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Abstract

Renewable energy sources play a major role in energy saving, thus it becomes the actual hope to improve one of the major challenges for the Wireless Sensor Networks (WSNs), which is network lifetime, especially when sensor nodes are placed in non-accessible human areas. Solar Energy Harvesting (SEH) is one of the most abundant and accessible types of renewable energy, which is produced by collecting sunlight and converting it into electricity. This paper proposes vaccinating the Low-Loss Low-Energy Adaptive Clustering Hierarchy Centralized Protocol (LLEACH-C), by SEH sensor nodes, to improve its lifetime, the protocol that proposed a Vice Cluster Head Mechanism (VCHM) for cluster head recovery during the round operation. That produced a new protocol called Solar Low-Loss Low-Energy Adaptive Clustering Hierarchy Centralized Protocol (SLLEACH-C). From simulation results; SLLEACH-C succeeded in increasing the network lifetime by on average 79%, and decreases the Packets Loss by on average 85%. It was observed that the VCHM needs to be improved to become more suitable for SEH environment, therefore the Enhanced SLLEACH-C (ESLLEACH-C) protocol was proposed, which uses Solar Cluster Head Recovery Mechanism (SCHRHM), for recovering cluster head during round operation. From simulation results; ESLLEACH-C succeeded in increasing the network lifetime by on average 13.5%, and decreases the Packet Loss by on average 93% than SLLEACH-C. Also this paper cares about studying the effect of the average number of SEH nodes on the network performance.


1. INTRODUCTION

Energy Harvesting - Wireless Sensor Networks (EH-WSNs) is a type of WSN which is capable of harvesting environmental energy for immediate usage or storage for future use. That’s by making a percentage of its sensors Energy Harvesting Sensors (EHS), which are able to harvest energy from the environment in addition to its sensing role. Harvesting environmental energy is the process by which energy is derived from external sources (e.g. solar power, thermal energy, wind energy, salinity gradients, and kinetic energy), captured, and stored for small, wireless autonomous devices, such as those developed using MEMS technology, like WSN. Energy supply for sensor nodes has been the greatest limiting factor on WSN, where they are traditionally powered by primary batteries, which limit their lifetime or lead to high maintenance costs especially when deployed in adverse and non-accessible areas without a fixed infrastructure. Especially for applications in which a system is expected to operate for long periods, energy becomes a severe constraint. Such as, Farming [1], Habitat Monitoring[2], Smart Home[3], Environmental Monitoring[2], Animal migratory patterns[4], Volcano monitoring[5], Structural Monitoring[6], Vehicle Tracking[7,8], Traffic Control[9], Natural disaster detection[10]. Recently, environmental energy has emerged as a feasible supplement to battery power for wireless sensor systems in which the manual recharging or replacement of batteries is not practical. Hierarchical protocols in a WSN, usually suffer from the loss of data packets due to the rapid energy depletion of Cluster Heads (CHs) during the data transmission between CHs and the base station. This decreases the communication reliability in WSN applications. Errors caused by data loss inevitably affect the data analysis of the structure and subsequent decision making. Therefore the Low-Loss Low-Energy Adaptive Clustering Hierarchy Centralized Protocol (LLEACH-C) [11] proposes a Vice Cluster Head Recovery Mechanism (VCHM) for CHs recovery during the round operation over Low Energy Adaptive Clustering Hierarchy – Centralized protocol (LEACH-C) protocol [12;13]. LLEACH-C has succeeded in decreasing the data packet loss by 43% lower than LEACH-C. Thus this paper proposes attaching a solar cell with sensor nodes for Solar Energy Harvesting (SEH)[14], which will harvest the solar energy and use it in the performance of the tasks assigned to the node during the sunlight, then use the battery otherwise, which will reflect on the hole network lifetime. Therefore this research studies the impact of the improvement in the network performance based on this additional source of power, and how much this proposal becomes essential in situations where it is either difficult or not cost effective to access the network’s nodes to replace the batteries.

The rest of the paper is outlined as follows: Section 2 presents related work on WSN Hierarchal protocols which applies the idea of SEH, and focuses on LLEACH-C protocol. Section 3 describes in details the proposed protocol SLLEACH-C and ESLLEACH-C. Section 4 views ESLLEACH-C System model. Section 5 shows the Performance evaluation for SLLEACH-C and ESLLEACH-C. Section 6 shows the Conclusion.
2. RELATED WORK
Numerous energy-aware routing protocols have been conceived for WSNs without energy harvesting capabilities[15;16], but only a small number of energy harvesting-aware routing protocols have been introduced to take advantage of the sustainable energy harvesting sources to increase WSNs lifetime. Attracting the attention to attach energy harvesting devices like solar cells to sensor nodes beside the traditional battery had been proposed in [17]. That's to extend the network lifetime. In clustered WSNs the most popular hierarchal protocol, This idea is applied on LEACH [18] protocol in[19] which produced a new version called VLEACH , and enhanced in A-SLEACH in [20], but in [21] it proposed a new protocol Adaptive Energy-Harvesting Aware Clustering (AEHAC) routing protocol for perpetual-operated EH-WSNs, at which the election of CHs is distributed and based on combining energy harvesting rate and the node residual energy. But in [22] the authors proposed an algorithm which selects the best locations of CH, then uses one SEH node as a relay between MN and BS and studies the maximization in lifetime, but that's for single cluster only, which is not enough for building a real network. For centralized version of LEACH, this idea is also applied only in [19] which produce SLEACH-C protocol. But as known in hierarchical routing protocols the unbalanced energy distribution among cluster nodes, make the CH considered as a cluster single point of failure, where the CH takes many energy consumption tasks rather than the Member Nodes (MNs), therefore it may fail during the round whereas, other MNs are alive and sensing data. That’s will cause the lost of the collected data from MNs, because it will never reach the Base Station (BS). This problem was solved by LLEACH-C. Despite its success in reducing the packet loss due to the CH failure during the round, but it was unable to improve the network lifetime. Like hierarchal protocols, LLEACH-C operation is divided into sequenced rounds; each round consists of two main phases, setup phase and steady state phase. During setup phase the BS forming the clusters, where it selects the CH and the Vice Cluster Head (VCH) for each cluster, then informing each node by its corresponding CH and VCH. Then the steady state phase starts by data transmission between MNs, CH and BS. During this phase, BS tests the Energy of CH (ECH) for each received frame, if ECH lower than the required energy for the next frame EF, the BS starts Vice Cluster-Head Mechanism (VCHM) over that cluster by sending a message to each node in that cluster, informing them that VCH will take the guidance of the cluster instead of the CH, Then the CH and VCH exchange the allocated Time Slots (TSs) for each of them, which was allocated to them in TDMA schema. After that the MNs establish a connection with VCH, and CH becomes a normal MN and also establishes a connection with VCH. VCH takes this role till the end of the round. After applying the VCHM, LLEACH-C succeeds in reducing the packet loss of LEACH-C by approximately 43%, but the lifetime of both is the same; therefore attaching solar cell to sensors to become SHE sensor nodes provides an attractive and green solution to improve the network lifetime.

3. SOLAR AWARE LOW-LOSS LOW-ENERGY ADAPTIVE CLUSTERING HIERARCHY CENTRALIZED PROTOCOL (SLLEACH-C)
This section describes in details the functionality of the proposed SLLEACH-C protocol. Section 3.1 presents the SLLEACH-C, which shows the enhancement in the performance of LLEACH-C after adding SEH to the network nodes. Section 3.2 presents the ESLLEACH-C, which shows the enhancement in the performance of SLLEACH-C, after adding some modifications to the VCHM to make it more suitable for SEH environment, which becomes Solar aware Cluster Head Recovery Mechanism (SCHRM). SLLEACH-C is a solar version of LLEACH-C protocol, which assumes that a percentage of nodes in the network are SEH in addition to the traditional battery. SLLEACH-C is the first solar protocol that applies the idea of CH recovery to achieve network fault tolerance, which causes sharp reduction in packet loss.

3.1 SLLEACH-C Protocol:
As in hierarchical protocols, the SLLEACH-C protocol divides the network into clusters, as shown in Figure 1 (a), using two main phases, setup phase for cluster formation, at which the selection of CH and VCH is occurred, and steady state phase for data transmission, at which the BS decides to replace the CH, before its failure, using VCHM.

![Image](image_url)

Figure 1 The network structure of SLLEACH-C: (a) before applying VCHM, (b) after applying VCHM on cluster X, and (c) after applying SCHRM on cluster X and Z.

3.1.1 Setup phase
This phase is subdivided into three phases, base station cluster formation phase, cluster send/receive phase and TDMA scheme formation phase as shown in Figure 2.

Cluster formation phase: BS uses its central algorithm to calculate the rating for each node, where rating is equal to the difference between the actual node energy (E) and the required energy for next round (E_R) if the node becomes CH. Then
select the VCH for each cluster, at where the BS sorts rating of the cluster MNs descendingly and select the highest one as VCH.

**Cluster send/receive phase:** Starts by sending a message from the BS to all nodes containing the CH and VCH IDs, informing each of them of the corresponding CH and VCH. When a node receives this message it compares its own ID with the received IDs, if it matches with the CHID the node will become a CH, else if it matches with the VCHID the node will become a VCH, otherwise, the node will be a MN and will establish the connection with the corresponding CH.

**TDMA schema phase:** After nodes know their role, the CH starts to create its TDMA schema, for allocating a Time Slots (TSs) for each MN. As shown in Fig.2(a), CH arranges TDMA scheme as follows, (i) TSs for MNi, (ii) TS for VCH, (iii) the last two TSs are assigned to CH Data Aggregation (CHDA) and CH Data Transmitting (CHDT). Then the CH announces its TDMA scheme by a message, sends it to its MNs containing the allocated TS for each one. When MNs receive this message each node knows its allocated TS for data transmission and goes to sleep until it is time to transmit data. Once the clusters are formed and TDMA schemes are constructed and distributed, the steady state phase is started.

![Figure 2 SLLEACH-C V1 TDMA Scheme](image)

During the steady state phase when the BS decides to apply the VCHM over a certain cluster, instead of creating a new TDMA the VCH uses the same TDMA already created, but only exchanges the last three TSs between itself and CH, as shown in Fig. 2 (b), that is as a result of exchanging the roles between them.

### 3.1.2 Steady state phase

All MNs of the network sense the surrounding environment to collect the required data and send it to the corresponding CH, if the node status is solar it will use the direct solar power, otherwise it will consume its battery power (E) by energy required for data sensing (EDS) plus the energy required for data transmission (EDT) to CH. Once the CH receives packets from all MNs; it aggregate the collected data in one packet and sends it to the BS. As shown in Figure 1(a), When the BS receives any frame, it checks the CH energy level (ECH), if it is enough for the next frame (EF), the BS will let it complete the next frame, otherwise it will start the VCHM to exchange the roles between CH and VCH to save the next frame from being lost. The VCHM starts by sending a message from BS to all cluster nodes informing them that the VCH will take the guidance of the cluster instead of the CH. Then the CH and VCH exchange the allocated TSs for each of them, as described above in TDMA schema.

![Figure 3 SLLEACH-C & ESLLEACH-C setup phase flow chart](image)
But when looked up on depth at Figure 1 (b) in cluster X we can see that, when the CH changed its status to battery powered and the BS decided to exchange the role between it and VCH, we find that the preselected VCH at the beginning of the round due to the applied VCHM is battery powered node, while through the round another MN changes its status to solar, therefore its becomes more suitable for VCH role than the preselected one. That’s why the Enhanced version of SLLEACH-C protocol was proposed, at which the selection of VCH will be start after the BS take a decision to remove the CH from the guidance of the cluster.

![Steady state phase flow chart](image)

**Figure 4** SLLAECH-C & ESLLEACH-C steady state phase flow chart

### 3.2 ESLLEACH-C Protocol:
This is the enhanced version of SLLEACH-C protocol, which is introduced to enhance the VCHM, which becomes; Solar aware Cluster-Head Recovery Mechanism (SCHRM) that’s to be suitable for SEH environment. As shown in Figure 1(c) the typical network structure after applying the new proposed SCHRM.

#### 3.2.1 Setup phase
This phase is the same as the one which was on the SLLEACH-C protocol, with some little modifications, as shown in Figure (3) where the selection of VCH is neglected in this phase.

#### 3.2.2 Steady state phase
Also, this phase is the same as the one which was on the SLLEACH-C protocol. But with enhanced idea for VCHM, it becomes SCHRM, which will be described as following.

#### 3.2.2.1 Solar aware Cluster-Head Recovery Mechanism
SCHRM is the enhanced version of VCHM, which starts when the BS decides to exchange the roles between CH and recovery node, as shown in Figure (4), the BS central algorithm scans the status of cluster MNs, if the cluster contains one or more MN with solar status, it selects the first scanned solar powered node to take the role of the VCH, and becomes a SRCH. Otherwise, the central algorithm sorts cluster MNs descendingly based on energy and selects the largest MN energy to take the role of the VCH. The SRCH or VCH starts its role by creating a new TDMA schema for the cluster members, to allocate TSs for each MN. As shown in Figure 1 (b) before applying the SCHM the CH is solar powered.

Figure 1 (c) shows that at cluster X the CH solar status is changed, while another MN changes its status from battery powered to solar powered, therefore when the BS decides to remove the CH of cluster X from cluster guidance, using SCHM it scans the status of all cluster MNs and select the solar powered node to take the role of VCH and becomes SRCH.
SRCH. But when the BS starts the SCHM over cluster Z, it finds that none of MN is solar powered, therefore it sorts the MN descendingly by energy and select the largest one to take the role of VCH.

4. SLLEACH-C AND ESLLEACH-C SYSTEM MODEL

This section describes in details the assumptions of SLLEACH-C system model. Section 4.1 explains the proposed network model in designing the protocol. Section 4.2 describes the adopted radio model in the protocol operation. Section 5.3 views the SCHRM.

4.1 Network Structure for SLLEACH-C and ESLLEACH-C

SLLEACH-C and ESLLEACH-C networks has the following design assumptions: (i) sensor nodes and BS are immobile after identifying ID, (iii) all nodes are able to reach BS and can communicate with each other, (iv) CHs perform overhearing, receiving, aggregating, and sending data to the BS, (v) propagation channels are symmetric, (vi) all nodes are sensing the surrounding environment in a fixed rate and send data periodically to CH, (vii) when a node becomes SEH, there is no battery charging or consumption, and finally (viii) all nodes start with the same energy level and the BS has unlimited energy.

4.2 Radio Signal Propagation and energy consumption Model

SLLEACH-C and ELLEACH-C are use the energy model as in LLEACH-C. Where energy dissipation 50nJ/bit for both transmitter ETx-elec and receiver ERx-elec to run the radio electronics and the energy dissipated in the transmitter amplifier in a free-space channel cfs = 10pJ/bit/m². Thus to send an (1-bit) message over a distance d the energy consumed by the radio can be calculated as:

\[ E_{TX}(I, d) = E_{TX-elec}(I) + E_{TX-amp}(I, d) = I^{*}E_{elec} + I^{*}E_{Fs} * d^2 \]  

To receive this message at destination the energy consumed by the radio can be calculated as:

\[ E_{Rx}(I) = E_{Rx-elec}(I) = E_{elec} * I \]  

4.3 Solar aware Cluster Head Recovery Mechanism

During the steady state phase the BS decides to start the SCHRM, when the CH is battery powered, so it computes the E_f required from each CH, using the following equation:

\[ E_f = E_{DR} + E_{DA} + E_{DS} \]  

Equation (3) explains the components of E_f. Where E_{DR} is the CH consumed energy for data receiving, E_{DA} is the CH consumed energy for data aggregation, and E_{DS} is the CH consumed energy for data sending to BS.

For any CH has MNs and receives packets of I data bits (PKT (I)), equation (4) can be expanded as follows:

\[ E_f = E_{elec} * I^{*}MN + P_{Kf}(I)^{*}E_{DA} * MN + I^{*}E_{elec} + I^{*}E_{Fs} * d^2 \]  

Equation (4) is the criteria for the SCHRM activation. Because when the BS received a frame, the SCHRM compares the E_{CH} for each CH, with the calculated E_f for that cluster, if E_{CH} < E_f, the SCHRM will start by scanning the cluster to search about SEH node, if available, it will be selected for the SRCH role, at which no battery consumption, otherwise it will sorts the cluster members descendingly according to the energy and select the largest one for VCH role.

5. PERFORMANCE EVALUATION OF SLLEACH-C & ESLLEACH

The SLLEACH-C simulation model is built by using OMNET++ discrete event Simulator[23], to evaluate its performance metrics like network lifetime, packet Loss, End-to-End Delay, and Throughput.

5.1 Simulation parameters

The values of the used parameters in the simulation are listed in Table.1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
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<tr>
<td>Field size (M-M)</td>
<td>1000 - 1000</td>
</tr>
<tr>
<td>Initial energy of sensor node</td>
<td>0.5 J</td>
</tr>
<tr>
<td>Transmitter /receiver Electronics</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>ETx and ERx (Elec)</td>
<td></td>
</tr>
<tr>
<td>Transmitter amplifier E_{Fs}</td>
<td>0.0013pJ / bit /m²</td>
</tr>
<tr>
<td>The energy for aggregation EDA</td>
<td>5 nJ /bit / signal</td>
</tr>
<tr>
<td>The data packet size</td>
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</tr>
<tr>
<td>Sunduration</td>
<td>1200</td>
</tr>
<tr>
<td>Frame/ Round</td>
<td>5</td>
</tr>
</tbody>
</table>
5.2 Results
This section contains the simulation results which were carried out to compare the performance of the SLLEACH-C protocol with LLEACH-C protocol, and then compare its performance with the ESLLEACH-C.
In simulation, the number of the deployed nodes is increased from 100 to 1000 node with unit step 100, selecting an average number to become SEH nodes, varies from 10%, 25% to 50% of all network nodes. Most of the results obtained in this paper were obtained by averaging ten independent simulation runs, where each run uses a different randomly-generated topology of sensor nodes.

5.2.1 Comparative analysis between SLLEACH-C and LLEACH-C
5.2.1.1 Network lifetime
The simulation calculates the network lifetime by counting the number of successive finished rounds till less than 10 nodes are alive. As shown in Fig.5 the SLLEACH-C has enhanced the lifetime of LLEACH-C by on average 79%, that is using only 10% of SLLEACH-C network nodes working as SEH nodes. That is because SEH nodes become CHs with a high probability, which saves their batteries, and give them longer lifetime.

![Figure 5](image1.png)

**Figure 5** Network lifetime vs. number of nodes (SEH = 10%)

5.2.1.2 Packet loss
Represents the lost packets sent from CH but don’t reach to the BS due to the CH failure, reducing the packet loss was the main target of LLEACH-C, which succeed in reducing it by on average 43% than LEACH-C.

![Figure 6](image2.png)

**Figure 6** Average packet loss vs. number of nodes, (SEH = 10%)

But as shown in Fig.6 the packet loss in SLLEACH-C has succeeded in reducing it than LLEACH-C by on average 85%. That is because SLLEACH-C reduces the CH failure by selecting them with higher probability from the SEH nodes than traditional nodes as in LLEACH-C; this reduces the consumption of their batteries, which offers them longer lifetime.

5.2.1.3 Throughput
It represents the average number of successive data bits received at the BS per second. As shown in Fig.7 the SLLEACH-C has enhanced the throughput of LLEACH-C by on average 7% that is due to the increase in SEH nodes lifetime.

![Figure 7](image3.png)

**Figure 7** Throughput vs. number of nodes (SEH = 10%)

5.2.1.4 End-to-End Delay
It represents the time taken for a packet to be transmitted across a network from source to destination. As shown in Fig.8 the the end-to-end delay of SLLEACH-C is lower than it in LLEACH-C by on average 8.5% that is due to difference in cluster
cluster forming time, where in SLLEACH-C the CH selection is based on both, its status and energy while in LLEACH-C its selection based on its energy only.

![Figure 8: End-to-End Delay vs. the number of nodes (SEH = 10%)](image)

5.2.2 Comparative analysis between SLLEACH-C and ESLLEACH-C

5.2.2.1 Network lifetime
As shown in Fig. 9 the ESLLEACH-C has enhanced the lifetime of SLLEACH-C by on average 13.5% that is done by using about 25% on average of network nodes as SEH. That is due to the applied SCHRM which selects the SRCH node with higher probability, than the VCH which selects by VCHM and based on its battery.

![Figure 9: Network lifetime vs. number of nodes (SEH = 25%)](image)

5.2.2.2 Packet Loss
As shown in Fig. 10 ESLLEACH-C has succeed in reducing the packet loss by on average 93% than SLLEACH-C, That is due to applied SCHRM, which contains two strategies for backing up the CH, one for SEH MN, and another for normal MN.

![Figure 10: Average packet loss vs. number of nodes, (SEH = 25%)](image)

5.2.2.3 Throughput
As shown in Fig. 11 the Throughput of ESLLEACH-C and SLLEACH-C are approximately the same.

![Figure 11: Throughput vs. number of nodes (SEH = 25%)](image)
5.2.2.4 End-to-End Delay
As shown in Fig.12 the ESLLEACH-C has decreased the end-to-end delay of SLLEACH-C by on average 4% that is due to applied SCHRM, which enhances the selection of CH recovery node, by making the selection in its current situation and based on both status and energy, rather than the preselected one which is only based on its energy at the beginning of the round, which used in VCHM.
That is makes SCHRM perform better End-to-End delay than VCHM in SEH environment.

5.2.3 ESLLEACH-C performance evaluation based on the SEH nodes percentage
After knowing the importance of SEH to improve the performance of the clustered WSN, therefore studying the effect of the used number of SEH nodes on the network performance becomes important. To find out its effect, three percentages have been suggested for the study, they are 10%, 25% and 50% of SEH nodes through the network.

5.2.3.1 Network lifetime
Using simulation study to find out the effect of increasing the number of SEH nodes on network lifetime, as can be seen in Fig.13 we found that when the number of SEH nodes is increased from 10% to 25% the network lifetime increased on average by 18.4%, and when it increased from 25% to 50%, the lifetime increased by on average 29.2%.

It illustrates that by increasing the number of SEH nodes the network lifetime will increased. That’s because when the nodes become SEH node and thus they save their battery.

5.2.3.2 Packet Loss
Using simulation study to find out the effect of increasing the number of SEH nodes on the network packet loss.

Figure 12 End-to-End delay vs. the number of nodes (SEH = 25%)

Figure 13 Network lifetime vs. number of nodes

Figure 14 Average packet loss vs. number of nodes
As can be seen from Fig.14, when number of SEH nodes increased from 10% to 25% the network packet loss decreased on average by 78.5%, and almost reduced to zero. But when it increased from 25% to 50%, the packet loss increased by 29.2% but still lower than 10%.

5.2.3.3 Throughput
Using simulation study to find out the effect of increasing the number of SEH nodes on the network throughput. As can be seen from Fig.15, the Throughput is approximately the same for each value of SEH nodes.

![Figure 15 Throughput vs. number of nodes](image)

5.2.3.4 End-to-End Delay
Using simulation study to find out the effect of increasing the number of SEH nodes on the network end-to-end delay, as can be seen from Fig.16, when the number of SEH nodes increased from 10% to 25% the network End-to-End delay increased on average by 5.4%. But when it increased from 25% to 50%, the End-to-End delay is approximately the same.

![Figure 16 End-to-End delay vs. the number of nodes](image)

6. CONCLUSION
Energy harvesting wireless sensor networks (EH-WSNs) offers a green alternative solution to tackle the challenging problem of limited lifetime of conventional WSNs. Therefore to improve the lifetime of LLEACH-C protocol, this paper proposed attaching a solar cell with a percentage of the network nodes to give them additional power source to increase their lifetime, and select them for energy consumption tasks with high probability than traditional nodes, which led to producing a new solar clustering protocol called SLLEACH-C, which starts by caring about improving the lifetime of LLEACH-C, that's by improving the selection of CHs, which give the higher priority to SEH nodes, thus the cluster formation strategy changed, as a result of that the others network metrics are improved, like the packet losses, end-to-end delay are reduced, and Throughput is increased, that is done by allowing only 10% of nodes working as SEH nodes.

Despite this improvement, it was found that the selection strategy of VCH needs to be improved to become more suitable for SEH environment, therefore the ESLLEACH-C was introduced, at which the SCHRM is proposed instead of VCHM, as a result of this improvement the network metrics show enhanced performance, where the lifetime and throughput are increased, end-to-end delay and packet loss are decreased.

Thus we found that studying the effect of SEH nodes number on the performance of ESLLEACH-C becomes important, therefore three percentages were suggested for that purpose, they were 10%, 25%, and 50%, this study shows that as the number of SEH nodes over the network increased, the lifetime also increased, the throughput remains approximately the same, the packet loss is reduced and the end-to-end delay is increased.

References


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