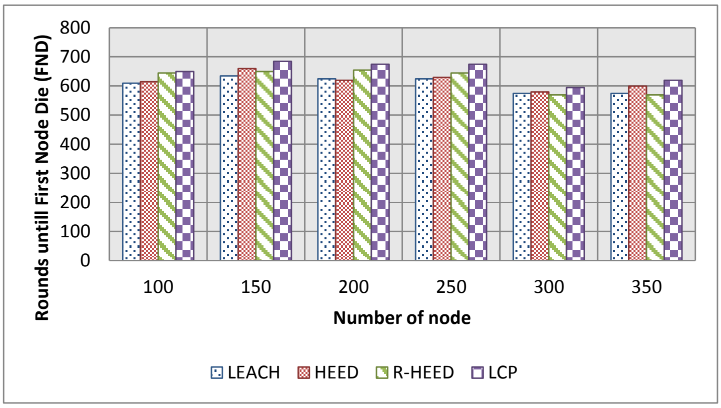

Fig.6. Comparing LEACH, HEED, R-HEED and LCP using different number of nodes for FND metric.

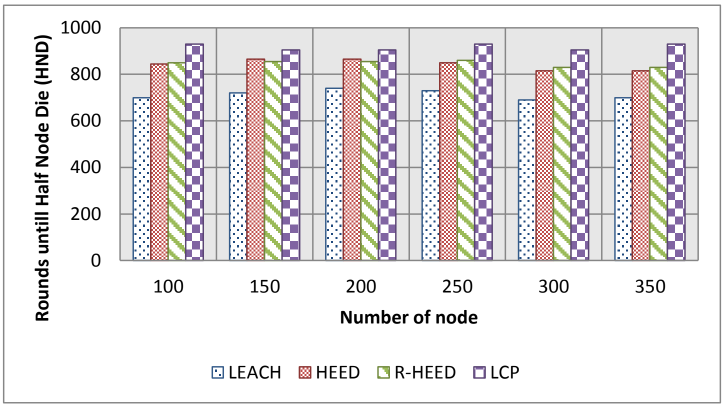

Fig.7. Comparing LEACH, HEED, R-HEED and LCP using different number of nodes for HND metric.

Consequently, this leads to minimising the energy consumption and increasing the network’s lifetime. It can be easily observed from the simulation results that when the number of the nodes increases the percentage improvement also increases. Therefore, it can be reasoned, that when the number of the nodes is increased the amount of energy consumed during the clustering phase reduces. Thus, the energy saved as a result of this new clustering scheme will be maximised, which will improve the network’s lifetime.

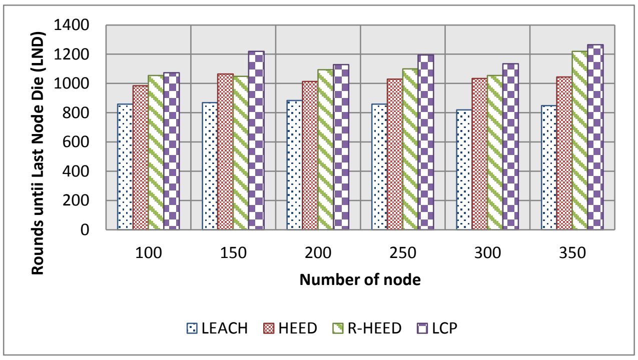

Fig.8. Comparing HEED and R-HEED using different number of nodes for LND metric.

V. CONCLUSIONS AND FUTURE WORK

In this paper, the clustering scheme LCP for wireless sensor networks was proposed as a more energy-efficient protocol. The main contribution of the LCP protocol is its ability to rotate the role of the CH between nodes of the same group, by selecting the node with the highest energy to become a CH. We compared and evaluated the proposed protocol performance with well-known clustering protocols in terms of network lifetime and energy consumption. The simulation results showed that the proposed approach balances the energy consumption well across all the sensor nodes and achieves an obvious improvement to the network's lifetime by 15%.

Finally, the performance metrics used in the evaluation of the protocols were limited to energy consumption. We propose, in future work, to evaluate the performance of LCP according to other networking metrics, such as packet delivery ratio and end-to-end delay.

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