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A Preliminary Investigation of LEACH, TEEN and DEEC Towards Wireless Sensing Application

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***Abstract*— In wireless sensor networks the nodes operating in a distributed environment operate on a limited source of energy and rely on efficient power optimization protocols to operate for the appropriate duration of their wireless data sensing application. In this paper we present a comparative analysis of three prominent hierarchical-based clustering protocols: LEACH, TEEN, and DEEC. These protocols are used for increasing and maintaining the lifespan of Wireless Sensor Networks (WSN). For measuring the performance of the three protocols concerning their application, we utilized the performance metrics such as network lifetime and the amount of data sent to the base station (BS). We have used MATLAB for simulating the application of each protocol in the WSN and based on our observations, we found out that TEEN performed well than the others. The TEEN protocol allowed the WSN to have a more considerable lifespan with reference to its operation. However, DEEC provided promising results in terms of reliability. The findings from our experiments would significantly assist in determining the employment of the specific protocol in a particular industry or research application.**

Keywords—Wireless Sensor Network, Power Optimization, LEACH, TEEN, DEEC, Network Lifetime

I. INTRODUCTION

A wireless sensor network comprises of spatially distributed sensors. These sensors work together to collect data, analyze the gathered data to reduce redundancy and route the captured data to the base station [1-2]. WSN has its application in various significant fields like healthcare, medical, power grids, military and so on. [2-4]. The sensor nodes in WSN are battery operated, i.e., the nodes hold limited power, so their energy consumption must be managed efficiently to maintain the network lifetime for the appropriate operational time [5]. The energy of sensor node is consumed in sensing and transmitting the data, hence routing protocols are required to select an optimal path for transmission and handle the data redundancy aspect to reduce power consumption. There are plethora of protocols available for ad hoc networks but none of them suits the power optimization requirements of sensor networks. The routing protocols for WSN are application specific, architecture dependent and aim towards improving the network lifetime by reducing the energy consumption [5]. Routing protocols in WSN aim to reduce the data redundancy by performing data fusion on the sensed data at cluster head (CH). The routing protocols are flat-based, hierarchical-based or location-based. In the flat-based protocols category, all the nodes share similar roles and responsibility. Each node will forward its sensed data to all the other nodes assuming that every other node is a BS. Some examples of flat based routing protocols are Flooding [6], Rumor Routing [7] and Energy-aware routing [8] and so on. In location-based routing, the sensor nodes exhibit the responsibility of routing the local data to the BS. Some location-based protocols are GAF [9], GEAR [9] and so on. While in hierarchical-based routing protocols the nodes are stratified as level one or level two nodes. The level two nodes are responsible for data processing and forwarding the processed data while level one nodes will only capture the required data and send it to the level two nodes. Common examples of such protocols are PEGASIS [10], HEED [11] and so on. In this research study, we have targeted the performance investigation of three prominent hierarchical-based routing protocols that have shown better performances than the prior mentioned ones in the relevant published studies [9-15]. These protocols use clustering technique that incorporates the data processing and forwarding operations. In this clustering scheme, the whole network is divided into clusters constituting the various wireless sensor nodes and for each cluster a cluster head is elected which will be responsible for data collection and data forwarding functionality. The protocols researched in this study are LEACH [15], TEEN [13] and DEEC [14].

In this paper, section II describes the protocols in detail. Section III provides details on experimental evaluation of the targeted protocols and the final section presents the conclusion of the study along with the prospects of future work.

II. PROTOCOL INFORMATION

A. LEACH

Low Energy Adaptive Clustering Hierarchy protocol is a TDMA (time division multiple access) based MAC (medium access control) protocol, which is used to improve the lifetime of WSN. It operates in two phases:

1) Setup Phase: In this phase, cluster formation and election of cluster head occur. It further involves three fundamental steps:

a) CH Advertisements: In this phase, during the initial rounds each node calculates its threshold value based on probability 'P' and the node having a value less than the randomly defined threshold value is selected as a cluster head. All the nodes have an equal probability of becoming cluster head and each node gets the responsibility of being a cluster head for only one round of operation. This scenario balances the energy consumption of the node. The formula for calculating the threshold is:

$$T(n) = \begin{cases} \frac{P}{1-P\times(r \bmod P^{-1})}, & \forall n \in G \\ 0, & \forall n \notin G \end{cases} \quad (1)$$

Where P is the probability, r is the round number, T(n) is a threshold value of an n^{th} node and G is the set of ordinary nodes.

b) Cluster Setup: After the election of CH each non-cluster head nodes receives the cluster head advertisements and then nodes inform CH about their membership in the cluster group. These non-cluster head nodes turn off their radio transmitter unless they have something to forward to the base station. This assists in saving the energy of the nodes present in the particular cluster.

c) Creation of Transmission Schedule: After cluster formation occurs each of the elected CH of the relevant cluster group will create a transmission schedule based on the TDMA mechanism. This mechanism prepares the schedule of each node present in the particular cluster group.

2) Steady Phase: Steady phase is found to be more protracted than the set-up phase and it primarily deals with data aggregation and transmission functionality. In this phase, the cluster nodes transmit data based on the generated transmission schedule to the CH in a single hop after which the CH perform data fusion and sends the fused data to the Base Station or via routing through the other CH's based on a static schedule [15].

B. TEEN

Threshold sensitive Energy Efficient sensor Network protocol is a reactive routing protocol for WSN that continuously senses the network environment for any dynamic changes and reports the WSN immediately when there is a presence of any change. It is a hierarchical routing protocol that uses a clustering technique for data capturing and routing. For forming the clusters and electing cluster heads, TEEN utilizes the same stochastic procedure as LEACH protocol. However, the CH's in TEEN broadcasts two significant values:

- Hard Threshold (HT): The node switch on its transmitter to report the sensed data to CH if the sensor node value is higher than the HT value.
- Soft Threshold (ST): The small change in the value of a sensed attribute that forces the node to transmit sensed data to CH.

For forwarding sensed data to the CH, the following rules need to be followed by each sensor node:

- The sensor nodes should turn on their transmitter when the sensed value of the attribute is higher than the value of HT and this detected value is stored in variable SV (sensed value).
- If the difference between the current value of the attribute and the SV is greater than or equal to ST then the nodes start transmitting the data.

C. DEEC

Distributed Energy Efficient Clustering selects CH on the basis of residual energy and the initial energy of the sensor nodes. In DEEC, the reference parameter is the average energy of the sensor network. It favors heterogeneous networks and multilevel heterogeneous networks in which different nodes comprise of different energy levels. DEEC calculates a threshold value for each node. A random function is used to generate some value. If the value calculated by DEEC exceeds the one generated by the random function then that particular node is declared CH for the specific round of operation. The formula for calculating threshold is:

$$T(s_i) = \begin{cases} \frac{P_i}{1-P_i(r \bmod P_i^{-1})}, & if\ s_i \in G \\ 0, & otherwise \end{cases} \quad (2)$$

Where Pi is the probability of becoming CH that is calculated as

$$p_i = p_{opt}\left[1 - \frac{\overline{E(r)} - E_r(r)}{\overline{E(r)}}\right] = p_{opt}\frac{E_i(r)}{\overline{E(r)}} \quad (3)$$

$E_i(r)$ denotes the residual energy of sensor S(i) in round r and denotes the average energy or network at round r which can be calculated as:

$$\overline{E(r)} = \frac{1}{N}\sum_{i=1}^{N} E_i(r) \quad (4)$$

III. Performance Evaluation

A. Simulations

MATLAB 2017 [16] software was used to simulate the working of LEACH, TEEN and DEEC. The simulation environment can be seen in Figure 1. The extensive experiments have been performed on a wireless sensor network consisting of 125 nodes placed randomly in the simulation grid of a defined area. All nodes have an initial energy of 0.5J and are programmed to sense the current temperature of the targeted region. The nodes capture the sensed data and communicate it to the primary control site for further processing.

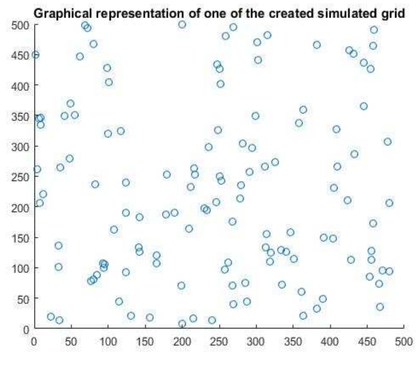

Figure 1. Graphical Representation of simulated grid

Our prime aim in experimenting is to evaluate WSN protocols: TEEN, LEACH and DEEC with regards to energy consumption.

B. Performance Metrics

For evaluating the performance of the protocols, we have used the following parameters:

- Residual energy: For computing residual energy of each node we have used radio dissipation model [3, 6]. This model computes the amount of energy exhausted in sending 1 bit of message over a distance d as:

$$E_{TX}(1,d) = \begin{cases} lE_{elec} + l\varepsilon f_s d^2, & d < d_0 \\ lE_{elec} + l\varepsilon mp d^4, & d \geq d_0 \end{cases} \quad (5)$$

Where E_{elec} indicates the energy dissipated, d is the distance between the nodes, while εf_s and εmp are readings associated with the transmitter amplifier.

- Network lifetime: Network lifetime of sensor networks is measured regarding the number of rounds it remains active.
- Alive nodes: This metric indicates the number of nodes remained alive after each round of simulation.
- Data sent: It measures the total amount of data that is sent to BS from the nodes.

C. Test Cases

Table I indicates the different test cases that we have used to compare the targeted hierarchical-based clustering protocols. In each of the test case, we have varied the number of rounds and we have taken five trials on the simulator to obtain the results.

Table I. List of test cases for simulation

ID.	No. of Trials	No of rounds	No. of nodes	Grid Size
1	5	1000	125	500×500
2	5	2000	125	500×500
3	5	3000	125	500×500
4	5	5000	125	500×500

D. Results

In simulations, we have executed five runs for each of the protocol and test cases. The readings are then averaged and plotted. A higher value of alive nodes and residual energy at any given instant specify a more useful protocol in terms of the overall network life.

1) LEACH

Table II illustrates the simulation results of LEACH protocol for each test case. From the results presented in Table II it can be observed that LEACH has less network lifetime, the whole network goes down within 1000 rounds.

Table II. Performance analysis of LEACH

ID.	Grid Size	No of rounds	Total nodes	Avg. alive nodes	First node dead (round)	Last node dead (round)	Network Lifetime (rounds)
1	500×500	1000	125	1	43	992	992
2	500×500	2000	125	0	37	944	944
3	500×500	3000	125	0	39	1014	1014
4	500×500	5000	125	0	30	894	894

2) TEEN

Table III depicts the simulation results of TEEN protocol for each test case. It has improved network lifetime of around 3600 rounds because it limits the number of transmissions between the cluster head and the base station.

Table III. Performance analysis of TEEN

ID.	Grid Size	No of rounds	Total nodes	Avg. alive nodes	First node dead (round)	Last node dead (round)	Network Lifetime (rounds)
1	500×500	1000	125	22	50	—	3538
2	500×500	2000	125	5	56	—	3538
3	500×500	3000	125	1	64	—	3538
4	500×500	5000	125	1	51	4774	4774

3) DEEC

Table IV illustrates the results of DEEC protocol under various test cases. DEEC also has improved network lifetime of around 3100 rounds. DEEC balances load distribution by allowing nodes with higher energy to become CH and lower energy nodes are used for sensing the targeted region.

Table IV. Performance analysis of DEEC

ID.	Grid Size	No of rounds	Total nodes	Avg. alive nodes	First node dead (round)	Last node dead (round)	Network Lifetime (rounds)
1	500×500	1000	125	18	44	—	3100
2	500×500	2000	125	5	40	—	3000
3	500×500	3000	125	2	29	—	3100
4	500×500	5000	125	0	36	3616	3616

E. Comparative Analysis of Protocols

1) Test Case 1: In test case 1 we have taken 125 sensor nodes in 500×500 square grid and executed each of the protocol (LEACH, TEEN, and DEEC) on the simulator for 1000 rounds. The results are shown in Figure 2(a), and figure

2(b). Figure 2(a) represents total nodes alive after each round of simulation for a total of 1000 rounds, and figure 2(b) represents total data sent to BS.

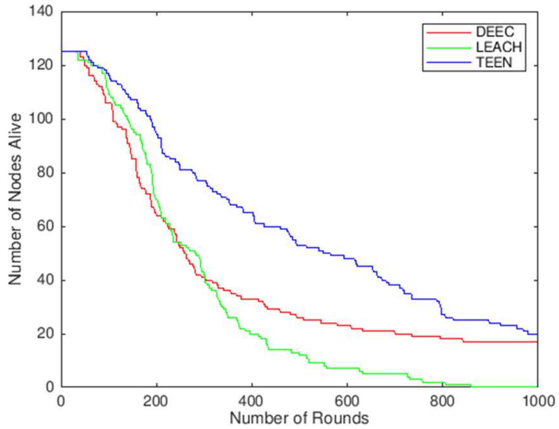

Figure 2(a). No. of nodes alive (1000 rounds)

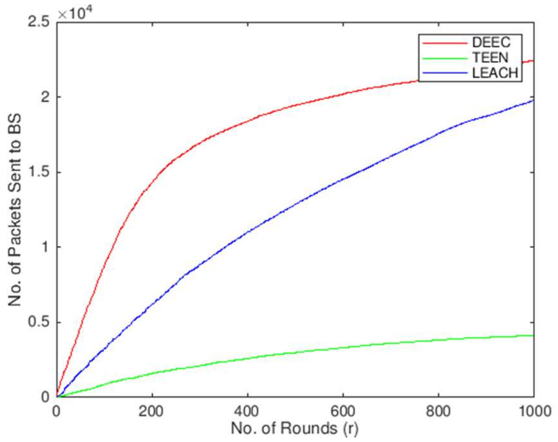

Figure 2(b). Amount of data sent to BS (1000 rounds)

2) Test Case 2: In test case 2 we have taken 125 sensor nodes in 500×500 square grid and executed each of the protocol (LEACH, TEEN, and DEEC) on the simulator for 2000 rounds. The results are illustrated in Figure 3(a) and Figure 3(b). Figure 3(a) illustrates no of nodes alive after each round of simulation for a total of 2000 rounds and Figure 3(b) represents total data sent to BS in 2000 rounds.

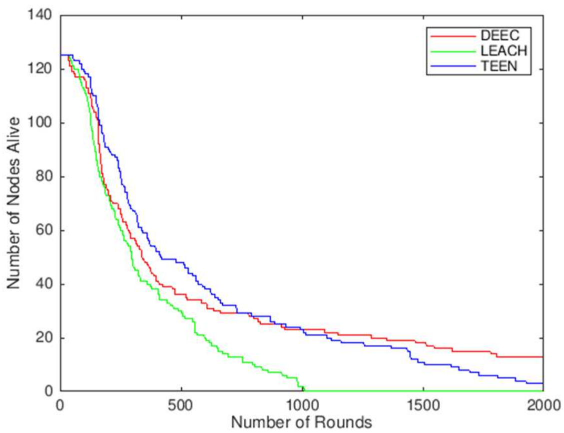

Figure 3(a). No. of nodes alive (2000 rounds)

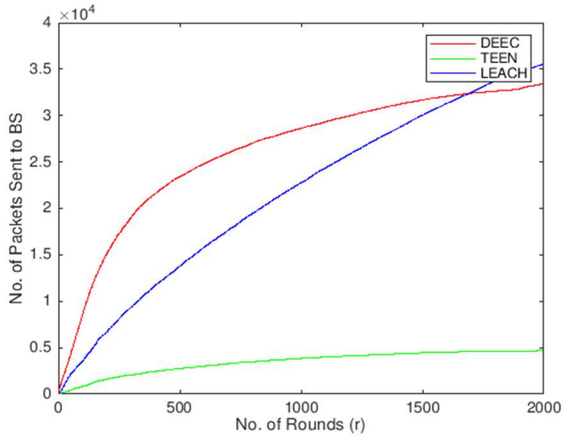

Figure 3(b). Amount of data sent to BS (2000 rounds)

3) Test Case 3: In test case 3 we have taken 125 sensor nodes in 500×500 square grid and executed each of the protocol (LEACH, TEEN, and DEEC) on the simulator for 3000 rounds. The results are shown in Figure 4(a) and Figure 4(b). Figure 4(a) depicts a number of nodes alive after each round of simulation for a total of 3000 rounds, and Figure 4(b) represents the amount of data sent to BS in 3000 rounds.

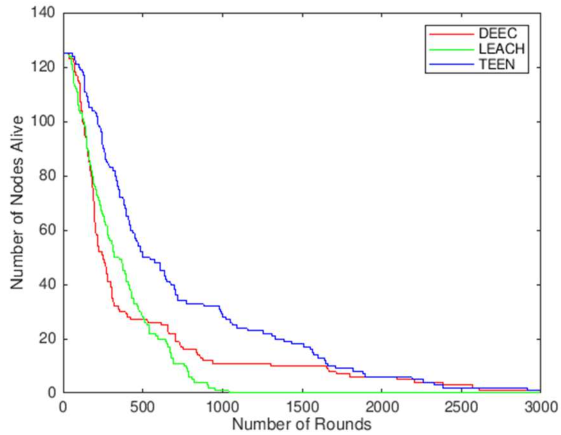

Figure 4(a). No. of nodes alive (3000 rounds)

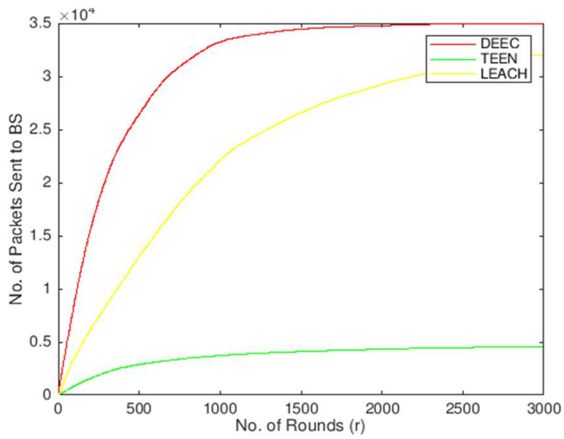

Figure 4(b). Amount of data sent to BS (3000 rounds)

4) Test Case 4: In test case 4 we have taken 125 sensor nodes in 500×500 square grid and executed each of the protocol (LEACH, TEEN, and DEEC) on the simulator for 5000 rounds. The results of the experiments are shown in Figure 5(a), and Figure 5(b). Figure 5(a) represents a number of nodes alive after each round of simulation for a total of 5000 epochs and Figure 5(b) represents the amount of data sent to BS in 5000 epochs.

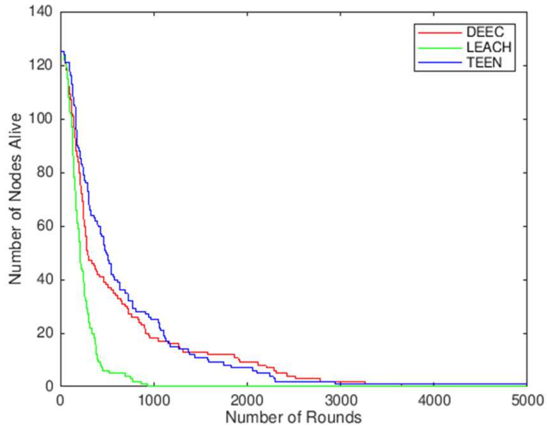

Figure 5(a). No. of nodes alive (5000 rounds)

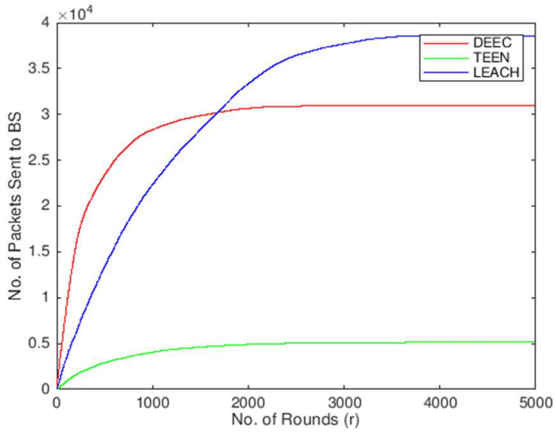

Figure 5(b). Amount of data sent to BS (5000 rounds)

From the above graphs of all test cases, it can be inferred that LEACH has the worst performance. In LEACH the number of nodes alive after each observational cycle reduces exponentially. In addition, LEACH has less residual energy after each operational cycle due to reduced load distribution among sensor nodes. TEEN provides better performance over LEACH by reducing the number of transmissions to the Base Station. DEEC also outperformed LEACH by choosing CH that has sizeable residual energy.

IV. Conclusion

Due to the page restriction scenario, we could not document the investigation and results of the amount of energy consumed by each node during the simulation of each protocol along with their investigation of security vulnerabilities. However, we state some significant conclusions from this study. The routing process of wireless sensor network plays an influential role in deciding the lifespan of sensor networks. The protocols viz. LEACH, TEEN, and DEEC try to reduce the power utilization of sensor nodes by reducing the number of transmissions to the BS and reduces the captured data redundancy by applying data fusion at CH. From the above observations, it can be inferred that LEACH has the worst performance regarding energy consumption and network lifetime. DEEC has satisfactory performance regarding network lifetime and residual energy. Nevertheless, if we consider the reliability aspect DEEC outperforms the other two in that context and becomes more suitable for a heterogeneous network. We briefly present the merits and demerits of all the three protocols that are substantially backed up by means of our experimental findings. These merits and demerits of each of the three protocol are as follows:

Merits of LEACH

- It performs data fusion that reduces the traffic and reduces the power consumption of sensor nodes in data transmission.
- It uses single hop routing to transmit data from CH to BS that reduces the energy consumption of the network.

Demerits of LEACH

- LEACH exhibits poor load balancing which reduces the lifetime of the sensor network.
- LEACH gives no prediction about the number of clusters in the network and the clusters are formed randomly. Hence, the nodes are not evenly distributed among the clusters. Some nodes are near the cluster heads and some are at the edge of CH. These variations result in increased energy consumption and reduced network lifetime.
- It was also found out that LEACH is vulnerable to security attacks such as HELLO flooding attack and sybil attack.

Merits of TEEN

- TEEN is a reactive routing protocol that senses the environment continuously and reports the sensed data to the BS or CH. However, with the support of the appropriate thresholds TEEN manages to reduce the number of transmissions thus saving energy of the sensor nodes.

Demerits of TEEN:

- TEEN is not suitable for periodic data reporting applications, this is because if the values do not get above the threshold the nodes will not capture any data and there is a presence of deadlock in the WSN.
- Our initial investigation of TEEN also revealed that TEEN was vulnerable to Selective Forwarding attacks and HELLO attack.

Merits of DEEC:

- DEEC estimates network lifetime that cuts the cost having global knowledge of the network.
- DEEC performs well in multilevel heterogeneous networks.

Demerits of DEEC:

- Advanced nodes in DEEC are always subjected to faster energy drain and are the first ones to die early while operating.

V. Future Work

We have only simulated the protocols. However, we still need to validate our findings on real-world wireless sensor network applications. We aim to achieve this by testing these protocols on real-world environmental data sensing problem and are currently seeking opportunities for the same at the related industries. In addition, a part of these efforts will be aimed towards optimizing the protocols with the intent towards achieving a better performance than the baseline one. Moreover, in the future we also plan to investigate the other wireless sensor protocols along with the ones mentioned in this study using similar research approach for a wider comparative performance analysis and providing recommendations related to the application of the relevant protocol for the appropriate scenario.

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ABBREVIATIONS

WSN - Wireless Sensor Network
CH - Cluster Head
BS - Base Station
SV – Sensed Value
MAC – Medium Access Control
TEEN - Threshold Sensitive Energy Efficient Sensor Network Protocol
LEACH - Low Energy Adaptive Clustering Hierarchy
HEED - Hybrid Energy Efficient Distributed Clustering
DEEC - Distributed Energy Efficient Clustering
TDMA - Time Division Multiple Access
GAF - Geographic Adaptive Fidelity
GEAR - Gateway based Energy Efficient Routing
PEGASIS - Power Efficient Gathering in Sensor Information Systems