**An Analysis of routing Protocols to Maximize the Lifetime of WSN for underwater Applications**

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**Abstract**

Wireless Sensor Network (WSN) consists of Sensor Nodes (SN) which are battery-powered and deployed over an area in an harsh environment. Applications of WSN includes military, agriculture, monitoring or surveillance etc. Due to limited battery, lifetime of sensor nodes can be increased by efficient routing protocols. The use of a perticular energy path repeatedly may lead to dead battery of SNs in that area and that will create energy holes and which in turn will deactivate that part of network. So, the protocol must be chosen to prolong the network lifetime by involving all the SNs to participate in data transmission. Clustering proves is an efficient approach for increasing the network lifetime. In clustering, the strategy to involve all the SNs will provide efficient and balanced consumption of battery and increase the reliability as well. Various clustering techniques have been proposed over the years but still, there are chances of improvement. Clustering is an efficient approach for under sea life because it will provide lots of information about marine life. Heterogeneous protocols are more reliable and energy-efficient than homogeneous protocols. In this work, a Heterogeneous Energy Efficient and Reliable Routing (HEERR), which is an advanced version of DEEC protocol is proposed and compared with other hierarchical routing techniques. Results revealed that HEERR not only enhanced the network lifetime but also increases the throughput.

**Keywords:** DEEC, TEEN, SEP, LEACH-C, energy efficient, hierarchical routing

**1. INTRODUCTION**

In present, WSN has emerged as a technology in which thousands of nodes are connected to form a large-scale network. WSN consists of devices knows as Sensor Node (SN) that are small, sensing capability, battery-powered, inexpensive, and low-computation capability [1]. These SNs are used for monitoring conditions such as humidity, moisture, temperature, motion, abnormal activities, etc. SNs can be deployed either on the ground or in water to perform applications such as surveillance, intelligence, medical, environmental, and underwater monitoring [2-6]. SN consist of devices such as a microcontroller, sensor, battery and, radio transceiver [3-10]. SNs are distributed, self-organized, work on dynamic topology [11-16]. The common features of SNs includes dynamic topology[17], self-organizing capabilities[18], node mobility[19-22], multi-hop routing[23], broadcasting[24], short-range communication etc. These SNs are connected to form an architecture known as WSN as shown in figure 1.

INTERNET

REMOTE CONTROLLER

 SINK

Sensing field

Sensor nodes

Figure 1: WSN Architecture

The key challenge is to balance the consumption of batteries and increase reliability [21-30]. But there are other challenges as well that needs to be taken care of. SNs are deployed randomly in an area without any infrastructure and prior knowledge about the topology [27-30]. In these cases, SNs have to self-identify the connectivity and distribution. For example, for surveillance purposes on a battlefield, SNs would be dropped in an area by plane. WSN protocols should be fault-tolerant to accommodate the failure of SN [31-39]. WSN protocols should be dynamic so that they can respond and operate in any number of SNs [17,36-39]. Protocols must work in such a way that they transmit the data to BS at a specific time to achieve Quality-of-Service (QoS). In this work, we have focused on the application of WSN in under water. In under water applications, various data are required periodically as well as critically to monitor the aquatic life, river and sea pollution discovery, oceanographic data compilation, monitoring etc. Clustering is a good approach to deliver the data from SN to sink in under water application. In next section, we have discussed various routing approaches that are using homogeneous i.e. in which initial energy of all the SNs are equal as they are having the same equipment and heterogeneous i.e. in which initial energy of all the SNs are not equal as they are having the different equipment.

**2. CLUSTERED ROUTING STRATEGIES IN WSN**

To keep these challenges in mind, researchers worked on various protocols to enhance the network lifetime [1-30]. In clustering, the strategy to involve all the SNs will provide efficient and balanced consumption of battery and increase the reliability as well. The clustering strategy plays an important role to collect the data from SN and then transmit it to BS[25-37]. A few of the routing protocols that are popular in this category are following:

**2.1 LEACH Protocol**

Low Energy Adaptive Cluster Hierarchy (LEACH),[7] , a hierarchical cluster-based protocol that optimizes the energy consumption through clustering approach. In LEACH, the network is divided into independent clusters and each cluster has a Cluster Leader (CL). CL will collect that data from neighboring nodes, after collecting and aggregating, CL will send the aggregated data to the BS. A random selection procedure is used for the election of CL [7]. LEACH algorithm contains a periodic process in which each round has two phases-

*2.1.1 Setup phase:* ***-***a) Advertisement Phase: In this phase, the CLs send advertisement packets to their neighborhood. By this packet, nodes get to know to which CL they are belonging. Every node n in the network chooses a random number k between 0 and 1. If k <T (n) for node n, the node becomes a cluster-head. The selection of CLs will be done by the following equation 1:

 (1)

b) Cluster Set-up Phase: CL received information about its member nodes.

c) Schedule Creation: CLs provide a time schedule for each node in which they can send their data to respective CL.

*2.1.2 Steady-State phase: -* Data Transmission: In the first transmission, all nodes transmit their data to respective CL. In the second transmission once CL received all data from its members it minimizes the data without losing the meaning of data so that it can save energy instead of sending the complete data. And then send minimized data to a destination node (sink).

Nevertheless, the CLs are randomly selected, so the network cannot remain with uniform energy dissipation. For this purpose LEACH-C [15] was introduced.

**2.2 LEACH-C protocol**

LEACH-C protocol [15] uses a centralized sink for CLs selection as shown in Figure 2. This concept enables low-energy networking in WSN. The only difference between LEACH protocol and LEACH-C protocol is in their Setup phase however the steady-state phase remains ideal in both of them. In LEACH-C cluster formation is performed by the base station (sink), unlike LEACH where nodes self-select themselves as CL. Initially in the LEACH-C, all nodes of the network send their information like location, energy level to the Base Station (BS) [16]. After this BS calculates the optimal number for SNs that can be CL. Only those SNs can be CL that has sufficient energy. Advantages of this protocol over LEACH are number of CLs in LEACH are not fixed it changes according to round but in LEACH-C BS calculates the number of CLs for every round.

The drawback of LEACH-C is sink requires global knowledge of the network for cluster formation.

Sensor node

Cluster head

Static Sink

**Figure 2: LEACH-C Protocol using Static Sink.**

**2.3 TEEN Protocol**

Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [17] is also a cluster-based hierarchical routing protocol like LEACH i.e. the nodes form clusters and selection of CL for transmission of data to BS. It uses both hierarchical techniques and a data-centric approach. Transmission of data is done less frequently so it saves energy efficiently. It is a reactive protocol in which nodes are sensitive to certain activities like temperature weather etc. so reactive protocols are best suited for time-critical activities. While inside LEACH, absolutely no certain actions are generally driven therefore it is a proactive protocol [18,19]. The sensor nodes behave instantly for immediate and also for extreme changes in the value of a sensed attribute. A pair of Thresholds is employed to check sensing changes:

*2.3.1 Hard threshold*: -This threshold value is assigned by the CL to the sensed attribute. When SNs sensed value is larger than the hard threshold value then this is the sign for nodes to switching on their transmitter and inform to its CL.

*2.3.2 Soft threshold*: -This is the value of the sensed attribute if this value has some small change then it implies the node to switch on its transmitter and transmit.

So data transmission happens only in two conditions either the sensed data value is larger than the hard threshold value or changes in the value of the sensed attribute is greater than/ equal to the soft threshold value.

**2.4 SEP Protocol**

In a heterogeneous sensor network, the initial energy of all nodes is not the same. The WSN contain various types of heterogeneous protocol like SEP [20] DEEC [21], using these energy efficiency protocols we can save the energy of the nodes and improve the network lifetime. In heterogeneous protocols the three types of models are used. These models are two levels, three levels, and multilevel heterogeneous model. Two or perhaps more nodes are equipped with different initial energy. A network that consists number of nodes with the same level of energy means all sensor nodes are equipped with a significantly equal amount of energy then such networks are known as a Homogeneous sensor network. Discussed routing schemes LEACH, LEACH C, TEEN are advisable only for homogenous sensor networks. So for heterogeneous purposes in terms of energy, Stable election protocol (SEP) [20] was proposed which carried two-level heterogeneity for sensor network. Here two-level heterogeneous sensor network means out of the total population of sensor nodes, some nodes are having significantly more battery power (energy) than the remaining nodes in the sensor network.

 Nodes which are having more energy power are known as advanced SNs. Suppose a sensor network composed of a total X number of SNs and each node is equipped with Einitial energy. For heterogeneity, let Y×X be the number of advanced SNs where Y is a fraction of the total number of SNs. Let advanced SNs have Z times more energy than the rest of the SNs. So initial energy of each advanced SN in the network is Einitial ×(1+Z). Thus total initial energy of two-level heterogeneous networks could be represented by equation (2).

 (2)

For a node to become a CL it should have optimal probability Popt, defined as in equation (3):

 (3)

Here is an optimal number of constructed clusters. When the distance of a population of nodes to the sink is less than do where , then the value of kopt given by the equation (5):

 (5)

When the distance of a population of nodes to the sink is more than *d0* then the value of kopt defined by equation (6):

 (6)

Let the area of network=X×X, D=Average distance from a CL to the sink , N=no of SNs in the network. anddepend on the transmitter amplifier model [20]. For every round, the average number of constructed CL should be N*×Popt* and its fix (constant) to minimize the energy consumption of nodes. SEP protocol assigns a weight to the optimal election probability (Popt) to maintain the fixed number of CL per round. Thus weighted election probabilities for normal and advanced nodes are shown by equations (7) and (8) respectively:

 (7)

 (8)

As election probabilities are changed so the threshold value for normal and advanced nodes can be defined by equation (9) and (10) respectively:

 (9)

 (10)

where, rd is the current round, Z’ is the set of SNs that have not become CLs within the last 1/Pnm rounds, Z" is the set of advanced SNs that have not become CLs within the last 1/*Pav* rounds[20].

Finally, the excellence of SEP protocol is that it does not require any global knowledge of nodes in the network for data routing. But SEP cannot perform well for more than two-level heterogeneity in terms of energy of sensor node.

**2.5 DEEC Protocol**

In Distributed Energy Efficient Clustering (DEEC) [21], the selection of CHs is not only based on the election probability. In addition, DEEC protocol merges a ratio of the remaining energy of each SN and the average energy to the election probability. Higher is the remaining energy, higher will be the chances to become CL. Let denote the average energy at round rd, which defined as in equation (11):

 (11)

For two levels heterogeneous network by adding residual and average energy concept we get election probability formula as in equation (12)

 (12)

As DEEC consider multilevel heterogeneity in terms of node’s energy then we get election probability for CL selection as in equation (13):

 (13)

Let Eavg(rd) represents the average energy at round rd of the network that is defined in equation in (14):

 (14)

Here R denotes total no round of network which can be calculated in the equation (15):

 (15)

Eround is the total energy dissipated in the network during a round, is equal to the equation (16):

 (16)

where, k: number of clusters,

 B: no of bits in a data packet,

 : Data aggregation cost expended in the CLs,

 : Average distance between the cluster-head and the base station,

 : Average distance between the cluster members and the cluster-head,

 Eelec: Energy dissipated per bit to run the transmitter or the receiver circuit [21,22].

**2.6 EDEEC (Enhanced Distributed Energy Efficient Clustering) Protocol**

EDEEC is a modified version of DEEC [23]. EDEEC works as a three-level network based on SNs which are normal, advance, and supernodes. Rest of the work will remain the same apart from the selection of CL which will be done according to equation (17).

pi= (17)

where, md'= % of advanced SNs

Pd = desired probability of CLs

md'o= % of super nodes

ad= portion of advance SNs

bd= portion of SNs

Ē(rd) = average energy

The threshold for CL selection T(CLj) is given in (18):

T(CLj)= (18)

where *M*' , *M*'' & *M*''' represent group of normal SNs, advanced SNs and super SNs that have not become CLs within the last 1/pj rounds.

The network average energy can be calculated as:

 (19)

R can be calculated as

  (20)

The total energy of the network Etotal is calculated by

 (21)

where, SN= total number of nodes

Eo = initial energy

The probability of CL selection for HEERR is given in (22)

pi= (22)

Where, ET is total energy

Fig. 3 depicts the radio dissipation model, where B is message size and d is the distance.

 (23)

Total energy consumed per round is given as,

 (24)

 (25)

 (26)

Where *k* is the number of clusters.

Figure 3. Radio Dissipation Model

**3. Algorithm for the Simulated Protocols**

In this work, various clustered routing protocols have been implemented and following assumption are to be considered.

* The sink will have an unlimited amount of supply.
* The sink position is fixed at the center.
* The SNs are equipped with power control capabilities to vary their transmitted power.
* After a periodic interval, each SN senses the environment and sends the data to CL or BS.
* All SNs are static.

The algorithm for simulated protocols has been shown in figure 4. And, the criterion for selecting CL has been shown in figure 5.



Figure 4: Framework for simulated protocols

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**Figure 5:** Cluster Leader Formation by Base Station

**4. Implementation and Results**

In this section, simulation and comparison of various protocols LEACH, TEEN, SEP, DEEC and new improved protocols such as E-DEEC and HEERR of the same category have been performed using MATLAB 8.1 based on the parameters like energy efficiency, heterogeneity level, cluster stability, CL selection criteria etc. . For this purpose, randomly distributed WSN consist of 100 SN in a 100m2 field is used and assumed base station is at the center of the sensing region. Here, considered the following scenarios and examine several performance measures. The radio parameters used in this simulation has shown in Table 1.

Table 1: Network Parameters

|  |  |
| --- | --- |
| **PARAMETERS**  | **Values** |
| Simulation Area (in meters) | 100 ×100 |
| Initial Energy Allotted to SN (in Joules) | 0.5 |
| Total no. of SNs | 100 |
|

|  |
| --- |
| ETX  |

 | 50nJ/bit |
| ERX | 50nJ/bit |
| EDA | 5 nJ/b/message |
| CL Probability | 0.05 |
| Data Packet Size( in bits) | 4000 |
| Threshold distance(d0) (in meters) | 87.7 |
| Transmit Amplifier Energy |
| EFS | 0.0013 pJ/b/m4 |
| EMP | 10pJb/m2 |



**Figure 6: Comparison of LEACH C, TEEN, DEEC, SEP and Proposed Protocols in terms of nodes alive.**

Figure 6 has shown a plot between the number of SNs alive and the number of rounds of different protocols named LEACH-C, TEEN, DEEC, SEP, E-DEEC, and HEERR Protocols which conclude that in large network area like the agriculture field where we have to include more number of SNs, E-DEEC and HEERR protocols perform well as more number of SNs are remain alive at almost all rounds. It has been clear from the figure when all the SNs of other simulated protocols are dead only 50% of SNs are dead for E-DEEC and HEERR.



**Figure 7: Comparison of LEACH C, TEEN, DEEC and SEP in terms of nodes dead.**

Refer Figure 7, it can be observed that E-DEEC and HEERR protocols performs better and showed more stability as compared to other protocols while LEACH-C performs worst.



**Figure 8: Comparison of LEACH C, TEEN, DEEC, SEP, E-DEEC and HEERR PROTOCOLS in terms of packets sent to BS**

Figure 8 showed information about how many data packets send to sink over the number of rounds. In this case, the HEERR protocol transfers more data from CL to the sink. So PROPOSED protocols are more reliable as compared to LEACH-C, SEP and TEEN. Hierarchical routing protocols have a certain process to choose CHs and have their unique architecture and many other parameters to perform a routing process. Comparison between these protocols based on various parameters like architecture, hop, heterogeneity level, cluster stability etc. as shown in table 2.

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**Figure 9: Comparison of LEACH C, TEEN, DEEC, SEP, E-DEEC and HEERR PROTOCOLS in terms of Energy Consumption**

Figure 9 depicts the energy consumption per round in protocols such as LEACH-C, TEEN, DEEC, SEP, EDEEC and HEERR. It can be observed from the figure that heterogeneous protocols has more stability and optimize consumption of battery as compared to homogeneous protocols.

**Table 2: Comparison of various routing protocol**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Performance Criteria** | **LEACH** | **LEACH-C** | **TEEN** | **SEP** | **DEEC** | **E-DEEC** | **HEERR** |
| **Architecture** | Distributed | Centralized | Distributed | Distributed | Distributed | Distributed | Distributed |
| **Hop** | Single Hop | Single Hop | Multi Hop | Multi Hop | Multi Hop | Multi Hop | Multi Hop |
| **Heterogeneity level** | Not present | Not present | Not present | Two level | Multilevel | Multilevel | Multilevel |
| **CL Selection** **Criterion** | Elected rotation- wise by probabilistic approach | Selected by BS w.r.t. nodes energy and distance | Randomly | Based on Initial and ResidualEnergy | Based on Initial,Residual and Average Energy of the network | Based on Initial,Residual and Average Energy of the network | Based on Initial,Residual and Average Energy of the network |
| **Cluster Stability** | Lower | Higher than leach | Very High | Moderate | High | High | High |
| **Global knowledge****of network** | Not Required | Required | Not Required | Not Required | Not Required | Not Required | Not Required |
| **Energy Efficiency** | Very low | Low | Moderate | High | High | High | High |

**5. Conclusion**

Cluster-formation-based routing is the best way to archive energy efficiency goal in hierarchical routing protocols for a large area like submarine field. In this work, we have simulated and compared protocols such as LEACH-C, TEEN, DEEC, SEP, E-DEEC and HEERR. The performances of such protocols are judged by the simulation results under the various performance metrics. Results showed that E-DEEC and HEERR protocols are reliable and energy-efficient than other strategies. Also, it has been cleared that the heterogeneous approach is more reliable and energy efficient as compared to homogeneous approach. From the simulation results, we can conclude that HEERR is reliable because it is sending maximum data packets to the sink as compared to other routing protocols.

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