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Energy-efficient Improvement for Heterogeneous Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSNs) are composed of a large number of sensor nodes with sensing capabilities. A sensor node will use much energy during the communication process compared to the amount of energy used during its computational work. But, the sensor node used the battery which put significant constraint to the energy available to them. Therefore, the energy of a sensor node will drain quickly and will degrade the lifetime of the network. As a result, a node clustering algorithm and relay node selection scheme have been selected as the best way to use energy effectively in the network. In this study, three methods for improving the energy efficiency of clustering algorithms for wireless sensor networks are presented. The first method is to formulate a new equation for cluster head selection in three-level heterogeneous networks. The second is to use a single parameter, residual energy, to determine cluster head suitability in adaptive cluster head selection. The third is to use relay node selection scheme for intra-cluster communication between the cluster head node and the sink node. This study proposes a protocol called Relay Efficient Three-Level Energy (Relay-ETLE). The work has been compared with the Energy-Efficient Heterogeneous Clustered Scheme (EEHC) and Low-Energy Adaptive Clustering Hierarchy (LEACH) in terms of the lifetime of the network. The comparative results indicate that the lifetime of WSNs can be increased by approximately 78% compared to EEHC and 22% compared to LEACH.

Key words: Heterogeneous wireless sensor networks, node clustering algorithm, relay node selection scheme, energy-efficiency

INTRODUCTION

WSNs have been used widely in many industrial applications. For example, these networks can be applied in environmental applications, health applications, home automation and smart environments (Hac, 2003). A WSNs is formed by a collection of several (sometimes hundreds or thousands) sensor nodes that collaborate among themselves to form a sensing study. After sensing an environment based on a query provided by the user, a sensor node can process the sensed data, may even sometimes aggregate it with the other nodes' data and send it to the sink node. Based on the results provided by each node, the network can act by providing the results to the user or to a node connected to the internet. A wireless sensor node is composed of four basic components: a sensing unit, processing unit, transceiver unit and power unit. The lifetime of WSNs strongly depends on the power unit (battery). Normally, the power unit has a very limited source (<0.5 Ah, 1.2 V) due to its limited hardware. For most applications, replenishing the power source is impossible. Thus, the source that consumes energy during the operation of each node should be analysed and maintained efficiently. Akyildiz and Vuran (2010) reviewed the energy consumed during the sensing operation of sensor nodes. Additionally, it shows that the energy consumption for data communication is higher than that for the computation process inside of the sensor node. In data communication, there are several routing protocols that have been applied. The routing protocol is a very important scheme to ensure that the data sensed will be transmitted to the sink node properly. In addition, the lifetime of WSNs must also be considered. Thus, an energy-efficient routing protocol must be developed.

A node-clustering algorithm is a scheme in which several nodes are aggregated to form a group (cluster). Usually, it operates in two phases: a node-clustering setup and clustering maintenance (Zhang *et al*., 2009). In the node-clustering setup phase, Cluster Heads (CHs) are chosen among the nodes in the network based on a selection scheme, as proposed by Heinzelman *et al*. (2002), Xuegong *et al*. (2010) and Handy *et al*. (2002). After selecting the CHs, another node affiliated with

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the CHs forms the clusters. Nodes that are not cluster heads are called non-CH nodes. As a router, a CH will transmit the data collected from the non-CH nodes to the sink node. In the clustering-maintenance phase, the clustering configuration may be changed after the initial cluster is set up due to node movements or topological changes.

In a homogeneous network, the sink node cooperates with the sensor node, which has the same capabilities with respect to computational power and storage. Some researchers have proposed a routing protocol based on these characteristics in reducing the energy consumption of sensor nodes, such as the Low-Energy Adaptive Clustering Hierarchy (LEACH) proposed by Heinzelman *et al.* (2002), the protocol proposed by Xiaoping *et al.* (2010), Energy-balanced clustering routing algorithm (EBC) proposed by Lan *et al.* (2009), the protocol proposed by Guo *et al.* (2010) and Advanced LEACH (ALEACH) proposed by Ali *et al.* (2008). It is assumed that this type of network is not practical because the sensor node itself does not always have the same communication and sensing capabilities. In fact, sensor nodes using the same platform are not guaranteed to have exactly the same physical properties (Das and Ammari, 2009). The performance of a heterogeneous network is different from that of a homogeneous network. Recently, researchers have shown increased interest in heterogeneous-network research because of the ability of the heterogeneous scheme to extend the lifetime of a network (Katiyar *et al.,* 2011), improve the reliability of data transmission (Yarvis *et al.*, 2005) and decrease the latency of data transportation (Yu *et al.*, 2007). Typical heterogeneous WSNs consist of a large number of normal nodes and a few heterogeneous nodes (Duarte-Melo and Liu, 2002; Yu *et al.*, 2007). The normal node, whose main tasks are to sense and report data, is inexpensive and source-constrained. The heterogeneous nodes, which provide data filtering, fusion and transport, are more expensive and more robust. A considerable number of Heterogeneous Wireless Sensor Networks (HWSNs) have been developed by Du *et al.* (2008), who provide examples of two real sensor-network deployments that utilise heterogeneous nodes for processing and transport tasks. Some routing protocols have also been proposed in the heterogeneous network environment, such as Stable Election Protocol (SEP) proposed by Smaragdakis *et al.* (2004), Energy Efficient Heterogeneous Clustered Scheme (EEHC) proposed by Kumar *et al.* (2009), Distributed Energy Efficient Clustering (DEEC) proposed by Qing *et al.* (2006) and energy efficient cluster head election protocol (LEACH-HPR) proposed by Han (2010). Stable Election Protocol (SEP) proposed by Smaragdakis *et al.* (2004) is among the first energy-efficiency routing protocols that used a heterogeneous network, in the sense that selection probabilities were weighted by the initial energy of the node relative to that of the other nodes in the network. The SEP protocol was improved of LEACH protocol in energy heterogeneous wireless sensor network. SEP is a two-level heterogeneous WSN that is composed of two types of nodes according to the initial energy: Normal nodes and second nodes, which are advanced nodes with higher initial energy. A SEP may extend the lifetime of the network, but it cannot be applied to multilevel heterogeneous WSNs. Energy Efficient Heterogeneous Clustered Scheme (EEHC) proposed by Kumar *et al.* (2009) is a three-level heterogeneous WSN. In this model, m is the fraction of the total number of nodes n and m_0 is the percentage of the total number of nodes m that is equipped with β times more energy resources than the normal node; these are called super nodes. The remaining $(1-m_0)*m*n$ nodes are equipped with α times more energy than the normal nodes and are known as advanced node; the remaining $n*(1-m)$ nodes are normal nodes. In the clustering process, the CH node was selected randomly without inclusion of the remaining energy level available in each node. As a result, each node will suffer its rest energy in that round and will die in the next round due to insufficient energy. It is because the node with much energy probably not selected as the CH node but on contrary, a node with minimum energy may become CH for that round. EEHC may extend network lifetime and are suitable for multilevel heterogeneous WSNs. DEEC (Qing *et al.*, 2006) is a distributed energy-efficient clustering algorithm for two level HWSNs which based on clustering. The CH node selection is based on probability which considering the ratio between residual energy of each node and the average energy of the network. The nodes with high initial and residual energy will have more chances to be the CH node than low-energy nodes. Thus DEEC can prolong the net study lifetime by heterogeneous aware clustering algorithm. This choice penalizes always the advanced nodes, especially when their residual energy depletes and become in the range of the normal nodes. In this situation, the advanced nodes die quickly than the others. Han (2010) examined multiple-hop routing in a clustering algorithm for HWSNs and proposed a three-level heterogeneous network. The nodes organize themselves into local clusters, with one node acting as the CH node in each cluster. Each node will have timer according to its remainder energy. The rule is, the more remainder energy, the less time of its timer. The node has more remainder energy will be selected as the CH node. Each CH finds its own optimum path to the sink node using a minimum spanning tree algorithm. As a result, more time step is needed in transferring the data from the sensor node to the sink node. Hence, it will increase the throughput of the network. LEACH-HPR is more efficient to prolong the lifetime of WSN but need to consider the delay time problem in the network.

In this study, we propose an approach that prolongs the lifetime of WSNs through a node-clustering algorithm. Clusters were formed in each iteration by rotating the CH among all nodes. CHs were selected based on the remaining energy of each node and then the cluster was organised by considering the distance between ordinary member nodes and their CH (we assume the sensor node uses the GPS). Consequently, the data collected from the CHs was transmitted to the sink node using relay node selection scheme.

SYSTEM MODEL

A Relay-ETLE protocol was considered in the heterogeneous network. The network is organised into a clustering hierarchy and the cluster head collects measurement information from the cluster nodes and transmits the aggregated data to the sink node. The CH node uses relay node selection scheme for data transmission. All of the nodes in the WSN are heterogeneous with respect to their initial amount of energy. Here, we explain the conceptual model in detail.

Radio energy model: The energy consumed by sensor nodes in WSNs can be calculated using the energy model proposed by Heinzelman *et al.* (2002). The energy consumed while sending k bits of data over a distance d was calculated using (1). The distance threshold value d_0 will differentiate among types of data communication. The first equation is called the free-space model, in which the transmission power is attenuated d^2 for $d<d_0$. The second equation is called the multi-path fading model, in which transmission power is attenuated d^4 for $d>d_0$. Note that the energy consumed during the communications process is not considered in our experiments because we assume that the energy used to send data packets and that the energy used by the communication process is the same for all algorithms:

$$E_{Tx}(k,d)=\begin{cases} kE_{elec}+k\varepsilon_{friss-amp}d^2: & d<d_0 \\ kE_{elec}+k\varepsilon_{two-ray-amp}d^4: & d>d_0 \end{cases} \tag{1}$$

Consequently, the energy consumed when receiving k bits of data was calculated using (2):

$$E_{rx}(k)=E_{Rx\text{-}elec}(k)=kE_{elec} \tag{2}$$

where, E_{elec} indicates the energy consumed while transmitting or receiving a bit of data and are the two channel model parameters of energy needed for power amplification.

Optimum number of clusters: The selection of the optimum number of clusters, K_{opt} in a WSN depends on the location of the base station. The optimum cluster number of the network was determined by differentiating the total energy dissipated in the network with respect to the number of clusters. Consequently, the optimal number of constructed clusters can be calculated using (3) for a base station located at the centre of the sensing area (Smaragdakis *et al.*, 2004):

$$k_{opt}=\sqrt{\frac{2}{2\pi}}\frac{M}{d_{toBS}}=\sqrt{\frac{2}{2\pi}}\frac{2}{0.765} \tag{3}$$

where, n is the number of sensor nodes in the network, d_{toBS} is the distance of sensor nodes to the sink node and M is the area of the network. If the base station is located outside of the sensed area, the optimum cluster number of the network can be calculated using (4) (Heinzelman *et al.*, 2002):

$$k_{opt}=\sqrt{\frac{2}{2\pi}}\sqrt{\frac{\varepsilon_{friss_{amp}}}{\varepsilon_{two_{ray_{amp}}}}}\frac{M}{d_{toBs}^2} \tag{4}$$

Calculating K_{opt} is particularly valuable in managing the energy consumption of the network. If the number of clusters in the network is not constructed in the optimum way, the energy consumed will increase exponentially when the number of clusters created is greater or less than K_{opt}. In an adaptive scheme, it is particularly valuable to calculate the optimal probability, P_{opt} of a node becoming a cluster head as follows:

$$p_{opt}=\frac{k_{opt}}{n} \tag{5}$$

The heterogeneous epoch concept: Figure 1 illustrates the heterogeneous epoch concept for a homogeneous and heterogeneous iteration for m_o and m_1 = 0.1, α = 1 and P_{opt} = 0.1. We defined x = r mod $1/P_{opt}$ and x' = r mod $1/P_{common}$ or r mod $1/P_{more}$ or r mod $1/P_{most}$.

Figure 1 shows a different concept of this type of iteration. If we consider a homogeneous scenario, then the epoch would be equal to $1/P_{opt}$ = 10 iterations. Therefore, on average, 10 nodes must become cluster heads per iteration. In our three-level heterogeneous case, the extended heterogeneous epoch is equal to $1/P_{common}$ = 11 iterations, each sub-epoch is equal to

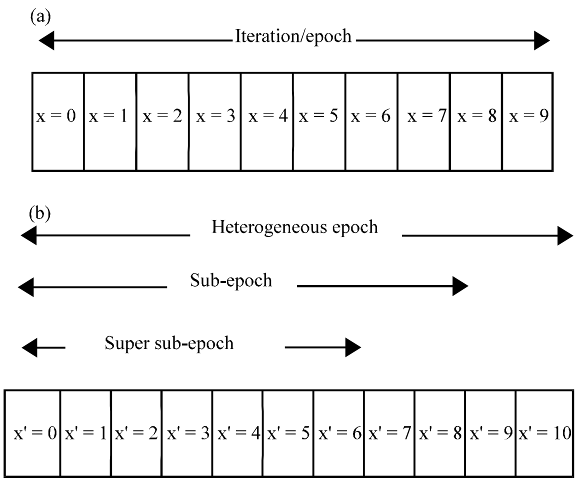

Fig. 1(a-b): A numerical example of the heterogeneous epoch concept for, (a) Homogeneous iteration and (b) Heterogeneous iteration

$1/P_{more}$ = 8 iterations and the super sub-epoch is equal to $1/P_{most}$ = 6 iterations. On average, $n*(1+(m_0+m_1))*P_{common}$ = 7 normal nodes become cluster heads per iteration and each one of them becomes a cluster head exactly once within 11 iterations. Furthermore, on average, $n*m_0*P_{more}$ = 1 advanced node becomes a cluster head per iteration and $n*m_1*P_{most}$ = 2 super advanced nodes become cluster heads per iteration. The total number of sensors that become the cluster head (common-energy nodes, more-energy nodes and most-energy nodes) is equal to 10, which is the desired number. The more-energy nodes will become the cluster head exactly once every sub-epoch and the most-energy nodes will become the cluster head exactly once every super-sub-epoch.

PROTOCOL DESCRIPTION

Here, we describe a Relay-ETLE protocol. The Relay-ETLE protocol for WSNs features periodic iteration; each iteration is divided into three different phases known as the cluster-head selection, cluster-formation and data-communication phases. To some nodes, a percentage of energy was added to generate the energy heterogeneity in the network. We use m to represent the percentage of nodes and α to represent the energy multiplication factor of the nodes. Normally, in a cluster-based network, some nodes will be selected as the cluster head. The cluster head will aggregate the sensing data of its cluster members and transmit it to the sink node. The cluster head uses relay node selection scheme to send data to the sink node.

For a homogeneous network such as LEACH protocol, it is guaranteed that every node has a chance of becoming a cluster head once every $1/P_{pot}$ iteration. In the heterogeneous scheme, the number of iterations is referred to as an epoch. The epoch concept is particularly valuable in balancing the average total number of cluster heads per iteration per heterogeneous epoch. Relay-ETLE is a network-layer protocol and this study discusses only the network layer. As in presented by Liu and Li (2009), an ideal MAC and error-free communication links are assumed.

Cluster-head selection phase: The network was formed by a three-level energy scheme. The first nodes are called the most-energy nodes, with m_1 percent of n nodes, which have α more times energy. These are followed by more-energy nodes, with m_0 percent of n nodes, with α/2 more times energy and finally common-energy node, with $(1-(m_0+m_1))$ percent of n nodes, which have an initial energy E_0. Suppose that E_0 is the initial energy of each common-energy node. Consequently, the energy of each more-energy node is $E_0\,(1+\alpha/2)$ and that for each most-energy node is $E_0\,(1+\alpha)$. As a result, the total energy of the new heterogeneous setting can be obtained as follows:

Total energy = Common energy nodes+More energy nodes+Most energy nodes

$$
\begin{aligned}
&= n.(1-[m_1+m_0]).E_0 + n.m_o.E_0.\left(1+\frac{\alpha}{2}\right) + n.m_1.E_0.(1+\alpha) \\
&= n.(1-[m_1+m_0]).E_0 + n.m_o.E_0.\left(1+\frac{E_0\alpha}{2}\right) + n.m_1.(E_0.+E_0\alpha) \qquad (6) \\
&= n.E_0 + n.m.\frac{E_0\alpha}{2} + n.m_1.E_0.\alpha = nE_0\left(1+\alpha\left(\frac{m_0}{2}+m_1\right)\right)
\end{aligned}
$$

From system (6), it follows that the total energy of the network increases by a factor of $(1+\alpha(m_0/2+m_1)$ in the network, virtually there are $n^*\,(1+\alpha(m_0/2+m_1)$ nodes, with energy equal to the initial energy of a common-energy node. In the network, it is necessary to maintain the minimum energy consumption for each iteration within an epoch. As a result, the average number of cluster heads must be constant and equal to n x P_{opt} for each iteration within an epoch. Consequently, for example, among the common-energy nodes there are:

$$n \times P_{opt} = \left(n * \left(1 + \alpha \left(\frac{m_0}{2} + m_1 \right) \right) \right) * P_{common}$$

cluster heads per iteration per epoch. The weighted probabilities of the common-energy nodes, more-energy nodes and most-energy nodes are determined as shown in Eq. 7-9:

$$P_{common} = \frac{P_{opt}}{1+\alpha\left(\frac{m_0}{2} + m_1\right)} \quad (7)$$

$$P_{More} = \frac{P_{opt}}{1+\alpha\left(\frac{m_0}{2} + m_1\right)} \times \left(1 + \frac{\alpha}{2}\right) \quad (8)$$

$$P_{More} = \frac{P_{opt}}{1+\alpha\left(\frac{m_0}{2} + m_1\right)} \times (1 + \alpha) \quad (9)$$

where, P_{opt} is the probability of each node becoming a cluster head in the network. In addition, a deterministic cluster-head selection (Handy *et al*., 2002) has been used to calculate the threshold, T(n), in each iteration as follows:

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left(r \bmod \dfrac{1}{P}\right)} \dfrac{E_{ncurrent}}{E_{n_{max}}} & \text{if } s \in G \\ 0 & \text{oterwise} \end{cases} \quad (10)$$

where, $E_{n\_current}$ is the current energy, E_{n_max} is the initial energy of the node, G is the set of nodes that have not become cluster heads within the last 1/p iterations and r is the current iteration number (starting from iteration 0). Then, for each iteration, the P value will be replaced by equation 4 for common-node cluster-head selection as shown in Eq. 11. If a node is selected as the cluster head during the current iteration, it will not be a cluster head in later iterations. However, for nodes that have not yet been selected as the cluster head (set G), their probability of becoming a cluster head increases during each iteration within the same epoch. Each node sϵG will independently chose a random number between 0 and 1. A node will be selected as the cluster head for the current iteration if the random number it selects is less than T(n):

$$T(S_{cmn}) = \begin{cases} \dfrac{P_{common}}{1 - P_{common}\left(r \bmod \dfrac{1}{P_{common}}\right)} \dfrac{E_{n_{current}}}{E_{n_{max}}} & \text{if } S_{common} \in G \\ 0 & \text{oterwise} \end{cases} \quad (11)$$

where, G' is the set of nodes that have not become cluster heads within the last $1/p_{common}$ iterations of the epoch and $T(S_{cmn})$ is the threshold applied to a population of $n.(1\text{-}[m_1{+}m_0])$ nodes. This approach will guarantee that each common node will become a cluster head exactly once every:

$$1/P_{opt}.\ 1+\alpha\left(\frac{m_0}{2} + m_1\right)$$

iteration per epoch and that the average number of cluster heads that are common nodes per iteration per epoch is equal to $n.(1\text{-}[m_1{+}m_0]) \times P_{common}$. The same procedure is also used for both types of nodes.

After considering the number of cluster heads for each type of node, the average total number of cluster heads per iteration per heterogeneous epoch is equal to

$$n \times P_{opt} = n.(1 - [m_1 + m_0]) \times P_{Common} + n.m_0 \times P_{more} + n.m_1 \times P_{most} \quad (12)$$

Cluster formation phase: After the cluster head is selected, each non-cluster-head node determines to which cluster it belongs by choosing the cluster head that requires the minimum communication energy, based on the received signal strength of the transmission from each cluster head. Note that typically this will be the cluster head closest to the sensor node. Consequently, non-cluster-head nodes will measure the approximate distance d between all cluster heads selected and itself. After making a decision, the non-cluster-head nodes will transmit a joint-request message to the chosen cluster head. This message contains a node's ID and the cluster head's ID. There is no restriction on the number of nodes in each cluster of the network.

Data communication phase: After cluster formation is complete, all living nodes for each cluster will periodically collect data and send them to the cluster-head node. The cluster head node will collect all of the data and send them to the relay node (RN). Consequently, the RN send the data to the sink node. The selection of CH as the RN has been done by using the highest energy level relay selection algorithm as outlined in Fig. 2.

```
Measure the residual energy for each selected CH
Identify the highest residual energy CH
Extract ID, distance of highest residual energy CH
Selection CH as the RN
All the selected CH will send data to the RN
RN submit data by the selected CH to the sink node
```

Fig. 2: The pseudo code for highest energy level relay selection

MODEL EVALUATION

Here, we discuss the simulations setup, assumptions and simulation results.

Simulation setup: One hundred sensor nodes were simulated in a wireless sensor network with field dimensions of 100×100 m. The packet length was 4000 bits. All of the nodes were deployed randomly over a square area. The heterogeneity value of m_1 and m_0 was 0.1 and α is 1. The initial energy is 0.5 J. The sink node was located outside of the sensing area [50, 150]. The optimal probability, p_{opt}, was 5%. Finally, we used radio transmission in our model, as presented in Table 1.

Assumption: To evaluate the network model, we made the following assumptions:

- The fixed sink node is located far away with an unlimited supply of energy
- All of the sensor nodes are distributed randomly and are not mobile
- All sensor nodes have limited power resources and recharging the batteries is impossible
- The MAC is ideal and the communication links error-free

Simulation results: the performance of our proposed protocol was simulated in MATLAB. We use '0' to denote a common-energy node, '+' a more-energy node, '*' a most-energy node and 'x' the sink node. The ch selection was performed over several iterations in each phase as shown in Fig. 3. In each iteration, a node was determined to be a CH with probability T(n). In the first iteration, the CH probability was determined according to the adoption of each type of node into Eq. 10. For example, T(n) for the normal nodes is calculated as shown in Eq. 11. Because T(n) is a function of the remaining energy, the nodes with higher residual energy have a greater chance of becoming current_selected CHs.

As shown in Fig. 3a, in the first iteration, 8 nodes were selected as CHs; the non-CH nodes in their cluster are shown as being connected to these CHs. If non-CH

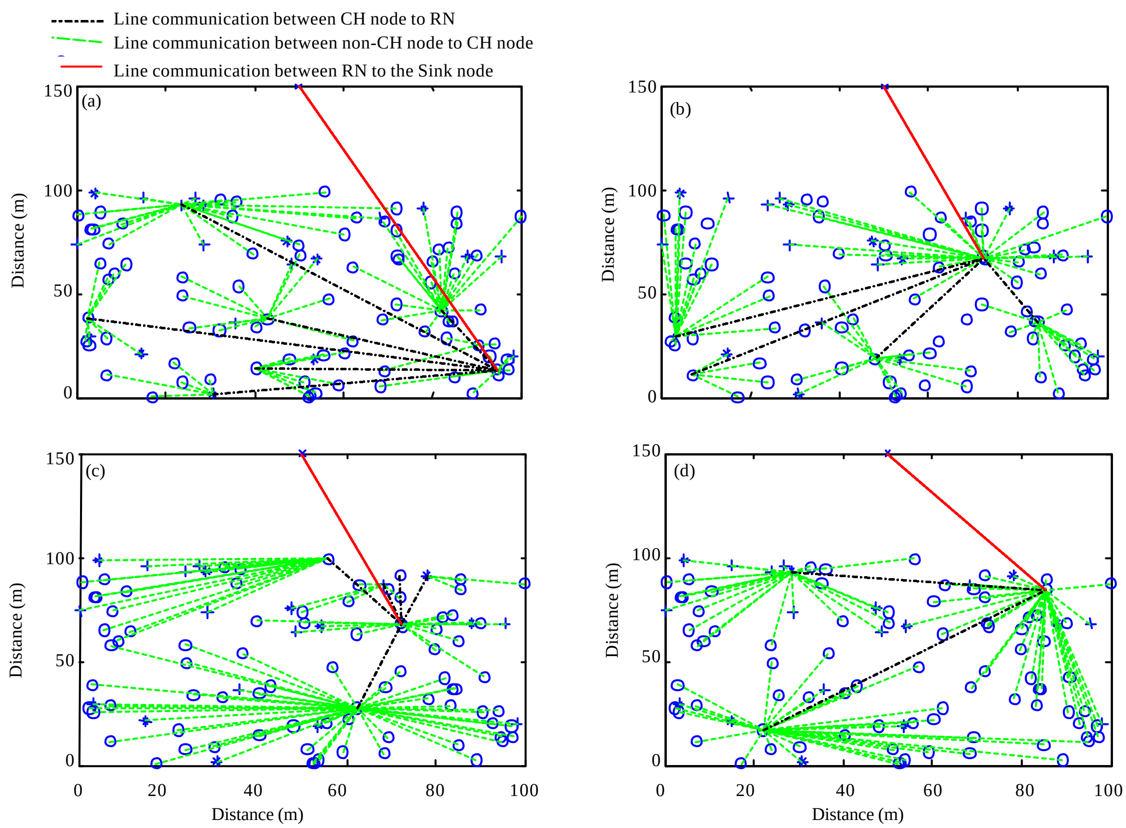

Fig. 3(a-d): Snapshots of the, (a) First, (b) Second, (c) Third and (d) Fourth iteration of the network when CHs aggregate data from node members (non-CH node) in the cluster and RN send information to the sink node

Table 1: The energy characteristics for the radio model*

Characteristics	Energy
Transmitter/receiver electronics, E_{elec}	50 nJ/bit
Data Aggregation, E_{DA}	5 nJ/bit/report
Power amplification,	10 pJ/bit/m^2
Power amplification,	0.0013 pJ/bit/m^4

*Heinzelman *et al.* (2002)

nodes receive advertisement messages from multiple CHs, then the cluster head closest to the non-CH nodes is used to select the best CH. Consequently, all the selected CHs were send data to the RN. In the following iterations, T(n) was doubled for each node and the same procedure was repeated. As shown in Fig. 3b, the RN was changed and 5 nodes were selected as CH nodes. After a limited number of iterations, Relay- ETLE results in a topology in which each node is a CH node, non-CH node or RN, as shown in Fig. 3c-d.

Accordingly, the cluster is formed. The iteration procedure ensures that within a limited number of iterations, the clustering algorithm converges. After the clusters are formed, intracluster communication is maintained by the CHs and each member can forward its data to its CH. Finally, the RN will collect the data from CHs and forward to the sink node.

Comparison with other protocols: Here, the Relay-ETLE protocol is compared with EEHC and LEACH. The LEACH protocol has been modified into heterogeneous network form. The performance comparison of all protocols is evaluated on the criterion of network lifetime.

The network lifetime is the time elapsed between network start-up and when the first node is disconnected from the network due to battery exhaustion. From Fig. 4 and Fig. 5, the first node death occurs in Relay-ETLE protocol after 1003 iterations and 911 iterations for network size of 100 nodes and 200 nodes respectively. Under first node death criterion, Relay-ETLE extends the network lifetime approximately 78% compared to EEHC and 22% compared to LEACH for network size 100 nodes. In networks size 200 nodes, the Relay-ETLE extend the network lifetime approximately 62% compared to EEHC and 14% compared to LEACH. These results clearly demonstrate that Relay-ETLE enhances network life significantly as compared to other protocols because its sensor-node density for higher-energy nodes (more- and most-energy nodes) is higher than that implemented in EEHC. Additionally, Relay-ETLE considers the remaining energy for each node during CH selection, which may extend the lifetime of the network which not consider in LEACH and EEHC. Moreover, the implementation of relay node selection scheme for intercluster transmission will extend the lifetime of the network.

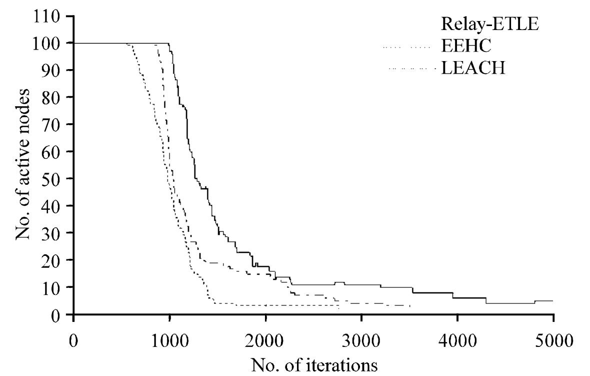

Fig. 4: The network lifetimes of Relay-ETLE, EEHC, EEHC and LEACH algorithms for 100 nodes

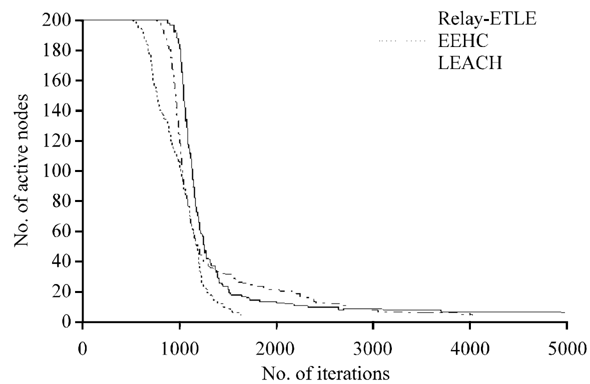

Fig. 5: The network lifetimes of Relay-ETLE, EEHC and LEACH algorithms for 200 nodes

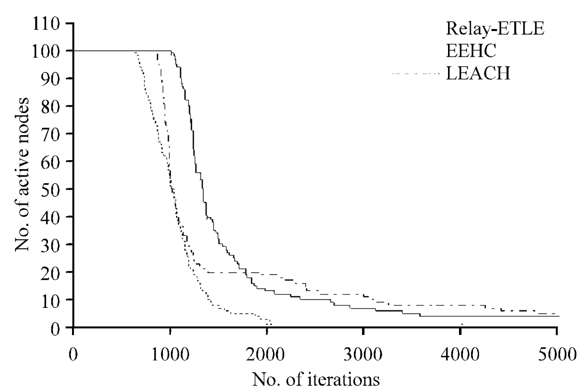

Fig. 6: performance of Relay-ETLE, EEHC and LEACH under 3 level heterogeneous networks m = 0.1 and $\alpha = 2$

Consequently, the lifetime of the network has been compare, where the extra initial energy of most and more energy nodes is uniformly distributed over all nodes in the sensor field. Figure 6 shows the result for the case

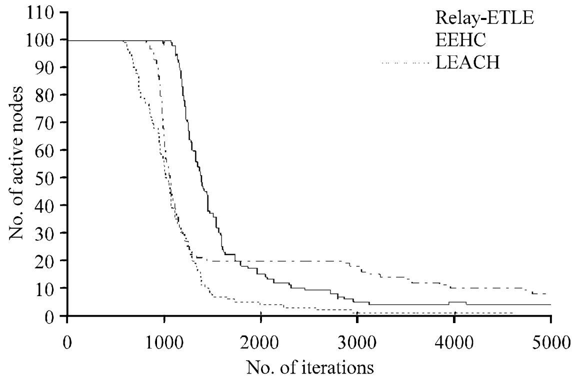

Fig. 7: Performance of Relay-ETLE, EEHC and LEACH under 3 level heterogeneous networks m = 0.1 and $\alpha = 3$

m = 0.1 and $\alpha = 2$. Under first node death criterion, Relay-ETLE extends the network lifetime approximately 56% compared to EEHC and 17% compared to LEACH. As shown in Fig. 7, the Relay-ETLE takes full advantages of heterogeneity (extra energy of most and more energy nodes) which extend the network lifetime approximately 87% compared to EEHC and 31% compared to LEACH.

CONCLUSION

The energy limitation of sensor nodes affects the lifetime of the wireless sensor network, a clustering algorithm was developed by considering a three-level heterogeneous network, the residual energy of each node during CH selection, adaptive organisation of the cluster and relay node selection scheme. A three-level heterogeneous network was formulated for cluster-head selection. During CH selection, the residual energy of each node was considered. A node with more residual energy is allocated a higher probability to become a CH. During cluster organisation, the distance between ordinary member nodes and their CH is taken into account to further extend the stable operational period of the network. During data transmission, the most-energy CH was selected as the RN. We compared our proposed protocol with EEHC and LEACH protocol. As a result, Relay-ETLE enhances network life significantly as compared to other protocols. Under first node death criterion, Relay-ETLE extends the network lifetime approximately 78% compared to EECDA and 22% compared to LEACH. The relay-ETLE assumes that the MAC is ideal, which the communication links is error-free. Future research will investigate the energy efficiency with the MAC consideration.

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