Rotated Hybrid, Energy-Efficient and Distributed (R-HEED) Clustering Protocol in WSN

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Abstract: - Minimizing the energy consumption for data transmission is one of the most important design considerations in Wireless Sensor Networks (WSNs). The clustering approach is considered one of the most effective methods to prolong the network lifetime in WSNs. Hybrid, Energy-Efficient, and Distributed clustering approach (HEED) is considered one of the most energy-efficient clustering algorithms that uses intra-communication cost and residual energy to elect the Cluster Heads (CHs). In this paper, we aim at examining different inter-cluster routing protocols over HEED and evaluate their performance. Moreover, an enhanced version to HEED, namely Rotated HEED (RHEED), is proposed in this paper. The modified version conducts the setup phase according to certain rules and schedule, with HEED performs this step at the beginning of some rounds. At the beginning of every round the CHs wait a pre-defined period of time to receive a re-clustering message from the BS. If they do not receive the re-clustering message, they will continue rotating the cluster head within the same cluster. The simulation results show that the RHEED outperforms the HEED protocol by more than 20% in term of network lifetime and residual energy.

*Key-Words:-S*ensor Network; Clustering Protocols; HEED; Cluster Head; Energy Consumption; Distributed; Hybrid.

1 Introduction

Wireless Sensor Network (WSN) is an emerging technology which has a wide array of applications. These applications include infrastructure protection, industrial sensing and diagnostics, battle- field and environmental monitoring, building's micro-climate controls system, biological and nuclear attack detection, context–aware computing such as intelligent home and responsive environment ([1], [15]) .This kind of networks usually consists of a large number of resource-constrained sensor nodes that are usually deployed randomly or uniformly in the sensing area to monitor physical conditions such as humidity and temperature in that area. The main components of a WSN are the sensor nodes and a Base Station (BS), which sometimes called a sink, where the monitored events data are collected [1]. Usually, the base station is not resource-constrained and might on a far distance from the area that is monitored. The sensor nodes have the ability to interact with the surrounding environment by sensing and monitoring the physical conditions around them. These small and resource-constrained sensors have to collaborate to accomplish their tasks. The collected data by sensors are transferred to a central point "the sink" which might be connected to the internet.

One of the main advantages of WSNs is their capability to operate in harsh environment where man-in-the-middle controlling and monitoring technique is inefficient and risky [23]. Depending on the application requirements, the wireless sensors are either deployed manually (in predetermined locations) or it could be deployed randomly in the environment by relatively uncontrolled means. In many applications a large number (hundreds or thousands) of sensors are deployed in the area of the interest given the wide area to be covered and the short life-time of the sensors. The most important problem in WSNs is the power consumption since the sensors have constrained energy resources (such as batteries) which also cannot be replaced as it is usually deployed in inaccessible sites such as natural habitats, wild areas, and earthquake-risky regions. Therefore; devising a power efficient a protocol dealing with this kind of networks is highly desirable to maintain the operability and extend the lifetime. WSN inherits most of the features from the traditional networks. However, the unique nature of such network adds more constraints that need to be addressed such as power consumption. For example, in traditional networks, the energy is not an issue where in WSNs each node is supplied by a tiny battery that has a limited operational time depending on the processing and communication the node carries throughout its life time. Moreover, a sensor node lacks the computational and memory needed when implementing a complex routing protocol.

There are various applications that wireless sensor networks have been utilized in such as disaster relief applications, environment control and biodiversity mapping, target field imaging, weather monitoring, tactical surveillance, facility management, medicine and health care and so on ([4],[7]). In general, all wireless sensor networks applications could be divided into three classes; surveillance applications, data collection application, and object tracking applications.

WSNs share common challenges and problems with ad hoc networks, however, there are new challenges that come from the fact that these devices are resource-constrained; limited memory and storage capacity, limited processing speed, limited communication range, and limited energy supply. Some of the challenges that face WSN are dynamic network topology, overlapping sensing areas, wireless communication media and short network lifetime [4]; Zhao, Shin & Reich, 2002). To overcome the challenges listed above and the other challenges, it is very important to build a sensor network that employs energy-aware routing protocols with multi-hop communication paradigm, and is self-reconfigurable, and self-organized.

The main protocols used in the operability of WSN are the routing protocols. There are many routing protocols have been designed in the literature for WSNs which differ in their intuitions and assumptions from other wireless networks [3]. These protocols can be classified into hierarchical-based routing flat-based protocols and location-based routing based on the structure of the network [6], [25].

In the flat-based networks, all the sensor nodes have the same capabilities and they all play the same role. In flat architecture, all the nodes are considered neighbors, and all are able to detect and forward data to the (BS). Various flat-architecture-based protocols is developed by the researchers such as Sequence Assignment Routing (SAR) routing protocol. In cluster-based sensor networks, the sensors should be organized into groups called clusters before sending the data to the BS. Each cluster has a CH responsible for sending the fused data to the BS. Other sensors can only send the data to the BS indirectly via their CHs. The routing protocols that depend on clustering have been proved as an efficient approach to decrease energy consumption and improve WSNs lifetime, especially, in large-scale networks. In location-based networks, the sensor nodes are addressed by means of their locations that are used for routing network data. A global positioning system (GPS) could be used to find location information. Another method is to exchange relative coordinates of neighbors for location estimation [6].

The sensors limitation in their energy supply is the most important constraint in WSNs. The developing of isolated and disconnected regions within the network is the main challenge when a group of sensor nodes lose their power. This can results in many other problems such as packets not delivered to their destinations, loss of data or delay of collected data. In WSNs, the manually power management is very tedious due to several obstacles such as [6]. Sensor nodes don't consume energy in a predicted approach and most of the times the senor nodes are deployed in harsh areas which are difficult to reach or control. To manage power consumption efficiently, the authors in [12]pointed out that the power management starts with the proper design of the four unites of sensor nodes: “designing low-power chips is the best starting point for an-energy-efficient sensor node.” The authors also said that good control and operation of the sensors will surely improves the energy consumption. Usually, a sensor node starts its work by collecting data according to the application requirements. The collected data are organized by the application layer which then is passed to the network layer. The network layer will encapsulate the collected data within a packet to be passed to the physical layer which transmits it using the antenna attached to that sensor. Normally, in a complex node (station), these layers are designed unaware of energy demands that a sensor requires. To reduce energy consumption, one might consider designing the layers with a little inelegance to accommodate the energy considerations which will reduce the energy consumption.

The power management at the system level is another alternative which include the transmission power optimization. It is noted that the transmission power level adjustment affects many parts of a wireless sensor network system. Some of the parts that could be affected by the transmission power are the sensor communication range, network dynamic architecture and topology, and route selection. The power level tuning can be made at the node level or at the system level [10].System’s power management could be also affected by application requirements. For example, an application that requires dense deployment of nodes means that a node can use a low transmission power, because the distance to its neighbors is small enough. However, like this deployment will produce correlated and redundant data that system has to control and manage. In addition, further manipulation like data aggregation of this redundant data should be conducted at the end point which will affect the power consumption. In summary, the power management in WSN systems is very important but tedious task. The designer has to compromise between node hardware restrictions and the application requirements. So, the nodes' proper design and configuration, routing protocols and algorithms selection are required [12].

A one-round distributed clustering scheme based on spatial correlation between sensor nodes were proposed in [22]. Moreover, a novel light-weight compressing algorithm to effectively save the energy at each transmission from sensors to the base station based on temporal correlation of the sensed data is also proposed. The simulation results show that the proposed schemes significantly reduce the overall number of communications in the cluster construction phase and the energy consumed in each transmission.

HEED is one of the most effective cluster-based routing protocols in WSN. It is a distributed, energy efficient clustering approach which makes use of two parameters to cluster the network; the sensor residual energy as a primary parameter and Intra-Communication like node degree and node proximity as a secondary parameter [30]. The HEED operation for clustering is divided into three phases; the initialization phase in which the sensors put their probabilities to become CHs, the main processing phase in which the sensors go through many steps to elect the CHs and the finalization phase in which each sensor join the least communication-cost CH or announce itself as a CH . The re-clustering in HEED is triggered dynamically at the beginning of each round which is a pre-defined period of time; the round in HEED can be in the range of seconds, minutes or even hours depending on the application at hand [30].

In this study, we aim at examining different inter-cluster routing protocols over HEED and evaluate their performance. The examined protocols are DSR, the routing component of DCR, and PEGASIS. Moreover, an enhanced version to HEED, namely Rotated HEED (RHEED), is proposed in this paper. The modified version conducts the setup phase according to certain rules and schedule, with HEED performs this step at the beginning of some rounds. At the beginning of every round the CHs wait a pre-defined period of time to receive a re-clustering message from the BS. If they do not receive the re-clustering message, they will continue rotating the cluster head within the same cluster. Evaluation performance results indicate that the new approach enhances the network life-time. The proposed scheme outperforms the HEED protocol by more than 20% in term of network lifetime and residual energy.

The rest of the paper is organized as follows: Section 2 presents literature review of routing and clustering protocols currently used in wireless sensor network and their different classifications. In addition, it investigates the clustering approach in wireless sensor networks and highlight how we can use this approach to decrease the energy consumption. Section 3 introduces the system model and explains in details our contributions. Section 4 presents detailed description of simulation environment and the obtained results. Finally, section 5 overviews the entire study and then presents conclusions and recommendation for future work.

2 Related Work

The routing in the wireless networks is very challenging and complicated task due to their limited resources especially in term of energy. The dominant communication paradigm in almost all sensor networks applications is having multiple point sources sending the data to a common destination called the base station. The routing in wireless sensor networks has many distinguishable futures comparing to ad hoc networks and contemporary communications [1]. Some of these features are as follows:

- IP-based protocols (internet protocols) cannot be used in these networks because it is impractical to build a global addressing scheme for them due to the enormous number of sensor nodes.
- There is significant redundancy in generated data because several sensors may gather the same data within a particular field. These redundant data need to be removed to reduce energy consumption in the network and also to increase the bandwidth utilization.
- Transmission power, storage and processing capacity are constraint factors to be considered when designing a WSN.
- Sensor nodes in most cases are assumed to be stationary and routing messages between sensor nodes depend on the application: the sensed event can be static or dynamic. In static events, the traffic is generated only when reporting has to be done; on the other hand in dynamic events, most application periodic reporting is required which results in generation of significant traffics that have to be forwarded to the sink.

Due to such problems imposed on these networks, there are many different routing approaches that have been designed for WSNs. The proposed routing approaches take in their consideration the application requirements, application architecture, and characteristics of sensor nodes. They mostly take care of reducing the energy consumption during data transmission which is the most challenging factor facing WSNs. The various WSNs routing protocols is classified into three classes; data-centric routing protocols [13] location-based routing protocols and hierarchical or cluster-based routing protocols. In the following sections we are going to discuss in details the various types of the routing protocols in WSNs.

In [15] maximum likelihood estimate or methods are proposed. The idea is to estimate parameters in decentralized fashion were the accuracy is a trade-off with the energy consumption. “The results show that estimation performance for clustering with the same number of cluster members can be comparable to that for cluster-free sensor networks, but with less energy consumption.”

The authors in [20] proposed a multi-objective genetic algorithm for clustering homogeneous wireless sensor networks. The proposed scheme is divided into two levels: top and low levels. The main goal of the proposed scheme is to optimize the network’s lifetime for different delay values while optimizing the transmissions’ topology from sensor nodes to the cluster head. Simulation results show that the proposed scheme outperforms the Low Energy Adaptive Clustering Hierarchy protocol in terms of network’s lifetime.

The authors in [26] propose a hierarchical and low-power address configuration scheme for wireless sensor networks. The idea is based on the cluster-tree architecture were the network is divided into multiple clusters and the generation algorithm of a cluster is actuated. Moreover, the paper addresses the mobility of sensor nodes and their failure rate and discusses the performance with respect to detection cost, address configuration cost and address configuration delay time, of the proposed scheme, Strong DAD and MANETConf.

The work in [17] presents two routing protocols for mobile sensor networks, in which a fixed transmission power is used in the clustering phase, while an adaptive distance-based transmission power is used for the data transmission phase. In one scheme, namely PCR, the nodes are assigned weights to associate with a cluster-head. However, in the second scheme, EPCR, the association is performed based on the distance.

2.1 Routing Protocols Overview

Routing is the process of finding routes in a network on which the data will be forwarded from a specific point (source) to a final destination.

2.1.1 Data-centric protocols

Assigning global identifier for each sensor node in a WSN is a difficult due to the large number of sensor in many applications. Thus transmission of the data from every sensor in the network will result in significant redundancy which in turn will lead to more energy consumption. Hence, the data-centric routing protocols were developed to reduce this redundancy [13]. In this type of protocols the sink is usually used to send queries to certain nodes in certain region and wait for data from sensor nodes in that selected region. Sensor protocol for information via negotiation (SPIN) [22] is the first data centric routing protocol that was developed in purpose of energy saving and elimination of the redundant data.

SPIN uses the meta-data that is high-level descriptors to characterize the data of interest. The meta-data are exchanged between sensors thought data advertisement phase. SPIN uses many types of messages to exchange the data between sensor nodes. The first message is the ADV message which indicates that the sensor has the permission to advertise the data to the other sensors. The second message is the REQ message in which the sensor can make request for specific data. The actual data will be carried in the third type of messages which is the DATA message. In SPIN, the topological change is localized because each node needs to recognize only its one-hop neighbors. However, it is not scalable and also, the nodes close to the BS could dissipate their energy early if the base station is concerned about too many event. Moreover, in data advertisement phase, data delivery cannot be guaranteed. For example, if there is data important for some sensors which are located far away from the source and this data is important for other sensors located between destination and source, such a data will not be transmitted to the destination at all.

Another data-centric routing protocol is the Direct Diffusion (DD) [9]. The idea behind this protocol is to diffuse the data through sensors using naming schema in purpose of eliminating the unnecessary network layer routing operations in order to decrease the consumed energy.

2.1.2 Location-Based Protocols

Location-based routing protocols depend in their operations on the exact locations information of nodes to build routing decision. The available location information helps the network in calculation the distance between two selected sensor nodes and exploiting this location information in reducing the energy consumption. For example, to get data form a specific region, using sensor location, a query could be sent to that region only and this will significantly reduce transmitted data comparing to a broadcast request being sent to the entire network [1]. In other words, the location-based protocol exploits the location information to forward the data to a specific region rather than forwarding it to the whole network. The Minimum Energy Communication Network (MECN) is one of the first location-based routing approaches that have been developed. MECN uses low power global positioning system (GPS) to define sensors locations.

2.1.3 Hierarchical protocols

Hierarchical routing depends in their operations on dividing the WSN into clusters in a form of hierarchy when sending data from the sensors to the sink. To reduce energy consumption, hierarchical routing utilizes multi-hop communication and aggregation of data in a way that decreases the number of transmitted data through the network to the base station. In most hierarchical protocols, the cluster formation depends on residual energy of the sensor nodes [1]. Fig. 1shows a WSN after it has been clustered using a clustering algorithm.

One of most well-known distributed clustering algorithms is Low Energy Adaptive Clustering (LEACH) for sensor networks [9]. Leach cluster the network by having the sensors, at the beginning of each round, choose a number randomly, if the chosen number is not greater than a pre-determined threshold probability, the sensor will elect itself to be a CH. The other sensor nodes join the CH which is reachable with the least communication energy. After the clustering has been done the normal sensors (not CHs) will send their sensed data to their CH which in turn aggregate the sensed data and re-transmit it to the BS.

Reduction in energy consumption in data transmission comes from that the CH is involved in transmission to the BS rather than individual sensor nodes and also due to aggregation at the CHs before forwarding the data to the BS. Because LEACH chooses the CHs randomly, it suffers from the problem that a node with a low residual energy can be elected as a CH [5]. Another problem with LEACH that it requires the CHs should forward the collected data from their members to the sink directly. This model is not efficient because of long distance between some CHs and the BS. As result, the farthest CHs from the BS will die early [28].

Power Efficient Gathering in Sensor Information System (PEGASIS) [14] is another hierarchical routing protocol which considered as an improvement over LEACH. In PEGASIS, The primary idea is having each node to receive from and transmit to adjacent neighbors and then each node will take its turn later to be the chain leader. The nodes in PEGASIS are organized to form a chain either by the sensors themselves using a greedy algorithm starting from the randomly chosen node, usually the farthest nodes from the sink, or by having the sink construct the chain and transmits these information to the rest of sensors. In PEGASIS, the data aggregation is performed at every node on the chain except the end nodes in the chain and the network topology is assumed to be known. PEGASIS [14] performs better than LEACH because it reduces the consumed energy in its phases. In its local gathering stage, the summation of distances among transmitting nodes is less than transmitting to a CH in LEACH. Also the amount of data received by the leader of chain is much less from that in LEACH. Finally, in each round, only there is one node envoys the collected data to the sink node.

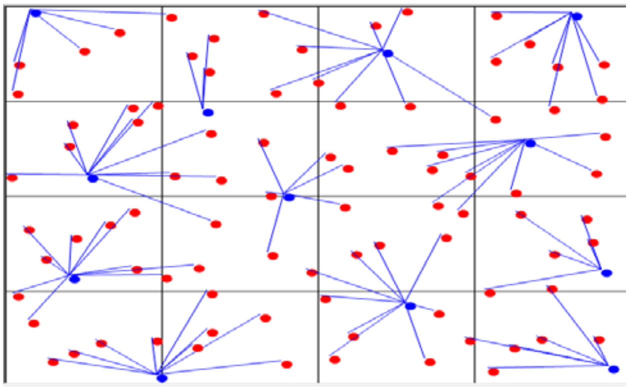

Fig.1. Clustered Wireless Sensor Network

Another well-known but more effective hierarchical-based protocol is the Hybrid Energy-Efficient Distributed (HEED) Clustering [30]. It is a distributed, energy efficient clustering approach which uses two parameters to cluster the network; the sensor residual energy and intra-communication cost. The HEED operation for clustering is divided into three phases; the Initialization phase in which the sensors set their probabilities to become CHs, the Main Processing phase in which the sensors go through many steps to elect the CHs and the Finalization phase in which each sensor join the least communication-cost CH or announce itself as a CH. The re-clustering in HEED is triggered dynamically at the beginning of each round which is a pre-specified period of time. The round in HEED can be in the range of seconds, minutes or even hours depending on the application at hand. The clustering in HEED is triggered every T_{CP} + T_{NO} seconds (round) where T_{CP} is the clustering duration; the clustering interval needed by HEED to cluster the network and T_{NO} is the network operational interval; the time between the end of a T_{CP} and the beginning of the next T_{CP} interval. The clustering process start by having each node computes its probability to become a CH CH_{prop}as in (1):

$$CH_{prop} = C_{prop} + E_{residual}/E_{max} \quad (1)$$

Where$C_{prop}$the initial percentage of CHs is, $E_{residual}$ is the node residual energy and E_{max} is the node initial energy after deployment. The clustering process in HEED is divided into iterations. During iteration, every node, which have not yet received a message from any tentative CH or final CH, elect to be a CH with probability ofCH_{prop}. If the node, during step i of an iteration, received a tentative CH message from its neighbors, then it selects the lowest cost CH to be its CH. The node also will choose itself as its tentative CH if it was elected to be a tentative CH with lowest cost between its neighbors. The problem with HEED that is it conducts the clustering process at each round and this consumes a significant part of its energy for the clustering process [19].

Another recently developed hierarchical clustering protocol is EESH [27]. In EESH, the node is elected to be CHs depending on its degree, its distance to neighbors and the neighbors' residual energy. So, every node should evaluate a cost function and then the sensor with the greatest cost is chosen as CH. The clustering process will be terminated when all the sensors have been joined at least one CH.

The authors in [16] proposed an energy efficient distributed clustering and routing protocol (DCR). DCR consists of three phases; distributed clustering phase, distributed multi-hop routing phase and route maintenance phase. In the clustering phase, the BS chooses randomly a number of candidate CHs to compete for final CHs. The nodes which were not selected as a candidate CHs will be switched to sleep mode until the clustering phase end for the sake of saving energy. Then the candidate CHs compete to be final CHs using a competition algorithm. In multi-hop routing phase, the multi-hop routes to the sink are constructed. The multi-hop routes are constructed by having each CH chooses the nearest neighbor to the BS within a communication radio range to be its next hop. If two neighbors are on the same distance from the BS, the CH will choose the one with more remaining energy to be its next hop.

The Dynamic Source Routing (DSR) [21] is routing protocol which finds the route to a specific destination only when a source requests one. DSR uses source routing. That is, the source data packet carries the full node-by-node path to its destination in its header. A Route constructing in DSR works by broadcasting a route request (RREQ) through the network. Every node who received this route request will rebroadcast it; the nodes that have a route to the destination will not rebroadcast the route request. Then such a node responds with a route reply message that is sent back to the sending node through the path visited by the route request packet. Then it put the new created route in its route cache. A message indicating error will be passed to the source once a link on the route is broken to notify it that the route is unavailable. All the routes that use this link will be deleted by the source node from its cache and as a result the source should initiate a new route discovery.

The authors in [21] have compared performance of DSR and Ad-Hoc On -demand Distance Vector (AODV) in wireless ad hoc networks. They found from their simulations that is for application-oriented metrics like throughput, DSR performs better than AODV in situations having lower load or/and no mobility and lesser nodes. However, AODV performs better than DSR in situations having more stress on parameters. They found also that DSR always generates less routing overhead than AODV. One of the trials to incorporate the hierarchical methods in the traditional routing protocols such as DSR is presented in [24]. The authors found that the traditional routing protocols such as AODV suffer from less packet delivery ratio and large routing overhead which reduce the performance of the system. They incorporate hierarchical algorithms in traditional protocols to avoid these limitations.

The clustering in WSNs is an approach in which the sensor nodes are organized into clusters in order to accomplish network scalability gaols and decrease the redundant transmitted data. Every cluster would have a CH which is responsible for receiving the information from its cluster members and then forwarding this data to the BS members. Transmission of data form the sensors to their CH is called the intra-cluster communication while forwarding the data form all the CHs to the BS is called the inter-cluster communication. Fig.2[8] illustrates the concept of intra-cluster communication and inter-cluster communication. There are two paradigms of inter-cluster communication between the CHs and the BS; single-hop communication and multi-hop communication. In single hop communication model, the CHs should send the collected directly to the BS. In multi-hop communication model, the CH should discover a route to the BS on which the aggregated data will be sent.

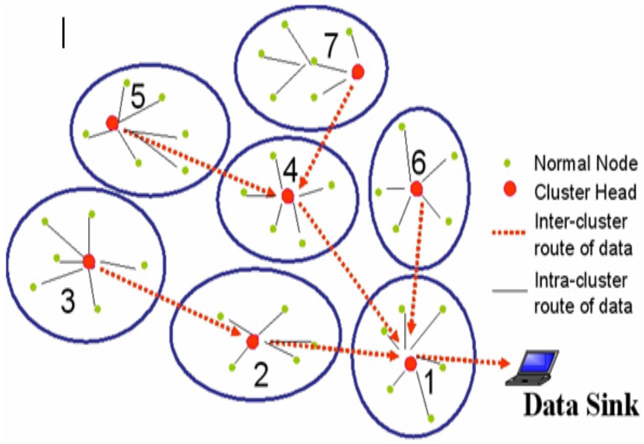

Fig.2. Intra-cluster and inter-cluster communication in WSN

The clustering has various advantages in addition to achieving network scalability. For example, it can reduce the routing tables maintained in each node by localizing the path setup within the cluster. Also by limiting the scope of inter-cluster communication to cluster heads, it can increase the available bandwidth for communication. Moreover, the data collected by sensor nodes can be aggregated by their CHs and thus decreasing the number of packets forwarded to the sink which will result in decreasing the consumed energy and increasing the network lifetime. Another advantage for clustering is that a CH can make schedule activities in the cluster such that the members in that cluster can switch to sleep mode most of the time which will decrease the energy consumption [2].

2.2 Clustering techniques properties

The clustering techniques in WSNs could be classified according to a set of common attributes, properties and design goals [11]. Depending on the network model the clustering algorithm can take in their consideration whether the sensor nodes are stationary or mobile. Mobility of nodes or even the BS will make the clustering is very complicated task since the clusters have to change over time due to that the nodes change their membership dynamically. Also the monitored event by the network could be continual or non-continual. For example, in object tracking application, the monitored event is continual while it is intermittent in early fire detection application. The clustering algorithms in application that have intermittent events tend to be adaptive while they tend to be proactive in the applications that have continual events [2]. Energy Saving Methods in Clustering Algorithms

The clustering algorithms in WSNs provide efficient methods for controlling the nodes in order to reduce the energy consumption and prolong the network life time as follows:

Cluster Head Formation

One of the early techniques to control cluster formation in WSNs is Random Competition based Clustering (RCC) [29]. Node identification and random number are used by RCC for cluster formation depending on First Declaration Wins Rule. This rule assigns governorship position for the sensor node that declares itself first as a CH to other nodes in its range. Another cluster formation method is broadcasting that can be divided into direct broadcasting and multi-hop broadcasting. The cluster advertisement message in the direct broadcasting is sent form the CH to all other sensors in the selected area. When receiving the advertisement message, the receiving node replies to the CH in addition to refrain itself from receiving any other advertisement messages. In multi-hop broadcasting the CH uses a specific transmission range to send the advertisement message to all other sensors. The receiving node has the ability to decide whether it should re-transmit the received advertisement message to other sensors in its transmission range or not. The multi-hop broadcasting reduces the energy consumption since there is a transmission limit. The sensor nodes which are not close to each other do not need to exchange messages directly. However, the multi-hop broadcasting has a disadvantage of having more delay when compared to the direct broadcasting. The incurred delay is due to that the data, in multi-hop broadcasting, are required to be processed be every node along the multi-hop path which will result in delay in cluster construction.

Cluster Head Election and Rotation

After cluster formation phase, each cluster has to elect its own CH which acts as a leader. Cluster head usually has two jobs; it is responsible for data aggregation or fusing and it is responsible for forwarding data of its cluster members to the sink node. As the reader could expect, the clusters that have many member nodes consume more energy a than fewer-sensor clusters. The CHs in clusters, that have more members have to receive, aggregate and transmit more data. To preserve energy resource, it is prefer to elect nodes with high residual energy as cluster heads during cluster head election due to that the CHs are known to have more responsibilities that make them consume more power than other member nodes. Therefore, the role of CH has to be rotated to balance the burden and as consequently improving network life time. Another approach for CHs election is to elect them and rotate the role of the CH them randomly based on some probabilities. The random election will reduce the overhead associated with the election process but it will often results in poor cluster election. Another approach for CH selection is based on minimizing the distance to cluster nodes as this offers reduction in energy usage during forwarding the data to the sink node. In both approaches, the role of the CH has to be rotated in order to distribute the power consumption through the whole network. Other approaches for energy saving in clustering are available such as cluster optimization by using K-hops which is not under scope of this study.

3 Methodology and Proposed Technique

In this section, we present a detailed description of the proposed scheme and the system model in addition to illustrating the modifications on routing protocols that were used as inter-cluster routing protocols over HEED and RHEED. First, we introduce the system model which consists of network model and radio model. After that, we discuss the modifications on routing protocols that were used as inter-cluster routing protocols to be suitable for WSN. Finally, we discuss in detail the proposed clustering scheme that is named Rotated-HEED (RHEED) clustering protocol.

3.1 Systemand Network Model

In this study, we consider a WSN that consists of N sensor nodes which are deployed randomly over a target area to periodically observe the environmental conditions in that area with a BS located far away from the monitored area. All the collected data should be forwarded in some way to the BS. The following assumptions about the network should hold:

- The sensors are deployed uniformly in the sensing area and there is a BS, which have unlimited resources, located far away from the monitored area.
- All sensor nodes are stationary, not mobile, and they are location un-aware.
- All Sensor nodes have similar capabilities in term of communication, storage energy and processing resources.
- The sensors can operate in sleep, active or idle mode.
- The sensor nodes can vary the transmission power amount in order to reach the desired destination.
- Symmetric links are assumed, i.e., two sensors A and B can communicate using the same energy level of transmission
- Radio Model

The radio module is responsible for the wireless communication between sensor nodes. In Fig. 3[9], we show the first order radio module used in sensor nodes devices. The *Transmit Electronics* is electronics circuit which performs signal modulation. *Tx Amplifier* (transmit amplifier) is used to amplify the modulated signal and output it to the antenna. The *Receive Electronics* is electronics circuit which decodes the modulated signal. E_{elec} is the circuit energy needed by *Transmit Electronics* or *Receive Electronics* for modulating or demodulating a bit of data. E_{amp} is the energy needed by the amplifier circuit to transmit a bit of data to an area of radius d = 1 meter. In a real sensor, the transmit module (*Transmit Electronics* and *Tx Amplifier*) usually stays in low-power sleep mode. It only wakes up when there is any bit that is required to be sent. On the other hand, the receiver module (*Receive Electronics*) wakes up only when waiting to receive messages.

According to first order model, the energy dissipated to transmit *l*-bit message for a distance *d* is calculated as in the (2):

$$E_{Tx}(l, d) = E_{elec} * l + E_{amp} * l * d^n \quad (2)$$

As mentioned before, $E_{amp}$is the energy needed by the amplifier circuit to transmit one bit of data to an area of radius d = 1 meter. $E_{amp}$and n varies according to the distance between the source and the destination; $E_{amp} = \epsilon_{fs}$ and n =2 assuming when the $d < d_0$, the free space radio energy dissipation model is used, while $E_{amp} = \epsilon_{mp}$and n = 4using the multipath radio energy dissipation model when $d > d_0$, where d_0 is a threshold distance that depends on environment conditions.

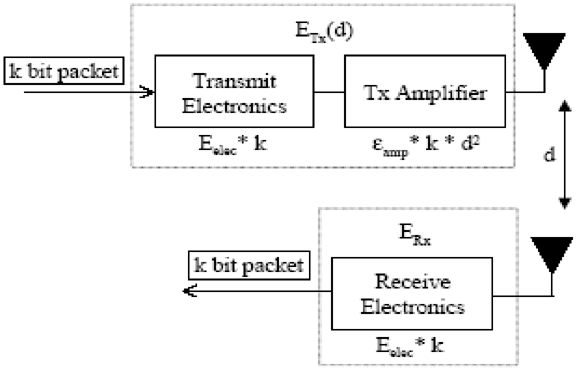

Fig.3.Radio Model of a Wireless Device. (Adapted [9])

The energy needed to receive or demodulate a k-bit message is calculated as in (3):

$$E_{Rx}(k) = E_{elec} * k \quad (3)$$

3.2 DCR, DSR and PEGASIS MODIFICATIONS

After CH election, each cluster head should construct a multi-hop path in order to deliver the gathered data to the sink. In our implementation of these protocols, we have made many modifications on the original versions of these protocols in order to make them suitable for our scenario. The following subsections demonstrate these modifications in details

3.2.1 DSR Modifications

For DSR, after CHs election has been done, the BS will discover the closest CH to it by sending many discovering messages with increasing range until at least one CH replies. Upon determining the closest CH, the BS sends a MULTI-HOP-PATH constructing message to the closest CH. This constructing message will have an empty record (list) listing the address of nodes through which the constructing message have been forwarded. Thus, initially the BS will add its address to this list. When the closest CH receives this message, it will copy the accumulated path to its cache to be used as its multi-hop path in the current round of communication. After that, the closest CH will add its own address to the path list and then forwards the MULTI-HOP-PATH constructing message to its neighbours of CHs. each receiving CH, who has not received this MULTI-HOP-PATH constructing message before, will also copy the accumulated path to its cache to be used as its multi-hop path and then forward the message to its neighbours after adding its own address to the path list, the process will be terminated when all CHs have received the MULTI-HOP-PATH constructing message.

3.2.2 PEGASIS

For PEGASIS, at the beginning of a round, all the CHs should send a message to the BS using the highest available power level in order to measure their distances to the BS which in turn will send a reply message to the farthest CH from it telling this CH to begin constructing the chain. Then the CHs will use the nearest neighbour algorithm for chain constructing with the last node in the chain is elected to be the leader in the current round of communication.

3.2.3 DCR

For DCR, we omitted the clustering part and used the routing part only. Each CH will firstly measure the distance to the BS using signal strength and then all the CHs will broadcast this information to their neighbours within inter-cluster communication range. After the information exchange has been done, each CH will choose the closest neighbour to the BS as its next-hop. Each CH need to measure its distance to the BS only once thought the network life-time.

3.3 Rotated HEED Clustering protocol

The proposed scheme builds on the success of HEED protocol. We have modified its clustering phase to be more energy-efficient. We called the modified version the Rotated HEED. In the Rotated HEED, the clustering operation is divided into rounds and each round has two phases; the setup phase in which the sensors are organized into clusters after receiving a clear request from the BS to construct the clusters and the steady-state phase in which the collected data are forwarded indirectly to the BS via the cluster heads as in HEED. The set-up phase in turn is divided into three phases, the initialization phase, the main processing phase and the finalization phase. The following steps describe the proposed protocols which are depicted in Fig. 4.

1- At the setup phase in the first round all sensors constructs the cluster heads according to the steps stated in HEED protocol.

2- After constructing the clusters in the first round and before entering the steady-state phase, every CH will construct a turn schedule for its members telling every member when its turn to be a CH. So, in the setup phase in the next round there is no need to re-elect the CH as in HEED. Nodes in the cluster will take turns to be cluster heads.

3- The nodes within the same cluster in the next rounds will continue rotating the CH role between them until the current CH's residual energy goes under a specific threshold.

4- When the current CH's residual energy goes under a specific threshold, it will send a re-clustering message to the BS via multi-hop route.

5- When the BS has received the re-clustering message from at least on CH, it re-broadcasts the re-clustering message to all nodes in the network.

6- After having all nodes received the re-clustering message they will goes to step 1 and re-cluster the network.

As in the previous steps the clustering process will be conducted on-demand after the residual energy of at least one CH has fall below a specific threshold. The threshold (*Thes*) is computed using formula (4):

$$\mathrm{Thes} = \mathrm{C} * \mathrm{CHRE} \quad (4)$$

Here, C is a constant between 0 and 1which is chosen experimentally, and $CHRE$ is the residual energy of the CH at the beginning of the last round in which the re-clustering has been occurred.

4 Performance Evaluation

Simulation is a flexible approach for performance evaluation of clustering and routing protocols under different conditions. In section 3, we proposed a clustering protocol that improves the network life-time. We also explain the routing protocols we plane to evaluate as inter-cluster routing protocols with our proposed scheme. In this section, we compare the performance of RHEED protocol with the HEED clustering protocol in terms of residual energy and network life-time.

4.1 Energy Consumption

As we explained in the previous sections, the units that consume the energy of the sensor node are the radio unit, the sensor unit and the controller unit. For the radio unit we have used the model described in section 3.1.2. In addition to the energy consumed by the radio unit for transmitting and receiving data, we also consider the energy consumed by the sensor unit and the controller unit in order to conduct a realistic performance evaluation of our protocols. The controller unit board and the sensor board work in two modes; the sleep mode and the full operation mode. According to [18]the energy consumed by the sensor board in the sleep mode is almost zero. The energy consumed by the sensor board in the full operation mode is shown in Table 1([18]) in which mA means milli-ampere and µA means micro-ampere. From the table, we deduce that the current of the sensor unit board in the full operation mode is around 2/3 of the radio board current in the receiving mode while the current of the controller unit board, in the full operation mode, is equals to that of the radio in receiving mode.

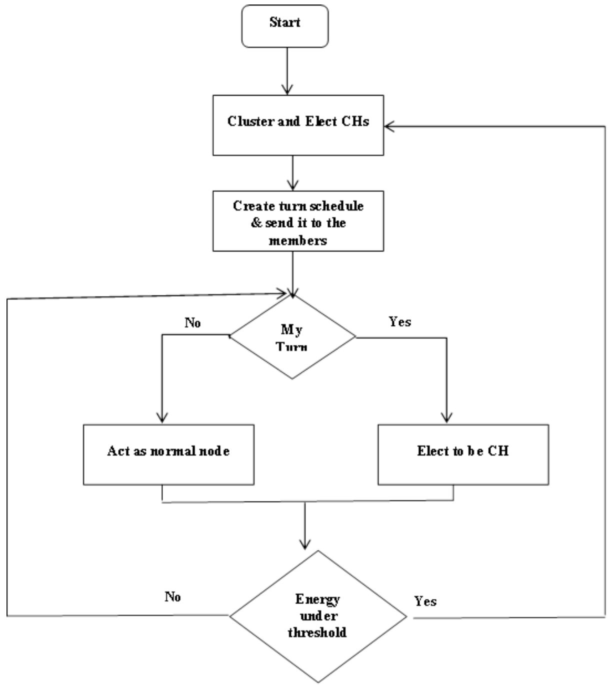

Fig.4. The steps of RHEED algorithm

4.2 Simulation Settings

Unless otherwise is specified, we have assumed that we uniformly deployed a network contains 200 nodes in a field with dimensions of 100m x 100m. The BS was located far away from the monitored field at location (50,200). The minimum probability (*Pmin*) for becoming a CH was set to be 0.0005 which is the same that of [30].

Table 1. Currents of boards in sensor node MICA2DOT

Currents	Example Duty
Processor	
Current (full operation)	1
Current (sleep)	99
Radio	
Current in receive	0.75
Current transmit	0.25
Current sleep 2µA	99
Sensor Board	
Current (full operation)	1
Current (Sleep)	99

The laws of wireless transmission direct that power attenuation of the sender is proportional to the distance square between the destination and the source. The power attenuation can be assumed to be linear with the transmission radius if the distances are small. In practical, there are other factors that could affect the received power, such as physical obstacles or noise. In our experiments, we ignore these factors and, thus, we use the distance between sensors to compute power consumption. This method for computation the power consumption was used in [30]. Table 2 lists the simulation parameters which indicate that most of them are similar to those in [30]. In addition to parameters stated in Table 4-2 the assumptions stated in section 3.1should hold.

Table 2. List of simulation parameters used

The Parameter	The Value
Deployment Field	100 x 100 m
Data Packet Size	200 bytes
Control Packet	25 bytes
Number of nodes	200
Cluster Radius	30 meters
Sink Position	200
Initial Energy	2 J
E_{elec}	50nJ/bit
efs	10nJ/bit/m^2
E_{fus}	5nJ/bit/signal
eamp	0.0013nJ/bit/m^4
Threshold Distance *d0*	87 meters
Deployment Method	Uniform, Random
Round	20 seconds = 5 frames
Pmin	10^{-4}
Constant C	0 – 1

4.3 Performance Metrics

The evaluation metrics used to evaluate the performance of the compared protocols are residual energy and network life-time. Some WSN applications require that each sensor should work to ensure that the network have a good coverage. Thus, the network life-time in these applications should be measured by the life-time of the shortest-living node. Some other applications require that only a specific per cent of the nodes should stay alive to achieve network objectives. Hence, in our simulation, the network life-time is measured by three different metrics; last node dies, half node die, and first node dies.

- Residual Energy (RE): we defined the residual energy metric as the average energy remaining in all nodes at specific round.
- First Node Dies (FND): it is the time elapsed in rounds until at least one of the nodes has consumed its whole energy.
- Half Nodes Die (HND): it is the time elapsed in rounds until half of the nodes have depleted their whole energy.
- Last Node Dies (LND): it is the time elapsed in rounds until all the nodes have exhausted their whole energy.

Here the round term refers to the time in seconds elapsed until a re-clustering for the network may occur. There is no difference between round concept in HEED and RHEED in term of time. The round time in HEED and RHEED could be in range of seconds, minutes or even hours. In our simulation, we specified the round time to be 20 seconds. The difference between HEED round and RHEED round is relating to type of actions performed at the beginning of each round. Generally, the round is divided in our simulation into two parts; the clustering time *Tc* and the operation time *To* as depicted in Fig. 5(a). In HEED at the clustering part (*Tc*), the HEED clustering mechanism (*Hc*) will be used at the beginning of each round as depicted in Fig. 5(b). In RHEED at the clustering part, the proposed clustering mechanism (Scheduling mechanism *Sc*) and also HEED clustering mechanism both could be used depending on rules mentioned in previous sections. This case is depicted in Fig. 5(c).

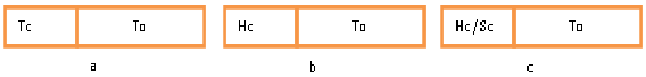

Fig.5. Round concept in HEED and RHEED

4.4 Results and Discussion

The results of our simulation are presented and discussed in this section. Every result presented is the mean of 5 experiments. First, we show the comparisons between single-hop RHEED and single-hop HEED. Then, we compare between multi-hop RHEED and multi-hop HEED using the previously discussed inter-cluster routing protocols.

4.4.1 Single-hop RHEED vs. Single-hop HEED

In this set of experiments the nodes were deployed uniformly. Fig. 5shows the number of live sensors in the network verses number of rounds. The constant C, which is used by RHEED to control the re-clustering process, was chosen to be 0.6 in this scenario. The results from Fig. 5 show that the proposed scheme RHEED performs better than

HEED.

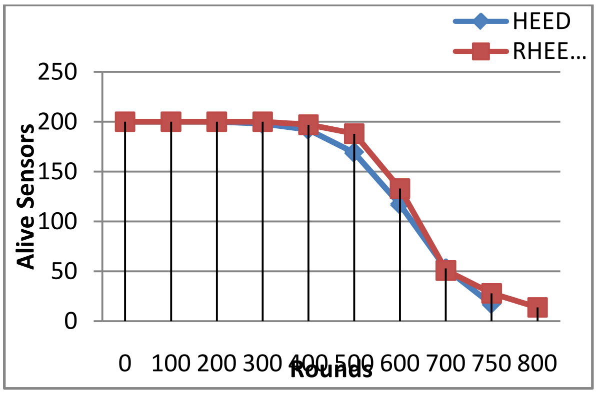

Fig.6.The comparison of the number of alive sensors in HEED and RHEED with a constant value of 0.6.

Fig. 6 depicts the results for both schemes in terms of number of alive nodes over time but with different choosing for the constant *C* to be 0.97. As you can notice, the proposed scheme outperforms the HEED protocol. The proposed protocol increased the network life-time for the LND metric by more than 100 rounds when the value of the constant C is 0.97. This improvement is due to the operation of rotating the CH within the same cluster which decrease the energy consumption and increase the network life-span. Rotation of the CH role within the same cluster instead of conducting a new clustering process as in the original HEED allows the energy consumed during the clustering phase to be saved and as consequently improving the network life-time.

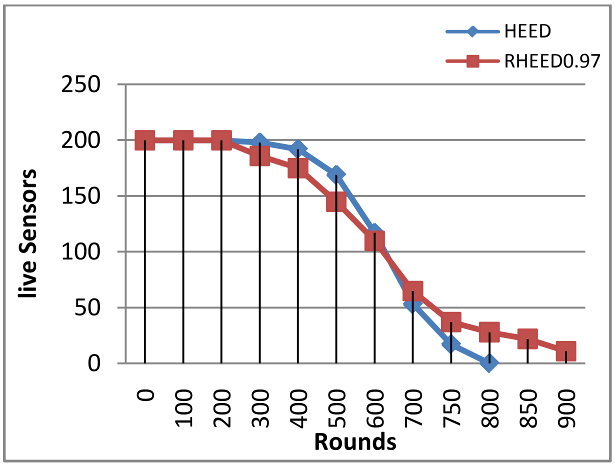

Fig.7. The comparison of the number of Alive sensors in HEED and RHEED with a constant value of 0.97.

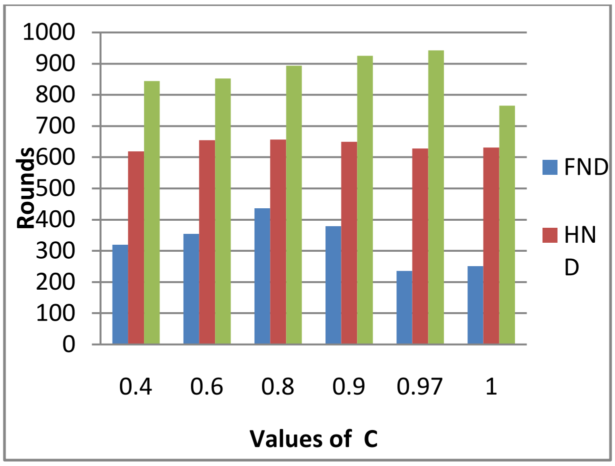

Fig.8.Fig.4.3: RHEED with Different Values of C.

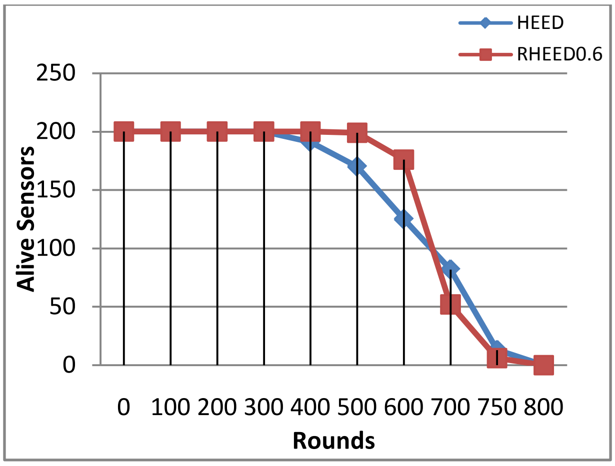

Fig.9. The comparison of HEED and RHEED with random distribution

In Fig. 7we demonstrate how RHEED behave in term of the First Node Dies (FND), Half Nodes Die (HND) and the Last Node Dies (LND) with different values of the constant *C*. the constant value of 1 means that the clustering process will be conducted at every round as it exactly in HEED. The fig. shows that for the first node dies metric, the best choice for *C* is the value 0.8 while the best choice for the constant *C* when the LND metric used is the value 0.97. For the HND metric the best choice also occurs when the constant *C* equals 0.8.

We also compare between both schemas using the same parameters stated in table except that we have deployed the nodes randomly to see the effect of the random distribution on the results. In this scenario, we have put the constant c equal to 0.6. We show the results of this comparison in Fig. 8the results show also that our proposed scheme performs better than HEED especially in the earlier rounds of simulation.

4.4.2 Multi-hop RHEED vs. Multi-hop HEED

In this subsection we compare multi-hop HEED clustering protocol with multi-hop RHEED. Multi-hop in this context means that the cluster heads do not communicate directly with the base station. They instead find their multi-hop path to the BS using a specific routing protocol (for example: DSR) and then use this path to send their aggregated data on to the BS. Before that, we should fig. out which is the most suitable routing protocol; DSR, DCR or PEGASIS, to be used for inter-cluster routing in HEED or RHEED. Fig.10presents a comparison between HDSR, HDCR and HPEGASIS while Fig.11presents a comparison between RDSR, RDCR and RPEGASIS. The first letter in the names of the protocols refers to the name of the clustering scheme used; H for HEED and R for RHEED, while the remaining letters refer to the name of the routing protocol that have been used for inter-cluster routing. The number on the right side of protocol name refers to the value of the constant C. For example, RDSR0.5, this means that the clustering scheme is RHEED, the multi-hop routing protocol used is DSR and the value of the constant C is 0.5.

Form both figs. we could observe that DSR and DCR show close behavior while they perform better than PEGASIS when they are used for inter-cluster routing. This is due to that PEGASIS construct one long chain for all CHs within the WSN. This long chain results in a multi-hop path which contains more hops than supposed, for some CHs, which in turn consume more energy and as a results shorten the network life-time. Another reason for the poor performance of PEGASIS protocol that it needs to know the farthest CH from the BS which require that every CH should communicate with the BS to determine the farthest CH at the beginning of each round. In fact, this communications among the sink and CHs will consume an extra energy which also will shorten the network life-time.

In Fig.12we present the results of the comparison between the multi-hop HEED and our proposed multi-hop scheme RHEED in term of sensor alive over time. We used the DSR routing protocol as inter-cluster routing protocol for both scheme in this comparison. We have varied the values of the constant C in our scheme between 0.5, 0.8 and 0.97. Form the fig., it can be noticed that different choosing for the constant C value affect the network life-time in a different way. When the constant value of C is 0.97 the proposed scheme outperforms than HEED in the later rounds of simulation while it defeats HEED in most rounds of simulation when the constant value is equal to 0.5 or 0.8 especially in the earlier rounds. This fact also holds even if we used another protocol for the inter-cluster communication, PEGASIS, as depicted Fig. 13 consequently

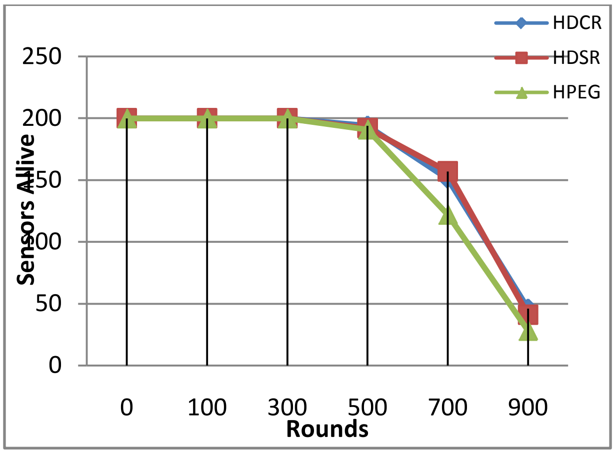

Fig.10.Number of alive sensors vs. number of rounds for HDCR, HDSR and HPEG.

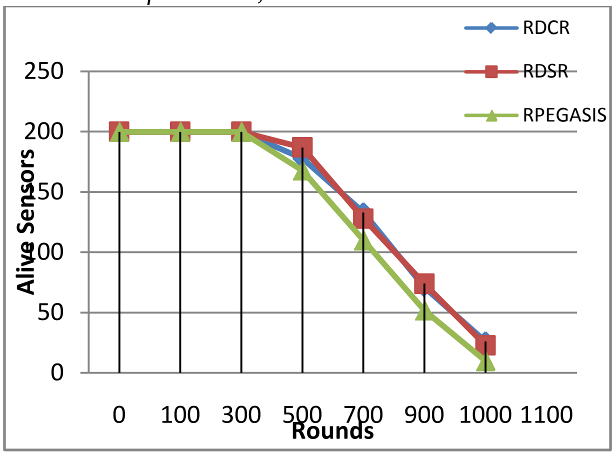

Fig.11. Number of live sensors vs. number of rounds for RDCR, RDSR and RPEGASIS

Thus, for the application that requires that each sensor should work, we should choose C value to be suitable enough for improving the network life-time until the first node dies. If the requirement of the application is to increase the life-time of the network until the last node dies, then the values of the constant C between 0.9 and 1 will be preferable because they improve the time until last node dies significantly.

We also evaluate how increasing number of the nodes could effect on both schemes; multi-hop HEED and multi-hop RHEED. The inter-cluster routing protocol used in these experiments is DSR. Fig.14 compares the life-time of the network with HEED to RHEED, where the network life-time is the time until the first node die and when the number of nodes is varied between 150, 200, 250, 300 and 350 nodes. Similar comparisons are conducted for the number of rounds until half nodes die and for the number of rounds until the last node dies as depicted in Fig.15 and Fig.16 consequently. Both protocols improve the network life-time when the number of nodes increases. The figs. show that, in almost all cases, multi-hop RHEED performs better than multi-hop HEED. This improvement is also due to the operation of rotating the cluster head within the same group (cluster). This leads to minimizing the energy consumption and increasing the network life-span.

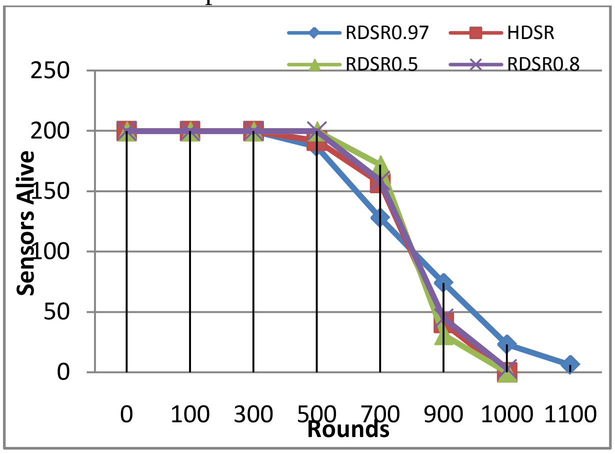

Fig.12.Alive sensors vs. number of rounds for multi-hop HEED and multi-hop RHEED using DSR.

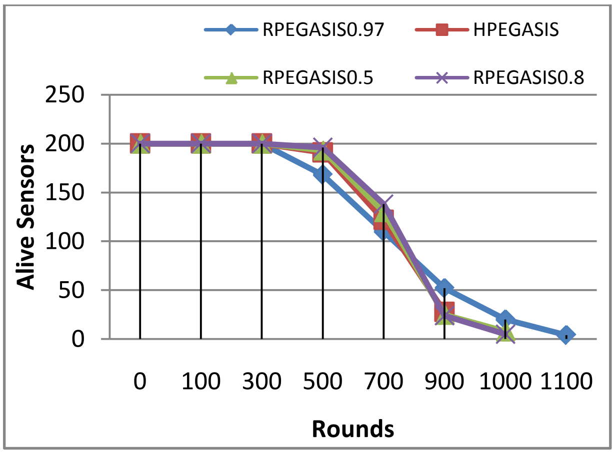

Fig.13.Live sensors vs. number of rounds for multi-hop HEED and multi-hop RHEED using PEGASIS.

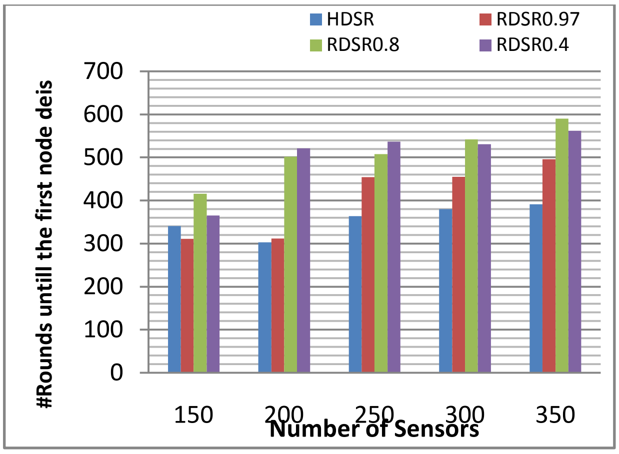

Fig.14. Comparing HEED and RHEED using different number of nodes for FND metric

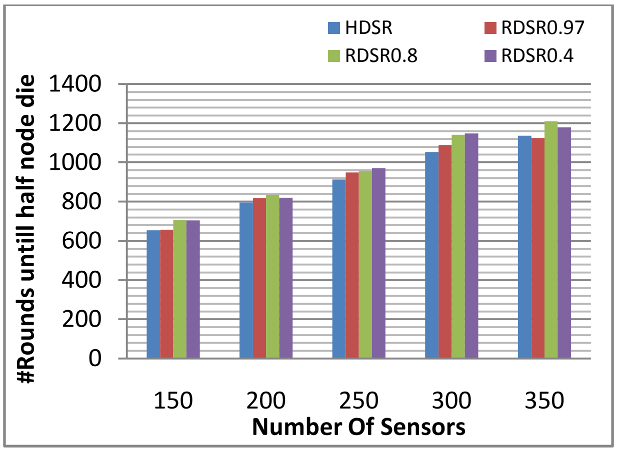

Fig.15.Comparing HEED and RHEED using different number of nodes for HND metric.

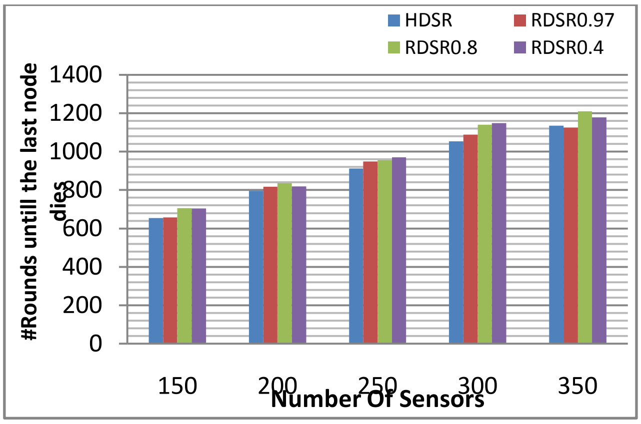

Fig.16.Comparing HEED and RHEED using different number of nodes for LND metric.

It can be easily observed form the figs. also that when the number of the nodes increases the percentage of improvement increase too. This could be justified as, when increasing number of the nodes, the amount of energy consumed during the clustering phase increases. Thus, the energy saved as a result of our powerful clustering scheme will be maximized which in turn will lead to improving the network life-time.

5 Conclusionsand Future Work

In this paper, we proposed a clustering scheme for wireless sensor networks that appeared to be more energy-efficient than HEED in most cases. The protocol main contribution is to rotate the role of the CH between nodes in the same group until the residual energy of at least one cluster head fall below a specific threshold. We compared and evaluate the proposed protocol performance with the well-known clustering protocol (HEED) in terms of network lifetime, and energy consumption.

Simulation results show that the proposed algorithm performs better than HEED. The percentage of improvement depends on the best choice of the constant C, the evaluation metric used and the characteristic of wireless sensor network. This improvement is due to that the proposed algorithm does not perform clustering at each round, it only perform it occasionally when the residual energy of at least one CH goes under a specific threshold. In addition to the proposed scheme, we also conduct a performance evaluation of using three different routing protocols for inter-cluster routing in our proposed schema and HEED. The three routing protocol compared here are DSR, DCR and PEGASIS. The simulation experiments show that using DSR or DCR for inter-cluster routing has the same impact on the energy consumption. The experiments also show that using PEGASIS for inter-cluster routing is poor choice because it consumes more energy than DCR and DSR and consequently shorten the network life-span. The poor performance of PEGASIS is due to that it constructs one long chain for CHs nodes in the network. This long chain results in a multi-hop path which contains more hops than supposed which in turn consume more energy and as a results shorten the network life-time. Another reason for the poor performance of PEGASIS protocol is the extra communications between the CHs and the BS required to determine the farthest CH from the BS.

During the time we have been working on this study, some ideas and questions regarding the subject arose to us. Here we outlined and presented some of these ideas to be pursued in order to improve our work.

The rotating of the cluster heads in our scheme was completely random. We think that using more controlled approach that takes in its consideration different parameters and conditions such as residual energy, received signal strength and the locations of the nodes is a good idea to be investigated.

The data aggregation of our proposed schema, like in HEED, is developed under the assumption that the close nodes sense similar data and as consequently there is a high data-correlation. For scenarios where there is not a correlation between the gathered data, aggregating the data into a single packet at the cluster head is not suitable. Thus, studying suitability of our proposed scheme under these scenarios is another good idea for future work.

In our implementation for PEGASIS as inter-cluster routing protocol, we have adopted a chain leader selection strategy in which the last node added to the chain was selected as a chain leader. Studying the effect of using other strategies for selection the chain leader is another good research area.

Finally, the performance metrics used in evaluation of the protocols were limited to the energy consumption. We propose for future work to evaluate

the performance of our proposed scheme with other metrics such as packet delivery ratio and end-to-end delay.

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