A ZONE-BASED DISTRIBUTED CLUSTERING METHODOLOGY TOWARDS WIRELESS SENSOR NETWORK

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Abstract
Much of the energy consumption takes place during wireless communication. An efficient way to reduce energy usage is to group the sensor nodes into several clusters and each individual cluster has a cluster head. The cluster head forwards the aggregated data to the base station. In distributed clustering, the cluster head changes from one node to another node based on some parameters. In most of the distributed clustering mechanisms, every sensor nodes use same amount of power for communicating with the cluster head and base station. A distributed clustering methodology, the variable power energy efficient clustering (VEEC) mechanism has been proposed. The proposed algorithm is a well distributed and energy efficient clustering algorithm which employs relay nodes, variable transmission power and single message transmission per node for cluster set-up. The performance of the proposed methodology is compared with two existing distributed clustering algorithms LEACH and HEED. The proposed methodology depicts an improvement in average communication energy and total system energy consumption. Ultimately, the overall network lifetime is much prolonged in VEEC methodology.

Keywords: Distributed clustering algorithm, energy efficiency, network lifetime.

1. INTRODUCTION

Energy efficiency can be accomplished at different levels starting from the physical layer, Media Access Control (MAC) layer and routing protocols up to the application level as specified by (Akyildiz et al 2002). To trim down the data transmission time and energy consumption, the sensor nodes are clustered into miniature clusters. This mechanism of grouping of sensor nodes into small-sized clusters is known as clustering, with each cluster having an individual cluster head. The CH forwards the aggregated data to the base station. The main drawback faced by many clustering methodologies is that every nodes use same amount of transmission power as worked out by (Pedro et al 2011; Younis et al 2003; Alain and John 2010; Banerjee and Khuller 2001; Chia and Yu 2012). In case of many clustering methodologies, the nodes that are nearer to the CH and those farther from the CH use the same transmission power. Also the CHs that are nearer to the base station and those farther from the base station use the same transmission power. To overcome this problem, the wireless sensor field could be divided into different regions (zones). The nodes in the zone nearer to the base station can use minimum transmission power and the nodes in the zone farther from the base station could use maximum transmission power [1-12]. By using this concept, energy wastage could be reduced to a greater extent. In this chapter, a zone-based distributed clustering methodology, the hybrid energy efficient clustering algorithm (HEECA) has been proposed, employing three novel methodologies: zone based transmission power (ZBTP), routing using distributed relay nodes (DRNs) and rapid cluster formation (RCF), for effectively connecting two separate wireless sensor network fields. The primary objective of the proposed algorithm is to achieve energy efficiency and extended network lifetime, when two far-away located WSN fields are to be effectively connected together for cooperative communication. The performance evaluation of the proposed distributed clustering algorithm is done against the two well evaluated existing algorithms O-LEACH and HEED.

2. LITERATURE REVIEW OF existing CLUSTERING METHODOLOGIES

In last few decades, research efforts have been taken to reduce the energy consumption and to prolong the lifetime of WSN. The algorithms described here are entirely distributed and the CH changes from node to node based on few parameters, and varies by the methodology by which the CH is selected [13-23]. ACE is a highly uniform clustering, lesser overlapping, efficient coverage and self-organizing cluster forming algorithm for WSN. In a distributed clustering algorithm, the nodes make autonomous decisions. In Hausdroff Clustering, once cluster formation takes place it remains unchanged throughout the network lifetime. Clustering methods have reduced the energy utilization in WSN. RECA uses deterministic CH management methodology to evenly distribute the work load among the nodes within a cluster. The CLUBS algorithm is capable of forming clusters through local broadcast and converges in time proportional to the local density of the nodes. MOCA is a randomized and distributed clustering mechanism for grouping the nodes into overlapping clusters. DWEHC is a well distributed clustering algorithm for organizing the sensor nodes into well-balanced clusters. The two distributed clustering algorithms that have fallen into the research interest are O-LEACH and HEED. In O-LEACH algorithm, the infrastructure of sensor network is composed of a distributed optical fiber sensor link and two separate WSN fields.

Though O-LEACH algorithm is comparatively much more energy efficient, the main drawback of this approach is the random selection of CHs. In the worst case, the CH nodes may not be evenly distributed among the nodes and it will have its effect on the data gathering. Also, distributed optical fiber sensor link is used to connect two separate wireless sensor fields. The aggregated data is forwarded from CH to the BS through this DFS link. The installation cost of this DFS link is costly and keeps on increasing with increase in communication distance. For transmitting the data over this DFS link, the data have to be converted into light. As the data has minimum energy level, the losses associated with the fiber are higher. It becomes necessary for replacing the optical fiber with some wireless medium for connecting two wireless sensor fields.

HEED is a distributed clustering methodology in which the cluster head selection is on the basis of both the residual energy and communication cost. In general, the algorithm HEED was proposed to avoid the random selection of CHs when compared to O-LEACH algorithm. The three subsequent phases of execution of HEED are the initialization phase, the repetition phase and the finalization phase. During the initialization phase, the percentage of CH nodes is given to the sensor nodes initially, where each sensor nodes compute its probability to become a CH. In repetition phase, a CH with least transmission cost will be sorted out, and in finalization phase the CH selection will be properly finalized. The main disadvantage of HEED is that, the phases (especially the repetition phase) consume much energy as it takes longer time duration to finalize a node with minimum cost. Also, all the nodes in the network use same amount of communication energy [24-32]. Therefore, a methodology to reduce communication energy and selecting a CH in very short duration has to be worked out.

3. THE PROPOSED HEECA ALGORITHM

The proposed algorithm, hybrid energy efficient clustering algorithm (HEECA) is a well distributed clustering algorithm in which the sensor nodes are deployed randomly to sense the target environment for two separate wireless sensor fields. The two separate WSN fields are connected together with the help of distributed relay nodes. The sensor network is partitioned into clusters with each cluster having an individual CH. The nodes send the information during their TDMA time-slot to their respective CH which aggregates the data to avoid redundant information by the process of data aggregation. The aggregated data is then forwarded to the distributed relay nodes which in turn routes the data to BS by forwarding through other distributed relay nodes. Every single round in the clustering mechanism in the proposed HEECA algorithm is partitioned in to two time slots (duration): Network Formation Time (NFT) and Network Relaying Time (NRT). The whole

WSN fields automatically get organized into three different energy zones: small energy zone (SEZ), moderate energy zone (MEZ) and highest energy zone (HEZ). During NFT, the finalized cluster heads get selected for the current round. During NRT, data transmission from cluster heads to the base station occurs via the distributed relay nodes. NFT and NRT get repeated for every successive rounds.The proposed algorithm HEECA has three main peculiar features.

First, HEECA employs zone based transmission power. The entire sensor field gets divided in to three energy zones: SEZ, MEZ and HEZ. The nodes in SEZ use less power for communication and the nodes in HEZ use maximum power for communication. In the existing algorithms, every sensor nodes use same power (the power usage similar to HEZ nodes in HEECA).

Second, CHs does not forward the data directly to the BS, instead the cluster head forwards data packets to the DRNs, and these dedicated distributed relay nodes routes data to the BS, thereby considerable energy utilization can be reduced. Third, the rapid cluster formation technique selects CH in just three stages, but the existing mechanisms use several stages to select a CH. HEECA use distributed relay nodes to connect two sensor fields, but in the existing O-LEACH algorithm, optical fiber is used which encounters higher cost and greater losses during communication.

In HEECA, the deployed sensor nodes get automatically organized in to three different energy zones: small energy zone, moderate energy zone and highest energy zone. In HEECA, the base station is assumed to be located at the central position of the two WSN fields. Since the regular sensor nodes or CHs in the three zones communicate with the base station using different power levels on the basis of zone, the technique is commonly referred as zone based transmission power. A distributed relay node is a node which is comparatively rich in resources like battery, storage, etc. In general, similar to the normal wireless sensor nodes, DRNs are also battery operated devices employed mainly for wireless communication. The DRNs also minimizes the transmission distance between a pair of distantly located nodes by acting as a hop between them. The DRNs have better capabilities than the regular sensor nodes in terms of initial energy provisioning, transmission range and data processing capability.

The main benefits of using DRNs are to extend the lifetime of sensor networks, energy efficient and balanced data gathering, provide fault tolerance in sensor networks and to offer wireless connectivity between two distant WSN fields. In HEECA, the DRNs perform only one function that is to route the aggregated data from CH to the BS by forwarding through other DRNs. In HEECA, the DRNs are distributed evenly within the coverage range of the two WSN fields, but in the existing O-LEACH algorithm optical fiber is used for connectivity. If optical fiber is used for connecting two WSN fields, the fiber losses are more and thus leading to lower throughput which could be clearly seen from the simulation results. But DRNs provide effective data delivery to the base station with less loss. The deployment cost of DRNs is also less when compared to the optical fiber, as the coverage of each and every DRN is higher.

When compared to other distributed clustering mechanisms, the clustering happens in few stages, reducing the clustering time and thus referred as rapid cluster formation. HEECA considers four factors for selection of CHs: the initial energy of nodes, the residual energy of nodes, the average energy of every regions and location of the sensor nodes. The operation of HEECA happens on the basis of rounds, with adjustable time duration. Each round is divided into network formation time and network relaying time. During NFT, the CHs are selected and multiple clusters are fashioned in very little length of time. During NRT, the sensed information from all the sensor nodes will be transmitted to the base station with help of distributed relay nodes.

4. SIMULATION

The following assumptions are made in HEECA: (i) Sensor nodes, CHs, DRNs and BS are assumed to be stationary. (ii) DRNs are rich in energy and dedicated only for routing the aggregated data from CH to the BS. (iii) Nodes use variable power for transmitting the data (based on SEZ, MEZ and HEZ). (iv) Clustering process is purely distributed. (v) Clustering process terminates after particular interval of time. (vi) CHs have higher residual energy in comparison with any ordinary nodes. The simulations have been carried out using NS-2. For energy consumption, the first-order radio model has been employed. The proposed distributed clustering algorithm has been simulated with 30 nodes and at each time the energy utilization, node's residual energy, etc., are recorded. The performance of HEECA is compared with the two existing distributed clustering algorithms O-LEACH and HEED, based on the above recorded readings. The data collection process is said to be completed when the DRNs have completed forwarding data to the BS. The sensor nodes are deployed in a square sensing field (x, y) of 500 x 500 meter2. Once deployed the sensor nodes are assumed to be stationary (immobile). The DRNs are evenly distributed between the two WSN fields. The BS contains sufficient energy and at any cost energy scarcity does not occur. The sensor nodes have limited energy with initial energy of 1 Joule. When the residual energy of a node is dropped to 0 Joule, the sensor node is considered to be dead. The DRNs are assumed to be in sleep mode till the CHs send data to them. The main feature of the proposed algorithm is that, CHs does not forward all the data collected from the sensor nodes to the DRNs. Instead, it compares the collected data with the threshold values and sends only limited number of data packets to the DRNs. Thus, redundant data packet transmission is avoided, which reduces energy utilization and increases the network throughput. The DRNs forward the data received from CH to the BS by hopping through other DRNs.

The proposed algorithm HEECA is simulated and the results are recorded for various parameters, and these recorded values are compared with the existing distributed clustering algorithms O-LEACH and HEED. Figure 1 illustrates the performance evaluation of HEECA in terms of network lifetime in comparison with O-LEACH and HEED. The total energy spent in the system is the sum of sensing energy, processing energy, communication energy and the energy utilized for data aggregation for entire clusters in the wireless sensor system. In case of O-LEACH and HEED, the communication energy from CH to the base station increases based on the distance between them. When the wireless sensor field is considered to be dense with longer separation between the fields, much energy is used for communication between CH and the base station. As the number of cluster increases, the overall communication energy increases exponentially. In case of HEECA, the forwarding of the aggregated data from CH to the base station happens in a multihop manner through the DRNs. Also the concept of threshold extensively reduces unwanted transmissions, which is unavailable in both O-LEACH and HEED.

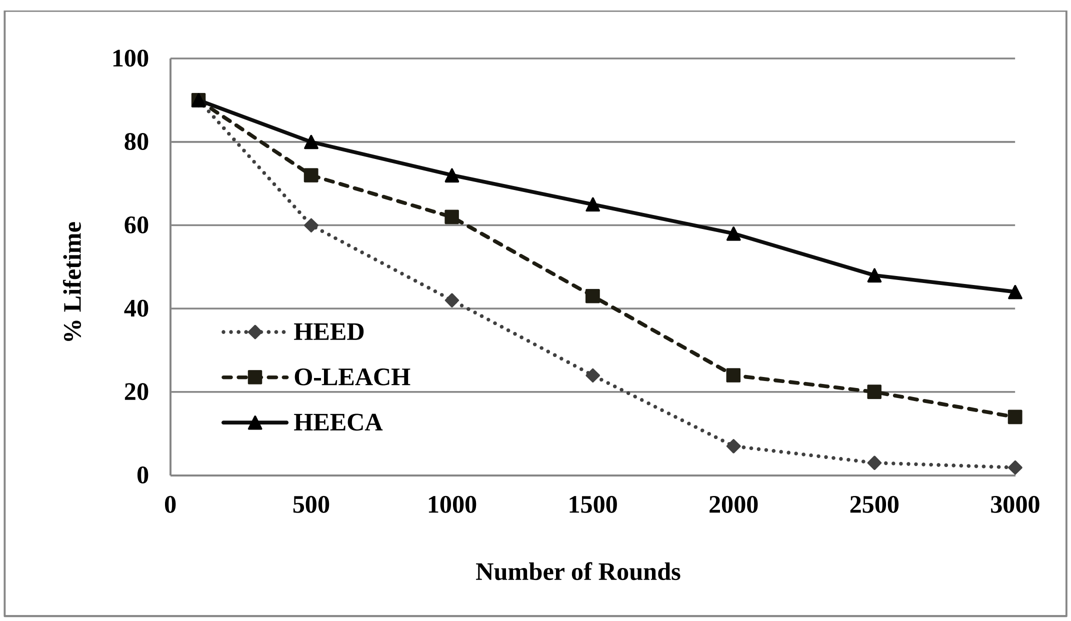

Figure 1: Lifetime versus Number of Rounds (HEECA, O-LEACH and HEED)

Initially at 100 rounds, the percentage lifetime is 90 for all the three algorithms. Considering the situation at 500 rounds, the percentage lifetime is 80 in HEECA, but in O-LEACH and HEED the percentage lifetimes are 72 and 60 respectively. This decrease (in O-LEACH and HEED) is mainly due to the exponential increase in communication energy.

Similarly in 3000 rounds, the percentage lifetime of HEECA is 44, but in the two existing algorithms O-LEACH and HEED, the percentage lifetime is found to be greatly reduced to 14 and 2 respectively. At an average, HEECA shows 50% and 29% lifetime improvement over HEED and O-LEACH respectively. This clearly shows that HEECA could be effectively employed in dense wireless sensor network.

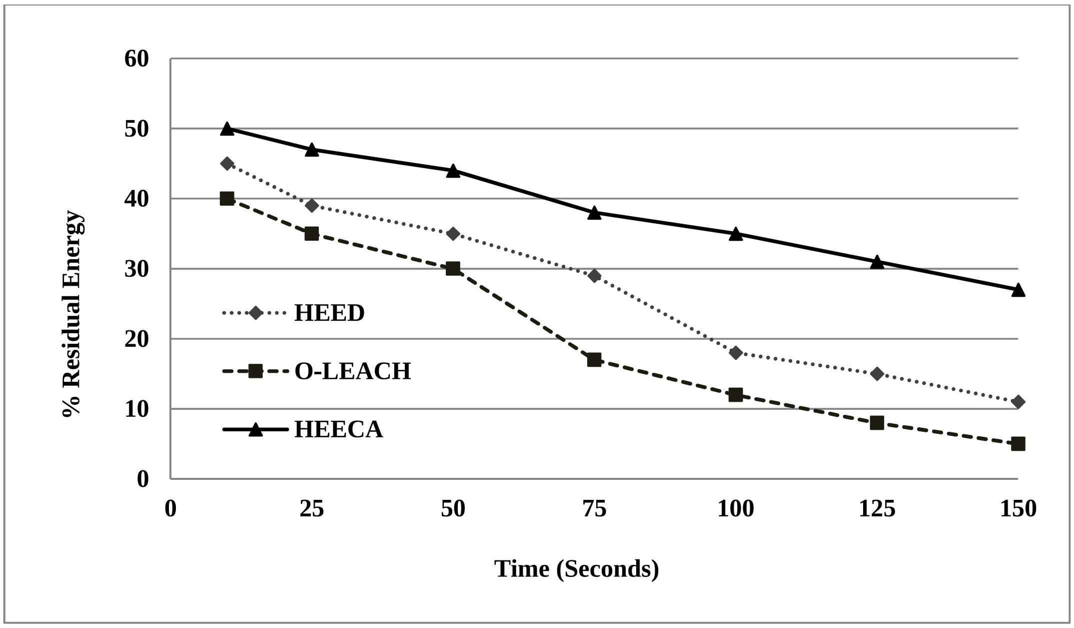

Figure 2: Residual Energy versus Time (HEECA, O-LEACH and HEED)

Residual energy is the total energy remaining within a particular node after particular number of rounds. An algorithm which maximizes the residual energy within a sensor node is said to be desirable. Figure 2 shows the performance evaluation of HEECA in terms of residual energy in comparison with O-LEACH and HEED. At particular instance of time, the total residual energy of all the nodes in the wireless sensor system is the difference between the total initial energies of all the nodes and the total communication energy. At 10 seconds, the percentage residual energies of O-LEACH, HEED and HEECA are 40%, 45% and 50% respectively. A 10% increase and 5% increase in residual energies is seen in HEECA in comparison with O-LEACH and HEED even at the very beginning, which is mainly due to the employment of zone-based transmission power. At 150 seconds, the percentage residual energies of O-LEACH, HEED and HEECA are 5%, 11% and 27% respectively. Thus the performance of HEECA is much improved in terms of residual energy until the last node stops functioning.

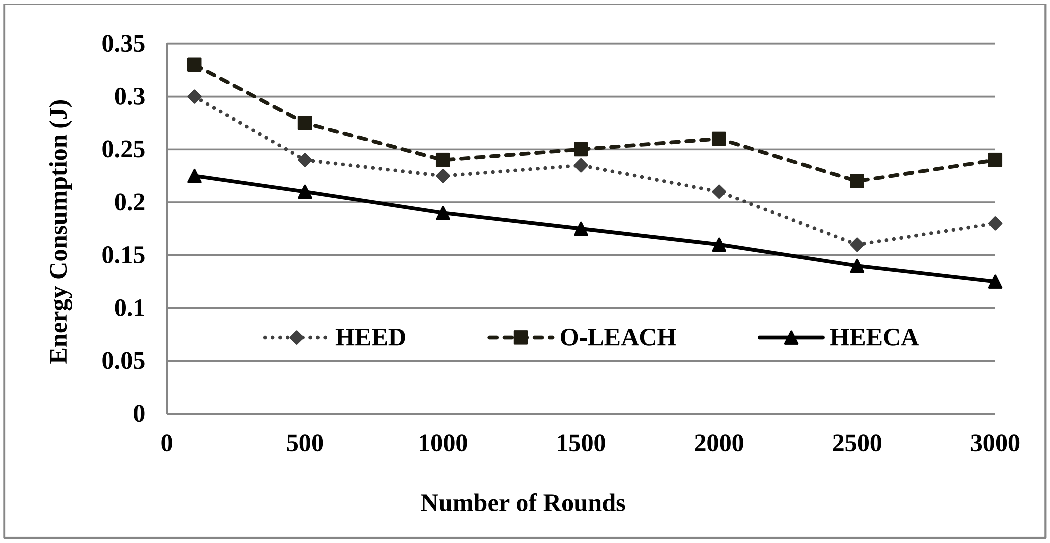

Figure 3: Energy Consumption versus Number of Rounds (HEECA, O-LEACH and HEED)

Figure 3 illustrates the performance comparison of HEECA in terms of energy consumption against O-LEACH and HEED. Initially at 100 rounds, the energy consumption of O-LEACH, HEED and HEECA are 0.33, 0.30 and 0.225 Joules respectively. From equation 4.17, the overall energy consumption of the two WSN fields, is due to the effect of total energy consumption of the wireless sensor nodes in the two fields and the distributed relay nodes. The energy consumption is greatly reduced at the DRN level in HEECA. At 3000 rounds, the energy consumption of O-LEACH, HEED and HEECA are 0.240, 0.180 and 0.125 Joules respectively. A reduction in energy consumption of 0.055 Joules and 0.115 Joules is seen in HEECA over HEED and O-LEACH at the final round. For a perfect and reliable sensor system, the slope of the resulting curve should be minimum with lesser irregularities.

HEECA displays better output when compared with the two existing algorithms. The energy consumption of HEECA is less when compared to O-LEACH and HEED. This lesser energy consumption is mainly achieved at the clustering level, DRN level and also due to zone based transmission power. Less energy is used by the nodes that are in SEZ and maximum energy is used only by the nodes that are in HEZ. But in the two existing algorithms, maximum energy (equal to the energy used by the HEZ nodes in HEECA) is used by every node in the wireless sensor network system.

Figure 4 illustrates the performance evaluation of HEECA in terms of throughput in comparison with O-LEACH and HEED. Initially at 100 rounds, the throughput of HEED, O-LEACH and HEECA are 22%, 32% and 40% respectively. An 18% and 8% difference in throughput is seen over HEED and O-LEACH very initially. HEECA employs hard threshold and soft threshold techniques, which reduces unwanted packet transmissions thereby leading to improved throughput. Also the data packets are transmitted by CHs to DRNs only at fixed intervals of time. At an average, 46% improvement and 22% improvement in throughput is seen in HEECA, over HEED and O-LEACH for every 3000 rounds. Thus in HEECA, the packets are more successfully delivered to the base station with lesser packet drop. Thus HEECA can be implemented in WSN fields, where throughput is a major parameter under consideration.

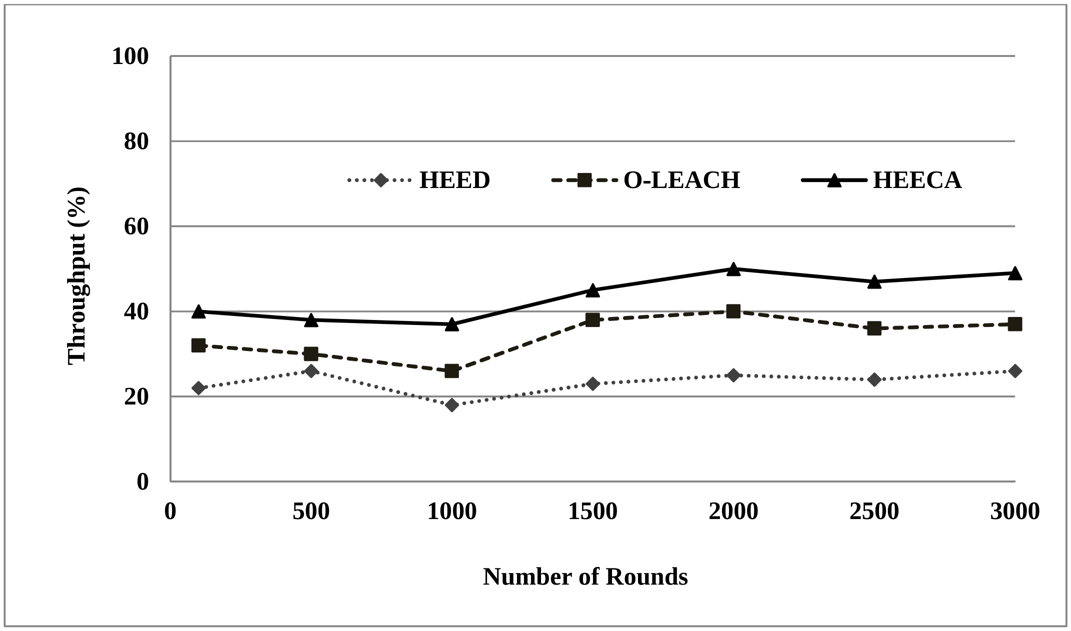

Figure 4: Throughput versus Number of Rounds (HEECA, O-LEACH and HEED)

5. SUMMARY

In this chapter, a methodology for evaluating the clustering efficiency, energy efficiency and lifetime of two separate wireless sensor network fields has been proposed. In the proposed HEECA methodology, the optical fiber link in the existing method is replaced by distributed relay nodes for connecting two separate wireless sensor network fields. Based on three novel techniques like zone based transmission power, routing using distributed relay nodes and rapid cluster formation, the proposed methodology has been well-evaluated for efficiency against the two distributed clustering algorithms O-LEACH and HEED.

Simulation results clearly show an excellent improvement in residual energy, throughput and energy efficiency. Also it is clearly seen that, the energy consumption by the nodes and the node death rate has been greatly reduced. Moreover, HEECA selects cluster heads effectively and packet loss is less while forwarding the packets from cluster head to the base station. Ultimately, the network lifetime greatly prolongs, thus HEECA can be employed for effectively connecting two separate wireless sensor fields with the aid of distributed relay nodes with reduced packet loss in comparison with the existing O-LEACH algorithm.

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