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CLUSTERING ARCHITECTURES FOR DENSE WIRELESS SENSOR NETWORKS

A MONOGRAPH

Written By

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ABSTRACT

A wireless sensor is a miniature component which measure physical parameters from the environment and transmit them to the monitoring station by wireless medium. In wireless medium, the sensor and its associated components are called as node. A node is self-possessed by a sensor, processor, local memory, transceiver and a low-powered battery.

To diminish the data transmission time and energy consumption, the sensor nodes are assembled into a number of little groups referred as clusters and the phenomenon is referred as clustering. Every cluster comprise of a leader which is known as cluster head. The cluster head will be chosen by the sensor nodes in the individual cluster or be pre-assigned by the user. The main advantages of clustering are the transmission of aggregated data to the base station, offers scalability for huge number of nodes and trims down energy consumption. Fundamentally, clustering could be classified into centralized clustering, distributed clustering and hybrid clustering. In centralized clustering, the cluster head is fixed. The rest of the nodes in the cluster act as member nodes. In distributed clustering, the cluster head is not fixed. The cluster head keeps on shifting form node to node within the cluster on the basis of some parameters. Hybrid clustering is the combination of both centralized clustering and distributed clustering mechanisms.

A distributed clustering methodology, the hybrid energy efficient clustering algorithm (HEECA) has been investigated. The proposed methodology is a well-distributed and energy-efficient clustering algorithm which employs three novel techniques: zone based transmission power (ZBTP), routing using distributed relay nodes (DRN) and rapid cluster formation (RCF). The proposed methodology is compared with the two well-evaluated existing distributed clustering algorithms O-LEACH and hybrid energy efficient

distributed clustering (HEED). The proposed methodology shows an improvement in residual energy, throughput and energy efficiency of the wireless sensor system. The clustering process could be effectively controlled, thereby the number of cluster head selection and the number of packets delivered to the base station shall be carried out effectively. Ultimately, the overall lifetime of the wireless sensor network is much improved. The distributed relay nodes employed in the proposed methodology could effectively connect two separate wireless sensor network fields with reduced packet loss and forms a better alternate to optical fiber link.

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.

A distributed clustering methodology, the energy efficient hierarchical distributed clustering algorithm (EHDCA) has been proposed. It is a well-distributed clustering mechanism and the cluster head selection is based on residual energy, communication cost and the distance to the base station. The main characteristic feature of the proposed methodology is the cluster head selection is carried out in just few steps. The performances of the proposed clustering methodology have been compared with LEACH. Its hierarchical nature shall be effectively employed for reduction in total energy consumption and backbone energy consumption. The energy efficiency and overall network lifetime shall be greatly improved.

A dynamic clustering algorithm for mobile wireless sensor networks, the mobility assisted dynamic clustering algorithm (MADCA) has been investigated and analysed properly. The proposed methodology is hierarchical, dynamic and energy efficient algorithm. This technique exhibits multiple clusters, with each cluster having one cluster head and two deputy cluster heads. The sensors start collecting the data only when the base station comes in range with the cluster head. The performance of the proposed algorithm has been evaluated against the existing LEACH-Mobile (LEACH-M) algorithm. This methodology shows a large reduction in average communication energy and node death rate. The network lifetime has been prolonged by integrating the novel concepts to the proposed methodology, thereby finds useful when both the sensor nodes as well as the base station are mobile. The research works reported in this monograph gives a clear view on the proposal of few distributed clustering methodologies and the manner by which the clustering parameters could be improved for both static and mobile wireless sensor networks. All the simulation works have been carried out using the network simulator (NS-2) and the results have been compared with the existing distributed clustering methodologies. Every modules concentrates mainly on the betterment of energy efficiency, throughput, clustering efficiency and network lifetime. Also, few future enhancements to this work have been entailed for giving further progression to these proposed distributed clustering methodologies.

Module 1

INTRODUCTION

GENERAL

Recent leading research topic that has been emerging is the wireless sensor network. They have enormous long-term economic potential, ability to transform lives and pose many novel system-building challenges. They also create a number of new conceptual and optimization problems such as location, deployment and tracking. The incorporation of multiple types of sensors such as seismic, acoustic, optical, etc., in a single network platform and the evaluation of the overall coverage of the system also presents numerous interesting challenges. The sensor-based military applications involves intrusion detection, perimeter monitoring, information gathering and smart logistics support in an unknown deployed area, sensor-based personal health monitoring, location detection with sensor network and movement detection using wireless sensor network as formulated by (Chang and Tassiulas 2004).

WIRELESS SENSOR NETWORK

Wireless Sensor Network (WSN) consists of a group of spatially distributed sensor nodes which are interconnected without using wires as worked out by (Hill 2000). Wireless sensor network has been originally motivated for the use in military applications like border monitoring. In recent years, it is mainly focused on civilian applications such as environment monitoring, object tracking and biomedical applications.

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Figure 1.1 depicts a typical wireless sensor network. Unlike centralized systems, the sensor network is subjected to a set of resource restrictions like finite on-board battery power and restricted communication bandwidth.

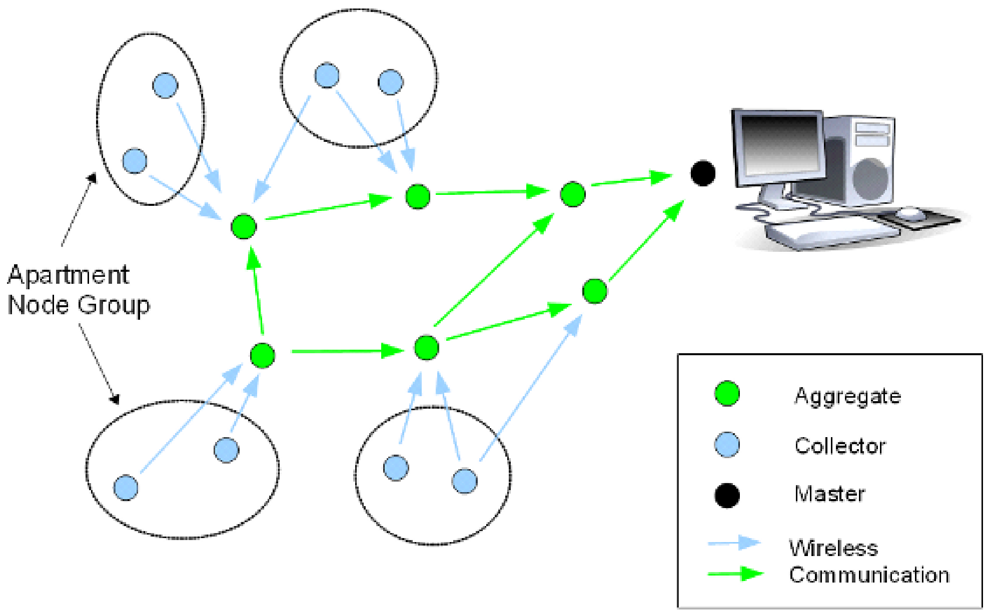

Figure 1.1 Typical Wireless Sensor Network

Sensor network inter-networks with an Internet Protocol (IP) core network via a number of gateways. A gateway routes queries or commands to appropriate nodes within a sensor network. It also routes sensor data, at times aggregated and summarized to users who have requested it or are expected to utilize the information. A data repository or storage service is available at the gateway, in addition to data logging at each sensor. The repository may serve as an intermediary between the users and sensors thereby providing persistent data storage. Additionally, one or more data storage devices are attached to the IP network to archive the sensor data from a number of edge sensor networks. One of the major advantages of wireless sensor network is their ability to operate in

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unattended, harsh environments in which existing human-in-the-loop monitoring schemes are uncertain, inefficient and sometimes impossible. Therefore, wireless sensors are expected to be deployed randomly in the predetermined area of interest by a relatively uncontrolled manner. Given the huge area to be covered, the short lifespan of the battery-operated wireless sensors and the possibility of having damaged sensor nodes during deployment, large population of sensors are expected in the majority of wireless sensor applications.

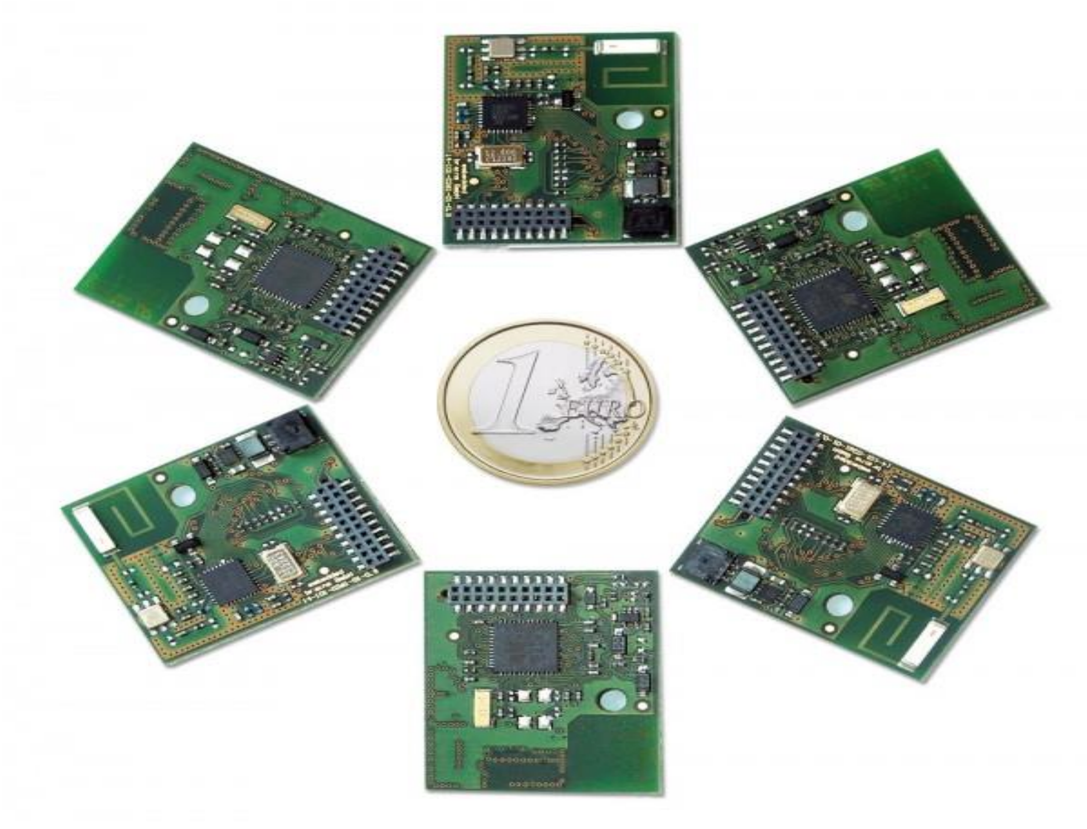

Figure 1.2 Wireless sensor node

The sensed data is collected, processed and then routed back to the desired end user through a designated sink point, referred as the base station (BS). It has become feasible to construct multifunctional sensor nodes with advanced capabilities. Such sensor nodes are relatively of smaller size, lower cost and lesser power consumption.

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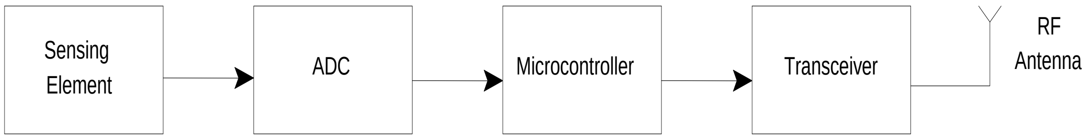

Figure 1.3 Internal Components of a Wireless Sensor Node

Figure 1.2 demonstrates a typical wireless sensor node. Figure 1.3 shows the internal components of a wireless sensor node. A typical sensor node consists of a sensing element, analog to digital convertor (ADC), microcontroller and a transceiver. The sensing element converts the physical parameters such as temperature, humidity, etc., to an equivalent electrical signal. The analog signal is then converted to an equivalent digital signal using the analog to digital convertor.

The processing of the digital signal is done by the microcontroller. The processed signal is transmitted or received using a transceiver. The Radio Frequency (RF) antenna is used at the transceiver to transmit the processed signal, thus minimizing the amount and range of communication as much as possible.

CLUSTERING IN WIRELESS SENSOR NETWORK

Grouping of sensor nodes into clusters have been widely pursued by the research community in order to achieve the network scalability objective as formulated by (Sandell et al 1978; Cheng et al 2011; Yajie Ma et al 2011; Bianchi 2000; Saraydar et al 2002; Yang et al 2010).

Every cluster has a leader, often referred to as the cluster head (CH). A cluster head may be elected by the sensors in a cluster or pre-assigned by

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the network designer. A cluster head may also be just one of the sensor nodes that are rich in resources.

The cluster membership might be fixed or variable. Cluster heads form a second tier network or just ship the data to the base station or sink node. Figure 1.4 represents the basic clustering mechanism in wireless sensor network. In addition to network scalability, clustering has numerous advantages. Clustering localizes the route setup within the cluster and thus reduces the size of routing table stored at the individual node. Clustering conserves communication bandwidth as it limits the scope of inter-cluster interactions to the cluster heads and evades redundant exchange of messages among the sensor nodes.

Moreover, clustering stabilizes the network topology at the level of sensors and thus cuts down the topology maintenance overhead.

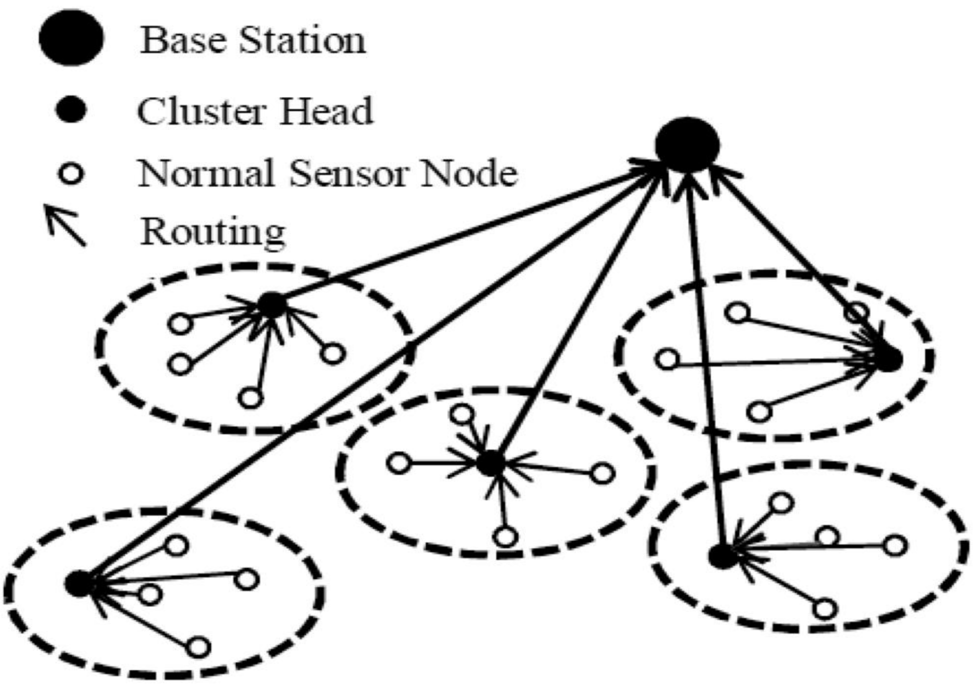

Figure 1.4 Clustering mechanism in Wireless Sensor Network

The cluster head implements optimized management strategies to further enhance the network operation and to prolong the battery life of the individual sensors. A cluster head schedules activities in the cluster so that nodes can switch to the low-power sleep mode most of the time and thus reduce the rate of energy consumption. Furthermore, cluster head aggregates the data collected by the sensors in its respective cluster by the process of data aggregation and thus decreases the number of data packets.

DESIGN ISSUES IN WIRELESS SENSOR NETWORK

The major technical issues and challenges for realization of wireless sensor network could be summarized as follows as given by (Ji 1997; Ragaey et al 2001; Mclurkin 1999).

a) Resource constraints

The implementation of sensor networks is mainly inhibited by resources like energy, memory and processing. Constrained by limited physical size, the sensor nodes have restricted battery energy. Similarly, their memories are also limited and have restricted quantity of computational capabilities.

b) Dynamic topologies

The topology and connectivity of the sensor network might vary due to link failure and sensor node failure. Furthermore, sensors may also be subjected to interference, highly corrosive environments, large humidity levels, vibrations, dust or other situations that confront their performance. These inconsiderate environmental conditions and dynamic network topologies cause a portion of the sensor nodes to get broken down.

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c) Quality-of-service (QoS) requirements

A variety of applications visualized on wireless sensor network will have dissimilar quality of service requirements. The quality of service offered by these sensor networks refers to the accuracy between the data reported to the sink node and what is really happening in the sensing atmosphere. Data with long latency due to processing may be invalid and lead to incorrect decisions in the ensuing monitoring system.

d) Data redundancy

Because of the high solidity in the network topology, sensor interpretations are seriously correlated in space domain. Additionally, the nature of physical happenings constitutes the temporal correlation between the consecutive observations of the sensor node.

e) Packet errors and variable-link capacity

Compared with wired networks, wireless sensor network have the attainable capacity of each wireless links that depends on the interference level perceived at the receiver. Moreover, wireless links display widely changing characteristics over time and space due to noisy environments, thereby making quality of service provisioning to be a demanding task.

f) Security

Security is an essential feature in the design of sensor networks, to make the communication safe from external denial-of-service (DoS) attacks and intrusion. Passive attacks happen by eavesdropping on transmissions including traffic analysis or exposure of the message contents. Active

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attacks constitute modification, fabrication and interruption which might include node capturing, routing attacks or flooding. In military applications, security plays a vital role during data communication.

g) Large-scale deployment and ad-hoc architecture

Many sensor network have a multitude of sensor nodes (hundreds to thousands or even more), which might be spread arbitrarily over the deployment field. Furthermore, the lack of predetermined network infrastructure demands these networks to setup connections and upholds the network connectivity autonomously.

h) Integration with Internet and other networks

It is of fundamental importance for the commercial development of sensor networks to provide services that permit the querying of the network to retrieve useful information. For this reason, these networks should be remotely accessible from the Internet and hence needed to be integrated with the IP architecture. The current sensor network platforms use gateways for integration between sensor network and the Internet.

REAL WORLD APPLICATIONS OF WSN

Although the implementations of wireless sensors are enormous, there are few strange applications of WSNs which could be categorized under: military applications, ecological monitoring, profit-making or human centric applications and in robotics as documented by (Arampatzis et al 2005; Xu et al 2001).

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a) Military and Surveillance Applications

Military applications are very intimately related to the perception of sensor networks. In detail, it is very tough to say whether motes (nodes)were developed because of military and air defence needs or whether they were invented autonomously and were subsequently applied to army services. Regarding military applications, the area of attention ranges from information collection, generally to the enemy tracking or battlefield surveillance. The avoidance of intrusion will be the answer of the defence system. One example project is “A line in the Sand” and refers to the deployment of several nodes which are gifted for detecting metallic objects. The ultimate goal was the tracking and categorization of moving items with metallic content, and specially the tracking of vehicles and weapon-carrying soldiers. Other civilians were uncared by the system. The principle here is to coordinate with a number of this category of sensors in order to keep sensing the moving object, thereby diminishing any information gaps about the track that could arise. Peacetime applications of wireless sensor networks like homeland security, possession-protection, surveillance, border patrol, etc., are the actions that possibly the future sensor network will be taking on.

B) Environmental Monitoring Applications

The ability of a wireless sensor node to sense temperature, light and indoor air pollution could be employed for indoor and outdoor environmental monitoring applications. A chief wastage of energy takes place through needless heating or cooling of buildings. Sensor nodes could be integrated with heaters, fans and other related equipment at an economic way, leading to healthier environment and greater level of comfort for the residents. Other environmental applications are the lessening of fire and earthquake damages. Fire and smoke detections are something widespread today in buildings, and in many countries it is forced by relevant regulations.

c) Wildlife Maintenance and their Conservation

Maintaining the faunas in remote areas is one of the vital applications of wireless sensor network. Their lifestyle could be analysed by placing wireless sensor nodes on their bodies. Their migration in the areas where human intervention is merely impossible could be analysed and steps could be taken for their conservation. These sensor nodes will be grouped into dynamic clusters, and the collected information will be sent to the distantly located monitoring station.

d) Application in Logistics

Management of precious assets like equipment, machinery and diverse stock or products could be predicament. The difficulty is extremely distributed as these companies increase all over the globe. A gifted technique to achieve asset tracking and cope with this crisis is believed to be with the employment of wireless sensor network. The application of wireless sensors in petroleum bunks refer to the storage supervision of barrels. The concept is that, the sensor nodes attached to these barrels will be able to position the nearby objects, detecting their content and alerting in case of impropriety with their own, etc.

e) Healthcare Applications

Healthcare systems can also profit from the use of wireless sensors. Applications in this group comprise of tele-monitoring human physiological data, monitoring of patients within the hospital, monitoring drug administrator in hospitals, etc. Cognitive disorders possibly leading to Alzheimer's could be monitored and controlled at their premature stages with these wireless sensors. The nodes can be used to outline the recent actions, and thus remind the senior citizens, point out the person's real actions or detect a growing problem. A comparable approach employs Radio Frequency Identification (RFID) tags to examine the patient behaviour and customs by recording the frequency with which they touch particular objects. These applications include a display which will assist the care-giver with the exact information about the indisposed person unnoticeably and without hurting their mental feelings. Sensor nodes can also be used in order to study the behaviour of young children.

f) Robotic Applications

The association of both static and mobile networks is accomplished with the help of mobile robots, which discovers the environment and deploys motes that operate as beacons. The beacons help the robots to explain the directions. The mobile robots can act as gateways into wireless sensor network. Examples of such tasks are satisfying the energy resources of the wireless sensor network indefinitely, configuring the hardware, perceiving sensor breakdown and suitable deployment for connectivity amid the nodes. This approach strives to answer the difficulty of unifying a network that is separated because of detached groups of sensor clusters. In all these cases, robots are the essential part of the sensor network. In the choice between robotics and medical applications is the virtual keyboard, which is an arrangement of wearable motes capable of sensing the acceleration. Motes are attached with a glove for every finger and at the wrist which is capable of recognition. Applications could be a wireless wearable keyboard or a pointing device, hand motion and gesture recognition for the disabled.

g) Landslide Detection Applications

Landslide detection employs wireless sensors for forecasting the occurrences of landslides. One sole trait of these systems is that it combines numerous distributed techniques to contract with the complexities of a distributed sensor network environment where connectivity is deprived and power budgets are unnatural, while fulfilling the real-world safety requirements. These sensors prepare point measurements at different parts of the rock but formulate no effort in measuring the relative motion between the rocks. The approach is based on the uncomplicated observation that rock-slides takes place because of bigger strain in the rocks. Thus, by measuring the source of the landslide, the landslides could be foreseen as easily as if one would be measuring the budding relative movement of rocks. Also, wireless sensor technology can be used to offer advance warning of a looming landslide disaster, facilitating emigration and disaster management.

h) Forest fire Detection Applications

Forest fires are wild fires happening in wild areas and become a reason for major damage to natural and human resources. Forest fires burns the infrastructure and might result in severe human death toll closer to urban areas. The universal causes of forest fires include lightning, human carelessness and disclosure of fuel to tremendous heat. It is known that in few of the cases, forest fires are part of the forest ecosystem and they are momentous to the life cycle of indigenous habitats. However, in many cases the losses caused by these fires to public safety and natural resources is intolerable, thereby untimely detection and suppression of fires deem crucial. Charge Coupled Device (CCD) cameras use image sensors which enclose an array of light sensitive capacitors or photodiodes. In case of fire

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or smoke action, the system alerts the local fire departments, residents and the industries.

i) Wireless Sensor-Cloud Applications

Sensor-Clouds could be used for health monitoring applications by means of merely available sensors like accelerometer sensor, proximity sensor, temperature sensor and so forth to gather patient's health-related data for tracking the sleep activity pattern, body temperature and other respiratory conditions. These wearable sensor devices have the support of wireless interface for streaming the data and are linked wirelessly to any smart phone through this interface. There are handful of simulation tools available for simulating both static and mobile wireless sensor network like Global mobile information system simulator (GloMoSim), Network simulator version-2 (NS-2), Network simulator version-3 (NS-3), Scalable simulation framework network models (SSFNet), Java based simulation (JSIM), Optimized network engineering tools (OPNET), Network based environment for modelling and simulation (NETSIM), Optical micro-networks plus plus (OMNeT++) and Realistic large scale network simulator (REAL). But for every modules presented in this thesis, NS-2 has been used for simulation and evaluation of the parameters.

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Module 2

COVERAGE-BASED CLUSTERING METHODOLOGY

INTRODUCTION

In a wireless sensor network, much of the energy is consumed during communication. On the other hand, data processing in WSN requires challenging tasks to be accomplished to avoid unnecessary processing power. 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. Figure 2.1 depicts the general clustering methodology.

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.

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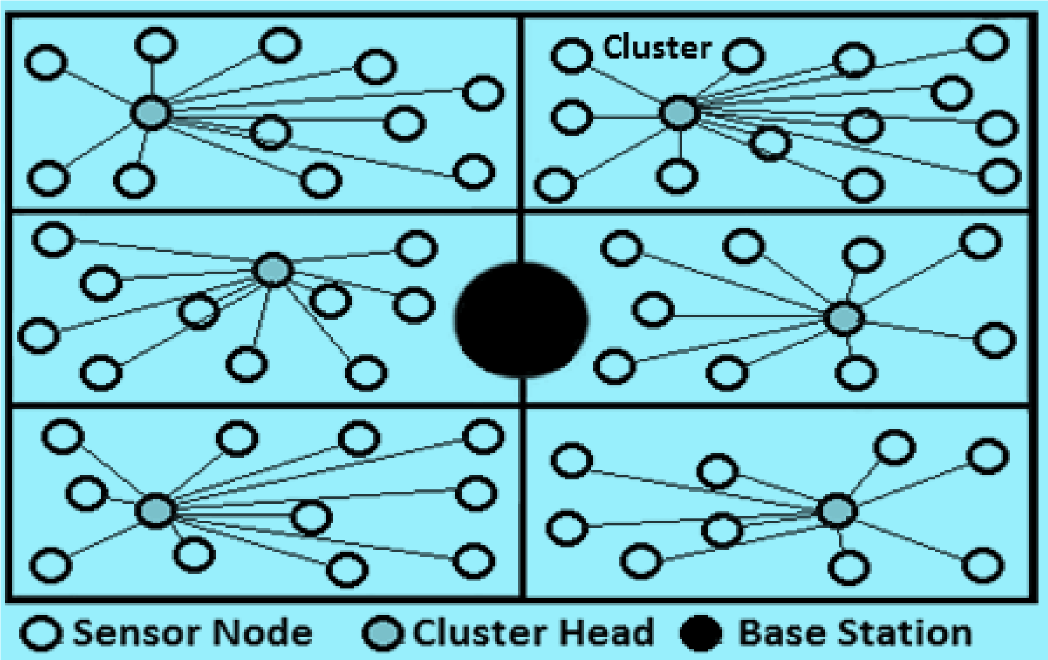

Figure 2.1 A Method of Cluster Formation

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. By using this concept, energy wastage could be reduced to a greater extent. In this module, 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 algorithms O-LEACH & HEED.

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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. 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. 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. Therefore, a methodology to reduce communication energy and selecting a CH in very short duration has to be worked out.

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. Figure 2.2 shows the general articulation of the proposed methodology.

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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).

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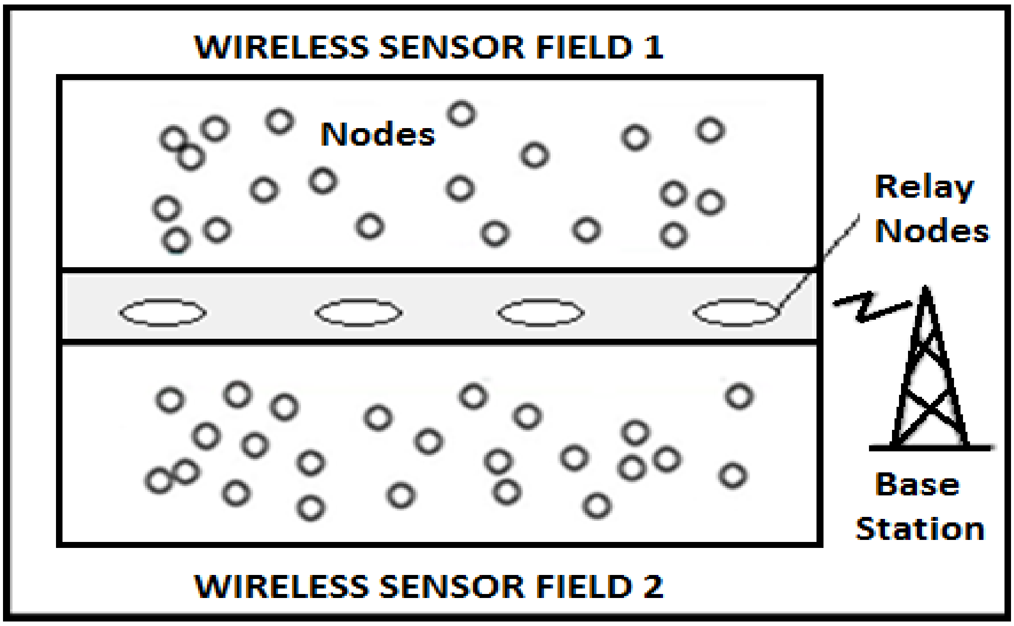

Figure 2.2 Articulation of HEECA Algorithm

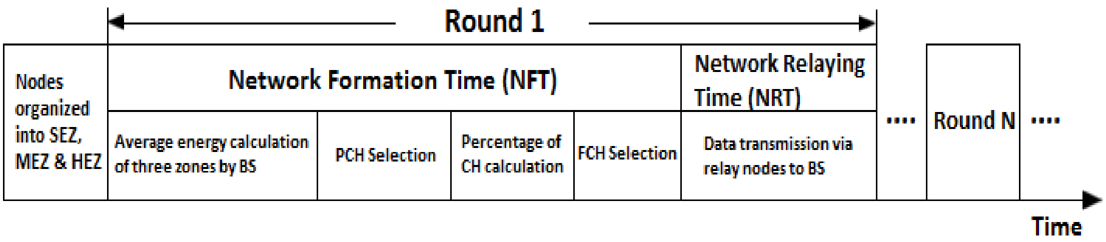

Figure 2.3 Timeline depicting the Clustering Procedures of HEECA

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. Figure 2.3 shows the timeline diagram of the proposed HEECA algorithm. 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.

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Zone Based Transmission Power (ZBTP)

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. Figure 2.4 depicts the energy zone organization in the proposed methodology. 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.

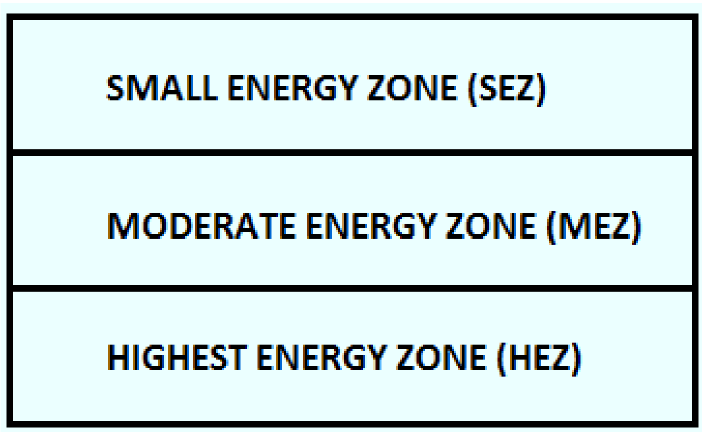

Figure 2.4 Organization of Energy Zones in HEECA

Here, the nodes and CHs in SEZ use transmission power P_1 for communication, the nodes and CHs in MEZ use transmission power P_2 for communication, and the nodes and CHs in HEZ use transmission power P_3 for communication. Considering, N_1 to be the nodes in SEZ region and thus the total transmission power in SEZ is expressed as

$$P_S = N_1 \times P_1$$

Considering N_2 to be the number of nodes in MEZ, the total transmission power in MEZ is given by

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$$P_M = N_2 \times (P_1 + \alpha)$$

The nodes in MEZ use α (factor) more transmission power than nodes in SEZ. The value of α is assumed to be a fixed value, whereas in the proposed methodology the value is equal to 1. The nodes in HEZ use 2α more transmission power than nodes in SEZ. Similarly, the total transmission power in HEZ is expressed as

$$P_H = N_3 \times (P_1 + 2\alpha)$$

The total transmission power of all the wireless sensor nodes is given by

$$P_T = P_S + P_M + P_H$$

$$P_T = (N_1 \times P_1) + (N_2 \times (P_1 + \alpha)) + (N_3 \times (P_1 + 2\alpha))$$

By partitioning the WSN field into such energy zones, energy balancing could be achieved using the concept of ZBTP of the proposed HEECA algorithm.

Routing using Distributed Relay Nodes (DRN)

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.

Rapid Clustering Formation (RCF)

When compared to other distributed clustering mechanisms, the clustering happens in few stages, reducing the clustering time and thus referred as rapid cluster formation. Figure 2.5 illustrates the rapid cluster formation mechanism in HEECA. 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.

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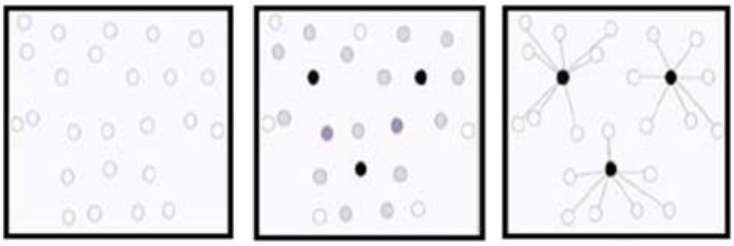

Figure 2.5 Rapid Cluster Formation in HEECA

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.

Network Formation Time (NFT)

Efficient cluster formation is a key methodology to prolong the network lifetime. During NFT, appropriate cluster heads are selected by the BS initially. The BS then calculates three different average energies for the nodes in SEZ, MEZ and HEZ, thereby forms separate cluster heads for all the three regions. The BS knows the initial energies of every node for the first round. After first round, the nodes provide their residual energy information to the base station. Another significance of HEECA is that the sensor nodes provide their residual energy information along with the data packets transmission, thereby reducing extra transmissions. Average energy of all the SEZ nodes, which spreads closest to the BS is given by

$$E_S(r) = \frac{1}{N_1} \sum_{i=1}^{N_1} E_{(Si)}(r)$$

where, $E_S(r)$ is average energy of the SEZ field, N_1 is the total number of nodes in SEZ, E_{Si} is the energy of an individual SEZ node and r is the current round of operation. Similarly, the average energy of all the MEZ nodes, which gets spread next to SEZ from the BS is expressed as

$$E_M(r) = \frac{1}{N_2}\sum_{i=1}^{N_2} E_{(Mi)}(r)$$

where, $E_M(r)$ is average energy of the MEZ field, N_2 is the total number of nodes in MEZ, E_{Mi} is the energy of an individual MEZ node and r is the current round of operation. Similarly, the average energy of all the HEZ nodes, which gets spread next to MEZ from the BS is given by

$$E_H(r) = \frac{1}{N_3}\sum_{i=1}^{N_3} E_{(Hi)}(r)$$

where, $E_H(r)$ is average energy of the HEZ field, N_3 is the total number of nodes in HEZ, E_{Hi} is the energy of an individual HEZ node and r is the current round of operation. After calculation of average energies of each region, BS compares the energy of each node to their corresponding average energy of the regions. The sensor nodes with higher or energy equal to the average energies ($E_i \geq$ Average Energy) are selected by the BS as Possible Cluster Heads (PCHs). Again the BS selects the preferred percentage P of cluster heads in each round, for nodes in all the three regions. If the number of PCHs is greater than the required CHs, BS will select Alive Nodes×P cluster heads with utmost residual energy and the least communication distance to the base station.

These lastly elected cluster head will be grouped as Finalized Cluster Heads (FCHs). Further, to minimize the computational overhead of non-CH nodes, BS multicasts the selection of FCHs. FCHs receive the final decision of selection from the BS and advertises their status updates to all other nodes lying in their communication range. If a non-CH node receives multiple advertisements, it selects its cluster head with highest Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI). Non-CH nodes send their connection request to their analogous CHs with the help of Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). Then CHs assign specific TDMA time-slots to its associate nodes for data transmission throughout the NRT. In HEECA, NFT is very small when compared to NRT, and the total time duration of a single NFT is between the end of a NRT to the start of next NRT.

Network Relaying Time (NRT)

During NRT, all the sensor nodes send their data to their corresponding CHs during their allocated time-slots. CHs receive the data from its cluster members and aggregate them. Data aggregation is a key technique to avoid unnecessary transmissions. The concept of threshold is applied in HEECA, which is highly significant in a variety of WSN applications such as fire alert, environmental monitoring, etc. The nodes send the sensor readings only when they fall above the hard threshold and change by given amount (soft threshold). The concept of soft threshold will further reduce the number of transmissions.

It is possible to set both hard threshold and soft threshold values in order to control the number of packet transmissions. Cluster heads only send necessary data to the distributed relay nodes. These DRNs perform effective delivery of the information to the base station. The proposed algorithm is assumed to be formed with N nodes, such that n different clusters are formed as given by

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$$N = \left(N_1 + N_2 + N_3 + \ \ldots\ldots \ + Nn\right)$$

$$Nn = \left(IN_1 + IN_2 + IN_3 + \ \ldots\ldots \ + IN_n\right)$$

where, Nn is the number of nodes in the nth cluster and IN is an individual node of a cluster. In case of O-LEACH, a sensor node assumes a random number between 0 and 1 and calculates a threshold T(n) as follows if n $\in G$

$$T(n) = \frac{P}{1 - P \times \left(r \bmod \frac{1}{P}\right)}$$

where, P is the percentage of nodes that can turn into CHs at any time, 1/P is the quantity of subintervals in an interval, r is the current subinterval, G is the group of sensor nodes that are not been CHs yet in the present interval.

By comparing the random number with this threshold value, a node can be moreover a CH or a follower in any one of 1/P subintervals of an interval. If the random number is less than the threshold T(n), the node makes a decision to become a cluster head. Otherwise, it decides to turn into a follower. At the initial subinterval, every node has a probability P to turn into a cluster head. The nodes that were cluster heads in the first subinterval cannot be cluster heads in the next (1/P - 1) subintervals of the similar interval.

The proposed HEECA algorithm sets the threshold values (hard threshold and soft threshold) at the CH level in order to avoid redundant data transmission to the distributed relay nodes. The threshold value K_{thres} is evaluated by the expression

$$K_{thres} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{E_{CAE}}{E_{BAE}}} \frac{M}{D_{BS}^2}$$

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where, N is the number of sensor nodes in the network, M is the dimension of the sensing area, D_{BS} is the distance between the CH and the base station, E_{CAE} and E_{BAE} are the amplifier energies of CH and base station respectively. The optimum threshold value is given by

$$K_{thres(opt)} = \frac{\sqrt{N}}{\sqrt{\pi}} \sqrt{\frac{E_{CAE}}{E_{BAE}}} \frac{M}{D_{BS}^2}$$

At the CH level, it becomes necessary to find out the optimum probability of election of CHs that depends upon energies including processing energy and energy required for data aggregation, which is expressed as

$$P_{(opt)} = \frac{1}{2} \sqrt{\frac{E_{CAE}}{\lambda(E_{BAE} D_{BS}{}^4 - E_{ELEC} - E_{DA})}}$$

where, $\lambda$is the density of sensor nodes, E_{ELEC} is the energy required for sensing, coding, modulation etc., and E_{DA} is the energy for data aggregation. The energy spent by a CH for data aggregation E_{DA} is given by

$$E_{DA} = \sum_{i=1}^{N} E_{IN(i)}$$

where, E_{IN} is the energy to be spent by the CH to process each individual node's data within a particular cluster. Generally, E_{DA} is proportional to the number of nodes in the cluster and increases linearly as the number of nodes within a cluster increases. For a single wireless sensor network field with N nodes and n clusters, the total energy consumption E_{TOT} for one complete cycle is based on the communication energy E_{Comm} of a sensor node, sensing energy E_{Sense} and processing energy E_{Proc} of a sensor node in the sensor network. The total energy consumption is given by

$$E_{TOT} = \sum_{j=1}^{N} (E_{\mathrm{Comm(j)}} + E_{\mathrm{Sense(j)}} + E_{\mathrm{Proc(j)}}) + E_{DA}$$

The proposed HEECA algorithm is efficiently used to connect two wireless sensor network fields with distributed relay nodes. Since there are two separate WSN fields, the overall energy E_{Over} spent by the nodes within two fields is based on the consideration of the energies used by the distributed relay nodes E_{DRNs}. The overall energy is expressed as

$$E_{Over} = 2 \times E_{TOT} + E_{DRNs}$$

SIMULATION

Simulation Settings

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 meter^2. 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.

Simulation Results

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 2.6 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

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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.

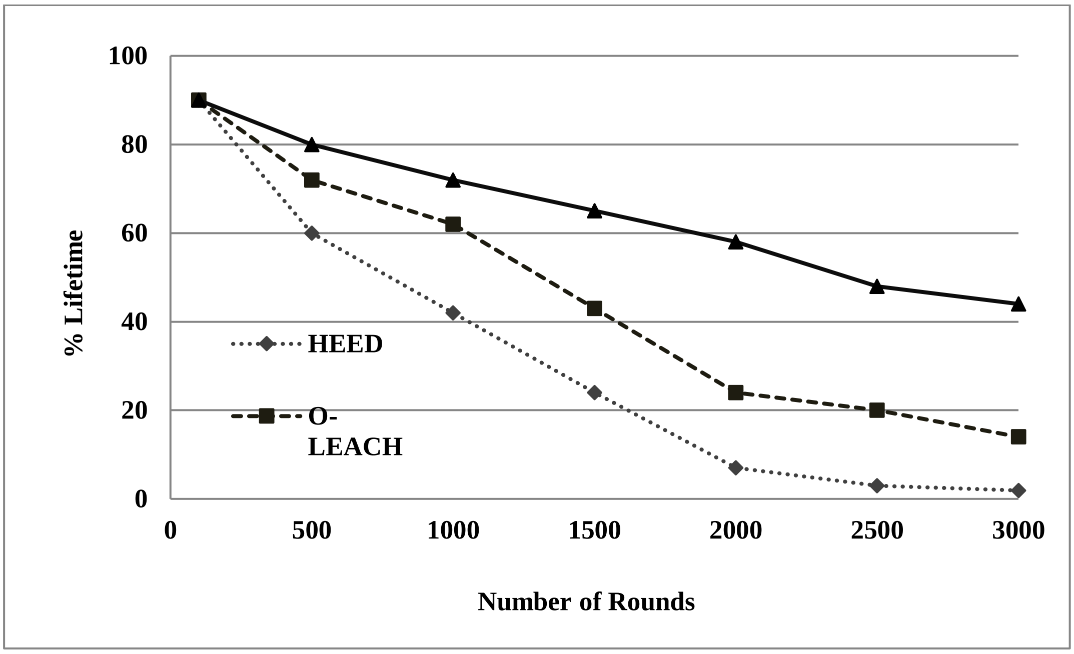

Figure 2.6 Lifetime versus Number of Rounds (HEECA, O-LEACH and HEED)

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

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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.

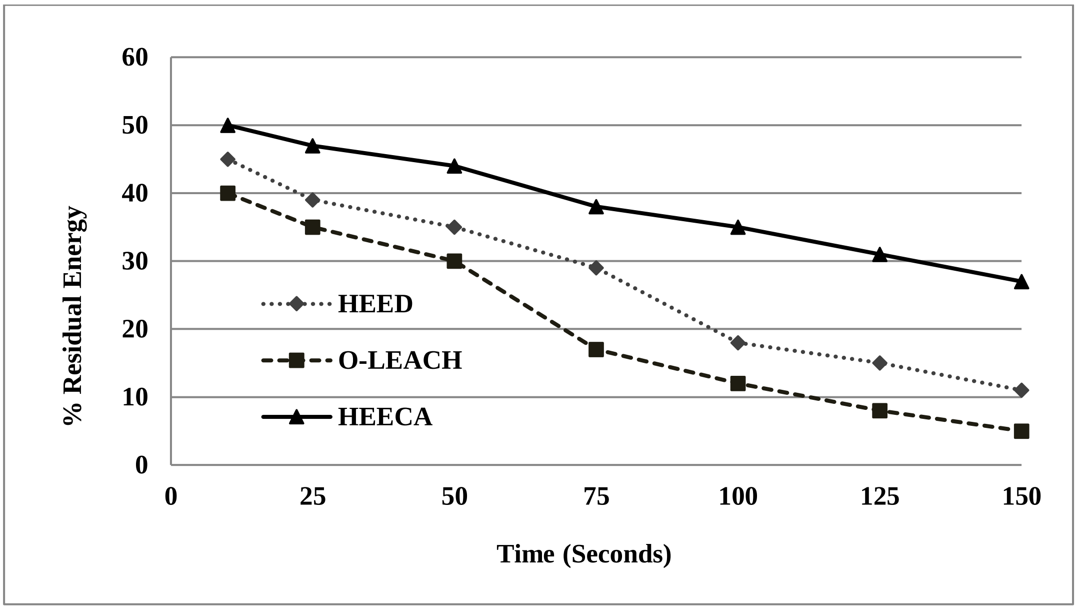

Figure 2.7 Residual Energy versus Time (HEECA, O-LEACH and HEED)

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 2.7 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. The total residual energy of all the nodes in the system is expressed as

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$$E_{RES(T)} = E_{INI} - E_{TOT(T)}$$

where $E_{RES(T)}$ is the total residual energy of the entire wireless sensor network system at particular time interval T, E_{INI} is the sum total of initial energies of all the nodes in the sensor network system and $E_{TOT(T)}$ is the total energy spent by all the nodes in the wireless sensor network system at particular time interval T.

At the beginning of the processes (T=0 seconds), the residual energy of every nodes in the system (E_{RES}) equals to the initial energies of every nodes in the system (E_{INI}) as expressed by

$$E_{RES} = E_{INI}$$

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.

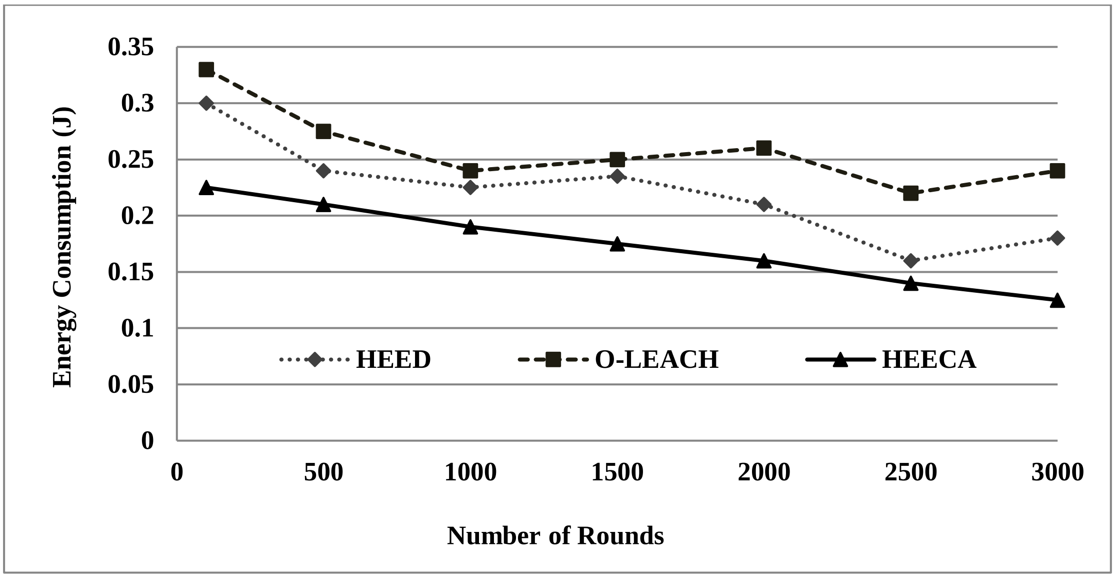

Figure 2.8 Energy Consumption versus Number of Rounds (HEECA, O-LEACH and HEED)

Figure 2.8 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. 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.

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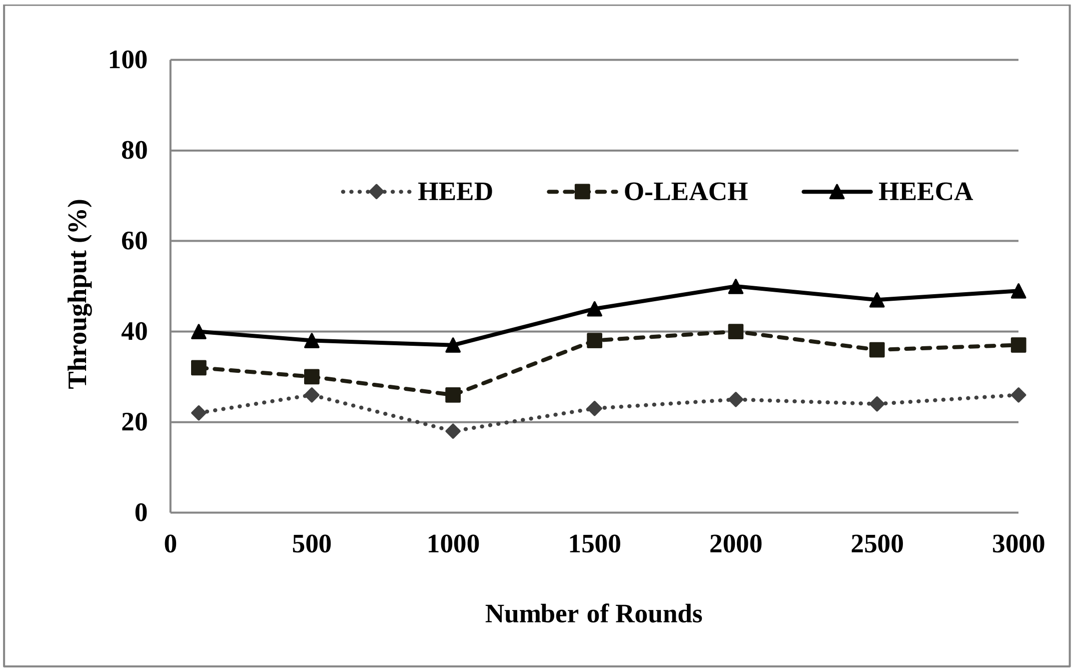

Figure 2.9 Throughput versus Number of Rounds (HEECA, O-LEACH and HEED)

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.

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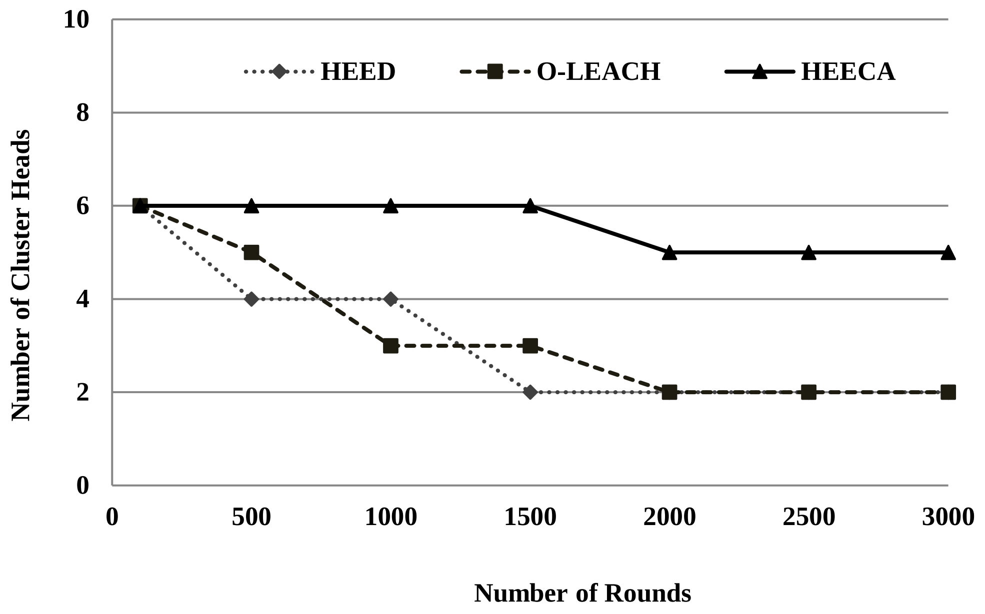

Figure 2.10 Number of CHs (HEECA, O-LEACH & HEED)

Figure 2.9 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.

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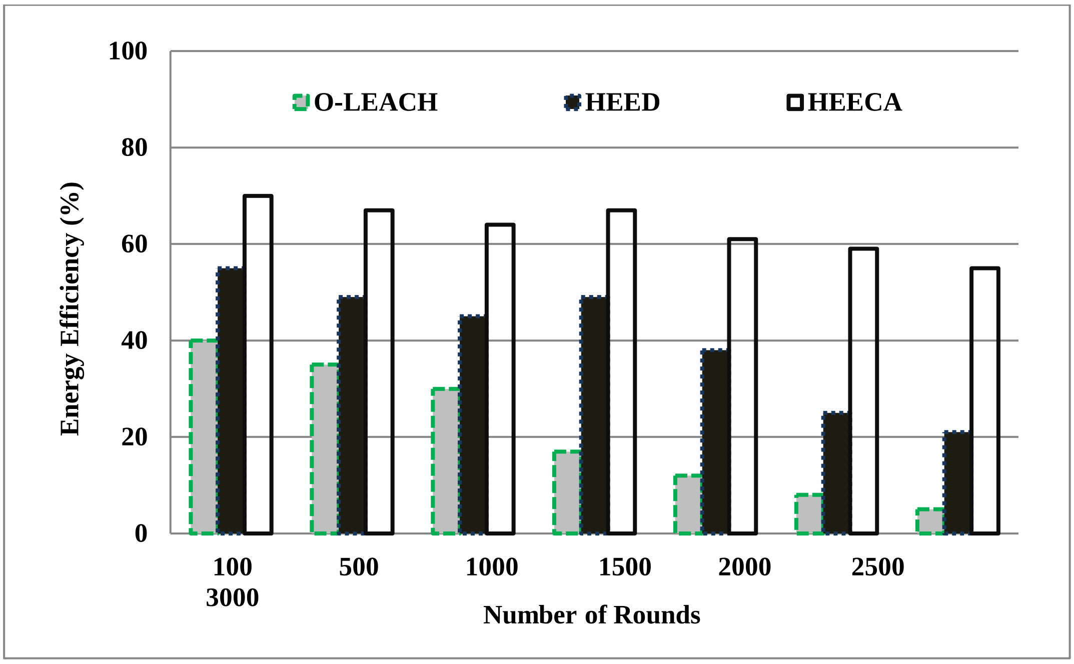

Figure 2.11 Energy Efficiency of HEECA, O-LEACH and HEED

Figure 2.10 illustrates the evaluation of the number of cluster heads selected for particular number of rounds. Random CH selection in O-LEACH leads to the failure of a particular cluster, when a node having very little residual energy is randomly selected to be a cluster head. For an effective and optimal clustering mechanism, the number of cluster head should not decline rapidly for successive rounds. For a network with 30 nodes, till 100 rounds all the three algorithms have 6 cluster heads. But at 500 rounds, the cluster heads of HEED, O-LEACH and HEECA are 4, 5 and 6 respectively.

The concept of ZBTP and RCF has an excellent effect on cluster formation of the proposed HEECA algorithm. Similarly in 2000, 2500 and 3000 rounds, the cluster heads of HEED, O-LEACH and HEECA are 2, 2 and 5 respectively. A sudden decrease in the number of cluster heads is seen in HEED and O-LEACH. This is a major concern to be carefully considered in dense wireless sensor networks, as the cluster fails once it has lost its CH. The proposed algorithm does not exhibit such sudden decrease, thereby can be effectively employed for dense wireless sensor network.

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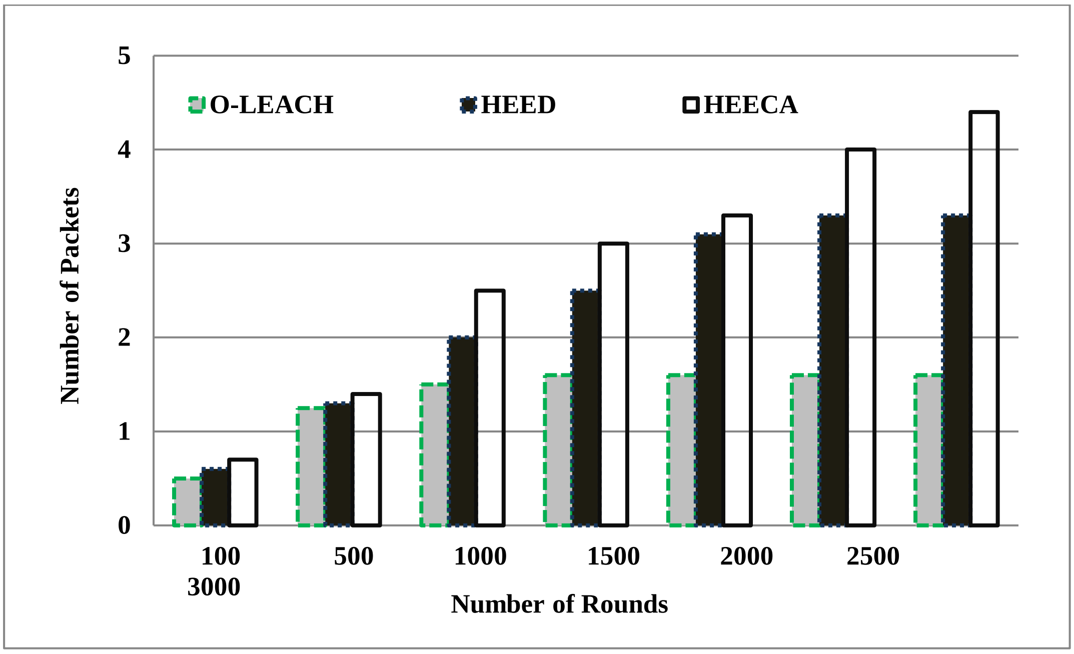

Figure 2.12 Number of Packets delivered to the Base Station

The overall energy efficiency of the wireless sensor network is the combined energy efficiency which is achieved during communication, routing, processing and clustering. Figure 2.11 illustrates the performance comparison of energy efficiency of the three algorithms. Initially at 100 rounds, the energy efficiency of HEED, O-LEACH and HEECA are 55%, 40% and 70% respectively. A difference of 15% and 30% energy efficiency is seen in HEECA, when compared to HEED and O-LEACH. At 3000 rounds, a difference of 34% and 50% energy efficiency is seen in HEECA, over HEED and O-LEACH. This improvement is due to the inclusion of ZBTP, RCF and by using DRNs. In O-LEACH, a sudden fall of energy efficiency from 40% to 5% happens from 100 to 3000 rounds. Similarly in HEED such fall from 55% to 21% is seen. But in HEECA, the difference in energy efficiency between successive rounds is comparatively lower. Figure 2.12 shows the performance evaluation of the number of packets delivered to the base station for particular number of rounds. At 100 rounds 600, 500 and 700 packets are delivered to the base station in HEED, O-LEACH and HEECA respectively. From 2000 to 3000 rounds, the number of packets delivered to the base station in O-LEACH is found to be constant (1600 packets).

This is mainly because of improper forwarding or due to cluster failure. The number of packets delivered to the base station should increase linearly with the number of rounds, as seen in the proposed HEECA mechanism. This linearity in HEECA is due to the efficient clustering of sensor nodes and effective forwarding by the distributed relay nodes.

SUMMARY

In this module, 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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Module 3

ADAPTIVE POWER BASED DISTRIBUTED CLUSTERING METHODOLOGY

INTRODUCTION

A wireless sensor node consists of low power processor, tiny memory, radio frequency module, sensing devices and limited powered batteries. 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. Since the nodes use different power levels for communication, the proposed methodology is called as variable power distributed clustering methodology.

In this module, a distributed clustering algorithm, the variable power energy efficient clustering (VEEC) has been proposed which is based on variable transmission power, relay nodes and single message per node for cluster-setup. The prime objective of the proposed algorithm is to achieve energy efficiency and extended network lifetime. The performances of the proposed algorithm have been evaluated against two existing algorithms LEACH and HEED.

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RELATED WORKS IN CLUSTERING

The distributed clustering methodology EEHC is a randomized clustering algorithm for organizing the sensor nodes into hierarchy of clusters with an objective of minimizing the total energy spent in the system to communicate the information gathered by the sensors to the information processing centre. LCA was mainly implemented to avoid the communication collisions among the nodes by using a TDMA time-slot. The revised version of LCA, the LCA2 was implemented to decrease the number of nodes compared to the original LCA algorithm. With an objective to form overlapping clusters with maximum cluster diameter of two hops, CLUBS algorithm has been implemented in wireless sensor networks. FLOC achieves re-clustering in constant time in a local manner in large scale network and exhibits double-band nature of wireless radio-model for communication.

Ye et al (2005) proposed Energy Efficient Clustering Scheme (EECS) which is based on the assumption that every cluster heads can communicate directly with base station. The clusters have variable size, such that those nearer to the CH are larger in size and those farther from CH are smaller in size. Ye et al (2005) proposed Energy Efficient Unequal Clustering mechanism (EEUC) for uniform energy consumption within the network. It forms unequal clusters, with an assumption that each cluster can have variable sizes. Based on the residual energy of the sensor nodes, connectivity and a unique node identifier, the cluster head selection is accomplished in Distributed Efficient Clustering Approach (DECA) as formulated by (Yu et al 2006).

The distributed clustering algorithms which have fallen into the research interest are LEACH and HEED. These algorithms organize the networks with different network topologies.

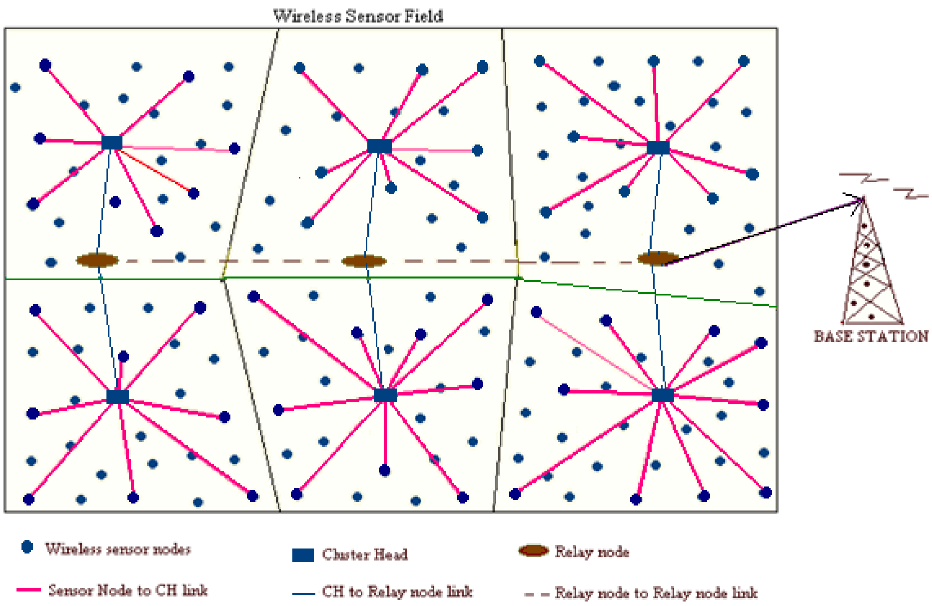

Figure 3.1 Articulation of VEEC Clustering Methodology

THE MODEL OF VEEC

The proposed algorithm VEEC is a well distributed clustering algorithm where the sensor nodes are deployed randomly to sense the target environment. The nodes are partitioned into clusters with each cluster having a CH. The nodes send the information during their TDMA timeslot to their respective CH which aggregates the data to avoid redundant information by the process of data aggregation. The aggregated data is forwarded to the relay nodes which in turn routes the data to BS either directly or forwarding through other relay nodes.

Figure 3.1 shows the general articulation of the proposed VEEC methodology. Compared to the existing algorithms, VEEC has three distinguishing features: First, in many clustering algorithms CH forwards the data to BS directly, which leads to energy wastage but in VEEC, CHs does not forward the data to BS. Instead CH forwards data packets to relay nodes and these rich-resourced relay nodes routes data to BS thereby considerable energy usage can be reduced. Second, VEEC uses variable transmission power. Nodes nearer to CH use lesser transmission power and nodes far away from CH use more power for transmission from nodes to CH or vice versa, which can further reduce considerable energy usage. Third, the cluster head sends one message for setting up the cluster but many existing algorithms use several messages for cluster-setup.

Variable Transmission Power

In a network of N nodes, each node is assigned with a unique Node Identity (NID) represented by n, where n=1, 2, 3…., N. The NID just serves as an identification of the nodes and has no relationship with location or clustering. The CH will be located at the center and the nodes will be organized in to several layers around the CH and these layers are assigned with Layer Number (LN). In the proposed methodology, a layer is formed on the basis of distance between the sensor node and the cluster head. LN is an integer number starting from zero. CH gets LN0, nodes surrounding the CH in the next layer are assigned LN1 and so on. The nodes in the outermost layer get the highest layer number. Nodes in first layer use lesser transmission power. The nodes in the last layer use maximum transmission power. The power transmission is variable and purely based on the layers, thereby VEEC attains excellent power reduction. Figure 3.2 depicts the concept of variable power transmission in VEEC.

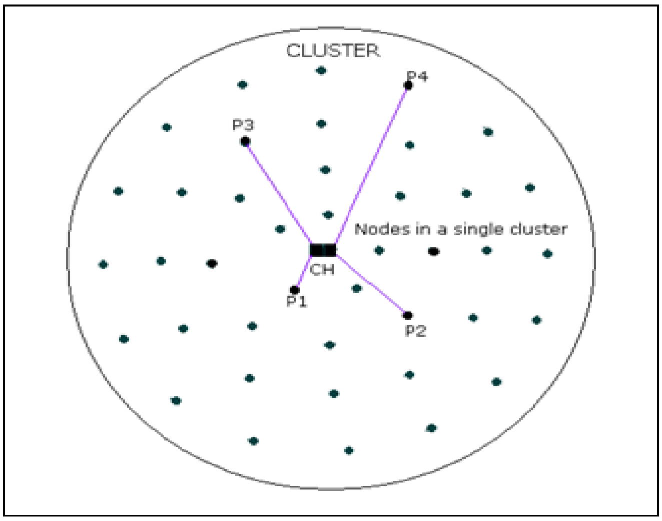

Figure 3.2 The concept of Variable Power in VEEC

Here the first layer nodes utilizes power (P_1), the second layer nodes utilizes power (P_2) and so on. It is to be noted that the transmission power increases with increase in layer number. The transmission power required for a node in layer M is

$$P_M = M \times P_1$$

where, P_M is the transmission power of a node in layer M, P_1 is the transmission power of a node in first layer and M is the layer number.

Relay Nodes

A relay node is a node which is rich in resources like battery, memory, etc. In the proposed algorithm, the relay nodes perform only the routing of data to BS either directly or forwarding through other relay nodes. In VEEC, the main fact to be considered is that the relay nodes nearer to BS requires more transmission power as they have to forward all the data packets from the preceding relay nodes. Figure 3.3 shows the concept of relay nodes in the proposed methodology.

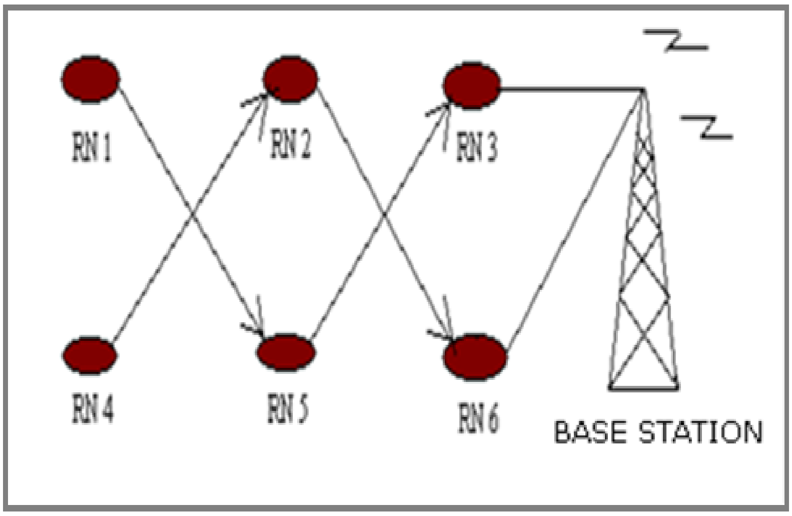

Figure 3.3 The concept of Relay Nodes in VEEC

The power consumption of a relay node is proportional to its location and number of relay nodes around it. If the power consumption of the sensor node is $(\lambda e_t+\sigma)$, the relay node density at a distance z meters from BS is given by

$$\rho_r(z) = \frac{w(z)}{(\lambda e_t + \sigma)}$$

where, parameter $\rho_r(z)$ is the relay node density at a particular distance z meters from BS, w is the width of the sensing field, e_t is the energy required to transmit unit data, λ is the data gathering rate of each sensor node and σ is the power consumption of each sensor node during sensing. Hence in VEEC, based on $\rho_r(z)$ more relay nodes are placed in region nearer to the base station and few relay nodes are placed at regions far away from the base station.

Number of Messages for Clustering

The proposed algorithm VEEC uses a single message for cluster-setup. Initially in each cluster, the nodes with relatively higher residual energy assume itself as a Provisional Cluster head (PCH).

It sends a message to its member nodes, in turn gathers their residual energy and NID during their respective TDMA timeslots. It then compares its residual energy with those of the cluster nodes and if it finds any node with higher residual energy, PCH transfers its CH role to that particular node thereby CH gets assigned.

The CH sends a single message to the member nodes requesting their residual energies and NIDs. In turn, the nodes send their residual energy and NID to CH during their TDMA time-slot, unnecessary transmissions are avoided thereby reducing power usage and prolonging the network lifetime.

ALGORITHM DESCRIPTION

In the proposed algorithm VEEC, the network consists of N nodes, node identity represented by n and the number of clusters formed is represented as K, K=1, 2,…., (N-1)/2.

The entire algorithm is executed in four stages: cluster-setup, data aggregation, functionality of relay nodes and CH re-election. Figure 3.4 shows the detailed flowchart of the proposed clustering methodology.

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Stage I – Cluster Setup

In VEEC, the node with highest residual energy has the maximum probability of becoming a CH. Initially the PCH compares the residual energy (RE) of the cluster nodes and transfers the CH to the node having highest residual energy within a cluster.

If it does not find any node having higher residual energy, PCH itself will become a CH. It then broadcasts join-request to the nodes within R meters, where R is equal to the cluster radius. The broadcast message includes the NID of the CH, the total number of layers in the cluster and local communication radius R_{COMM}.

The objective of this message is to suppress the interest of other nodes in becoming a CH. Nodes receiving this message will stop their action and joins that CH.

As discussed in the preceding sections, the clusters are arranged in concentric layers, the sensor nodes will make use of messages in the packet and with the following equation to calculate the bound B_M of the M^{th} layer

$$B_M = b_{m-1} + R_{COMM}$$

where b_{m-1} is the average distance between CH and the cluster member in the $(M-1)^{th}$ layer. Here b_{m-1} is expressed as

$$b_{m-1} = \sqrt{\frac{B^2{}_{M-1} + B^2{}_{M-2}}{2}}$$

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The cluster members will make use of RSSI and LQI of the CH to estimate their distances from CH and calculates their respective layers. Variable power can be thus effectively employed for transmitting data from nodes to CH and vice versa.

Stage II – Data Aggregation

The CH aggregates all the incoming data packets together and the aggregated data is forwarded to the relay nodes. In case when a node dies or does not transmit the data during its time-slot, it is regarded as unreachable and can be skipped from the data collection process.

The aggregation is performed by spatial correlation measurement by measuring the offset between the two sensor readings. If the error is within the tolerable range, then the two readings will be correlated.

Stage III– Functionality of Relay Node

In VEEC the relay nodes are static and only forward the data to BS. Every relay node has the same initial energy and transmission range. The MAC protocol puts the radio of the relay node in sleep mode if it is not the transmitter or receiver of the packet. The relay nodes are divided into different layers starting from the BS.

The relay nodes in the layer nearer to the BS need to relay more packets and hence more number of relay nodes has to be placed in the layer nearer to BS. The layer farther from BS requires fewer number of relay nodes as there is need for only little amount of data to be forwarded. Also the power consumption of the relay nodes nearer to BS will be more compared to the relay nodes far away from BS.

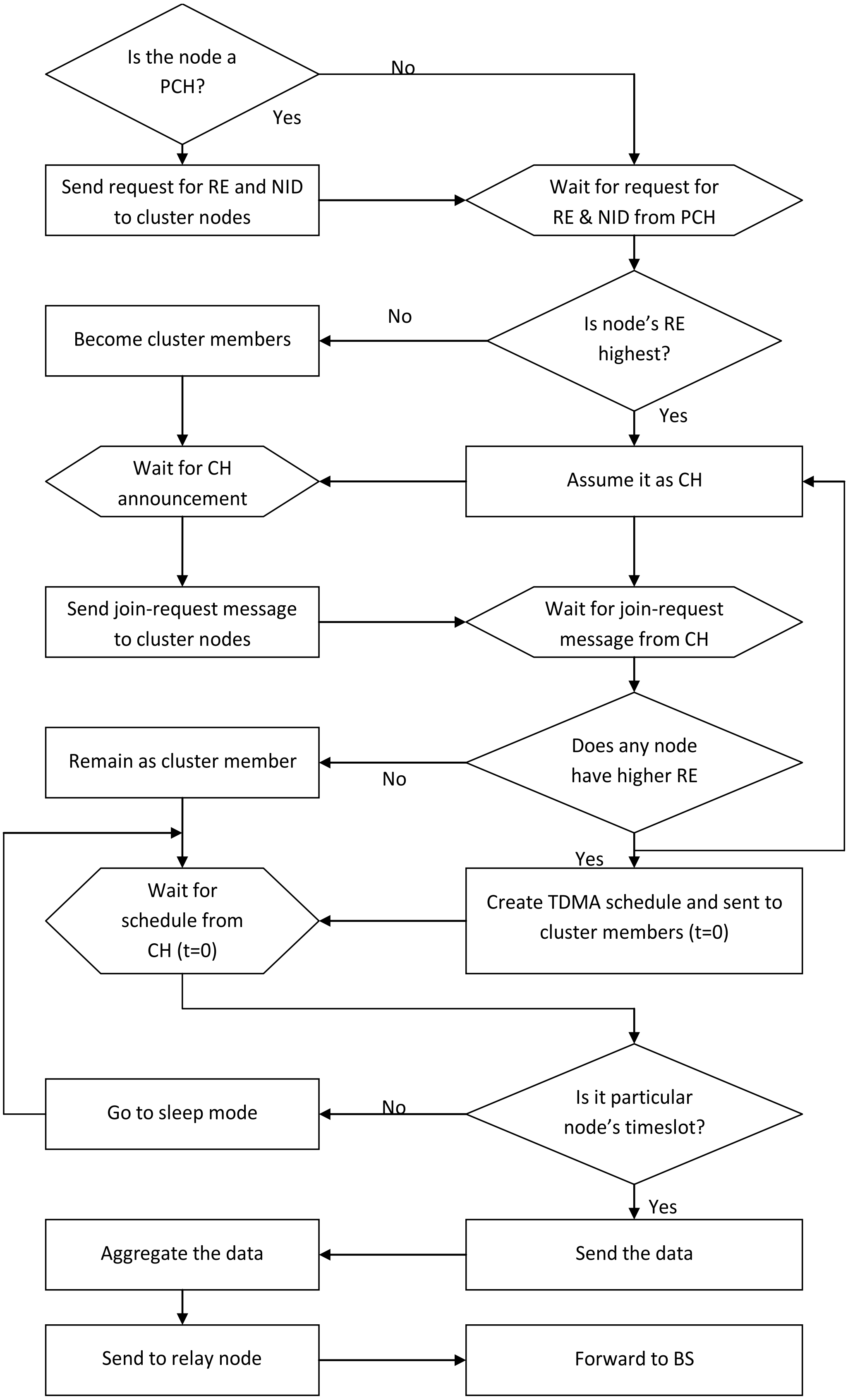

Figure 3.4 Flowchart of the Proposed Methodology

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Stage IV– Cluster Head Re-election

The CH calculates the lifetime of the member nodes based on their residual energies. The estimated lifetime $t_{LT(n)}$ of a node with NID represented by n, is expressed as the number of times it can be a CH. The CH uses the lifetime information to estimate the lifetime of the cluster. The lifetime of the cluster is estimated by the expression given by

$$t_{LT(C)} = \min(t_{LT(1)}, t_{LT(2)}, t_{LT(3)}, \ldots\ldots, t_{LT(N)})$$

where, N is the number of sensor nodes in the wireless sensor network. The CH periodically compares its residual energy against the received residual energy of the sensor nodes. If any node is found with residual energy greater than that of CH, that particular node is re-elected as new CH. All wireless sensor nodes which have reached their own expected lifetimes will be considered themselves as dead and becomes idle. An idle node will not participate in any of the upcoming operations.

SIMULATION STUDY

Simulation Settings

The following assumptions are made in VEEC: (i) Sensor nodes, CH and BS are stationary. (ii) Relay nodes are highly rich in resources. (iii) Nodes use variable power for transmitting the data. (iv) Nodes are all location-unaware. (v) Clustering process is purely distributed. (vi) Clustering process should terminate after particular interval. (vii) CHs have higher residual energy compared to ordinary nodes. (viii) Relay nodes solely perform routing of data to BS. All the simulations were carried using NS-2. The proposed distributed clustering algorithm is simulated with 30 nodes and at each time the energy utilization, node's residual energy, etc., are recorded. Finally, the performance of VEEC is compared with the two existing algorithms LEACH and HEED based on the above recorded readings. A data collection process is said to be completed when all the relay nodes in the sensor network forwards the data to the BS.

Sensor nodes are deployed in a square sensing field of 500m x 500m. Once deployed, the sensor nodes are assumed to be static. For simulation purpose the BS is placed at the center of the field but in real-world applications BS is located far away from the target environment.

The BS contains sufficient energy and at any cost energy shortage does not occur. The sensor nodes have limited energy with initial energy of 1Joule. When the energy is dropped to 0 Joule, the node is considered to be dead. The position of CH changes when its residual energy decreases compared to its cluster nodes.

The relay nodes are assumed to be in sleep mode unless CHs send the data to it. The main feature of the proposed algorithm is that, CHs does not send data directly to BS, instead they send to the relay nodes which in turn forward the data to BS to avoid energy wastage during long-haul communication.

Simulation Results

The proposed algorithm VEEC is simulated and the results are recorded for average communication energy, normalized total system energy consumption and network lifetime. These parameters are then compared

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with the two existing algorithms LEACH and HEED. Figure 3.5 demonstrates the simulation results for average communication energy for particular rounds in LEACH, HEED and VEEC. Initially in 100 rounds, the average communication energy is 0.13 Joules for HEED, 0.09 Joules for LEACH and 0.04 Joules for VEEC. Similarly in 3000 rounds, the average communication energy is 0.13 Joules for HEED, 0.09 Joules for LEACH and 0.04 Joules for VEEC. VEEC shows an improvement of 57.02% when compared to LEACH and 67.50% when compared to HEED in terms of average communication energy. Thus it could be clearly seen that, from the beginning till the last round the average communication energy is very less in VEEC when compared to LEACH and HEED. This is mainly because of the modifications that are adopted at the level of clustering in the proposed methodology.

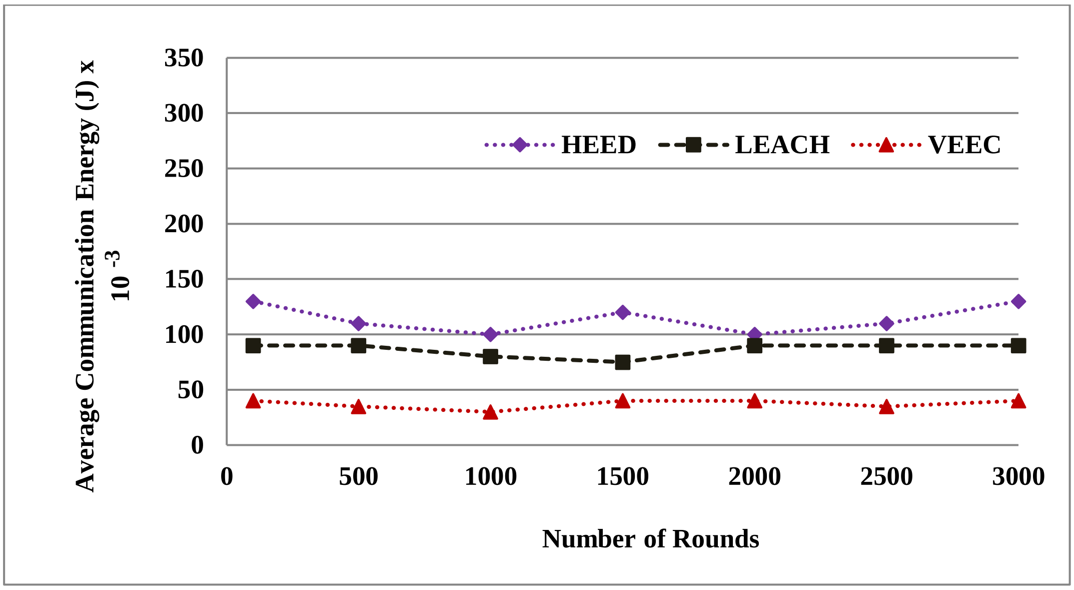

Figure 3.5 Average Communication Energy versus Number of Rounds (LEACH, HEED and VEEC)

Figure 3.6 represents the normalized total system energy consumption for all the three algorithms. Initially in 100 rounds, the total system energy consumption is 0.3 Joules for HEED, 0.22 Joules for LEACH and 0.09

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Joules for VEEC. Also in 3000 rounds, the total system energy consumption is 0.18 Joules for HEED, 0.135 Joules for LEACH and 0.09 Joules for VEEC.

The proposed algorithm VEEC shows 40.18% improvement in system energy consumption over LEACH and 56.77% improvement in system energy consumption when compared to HEED.

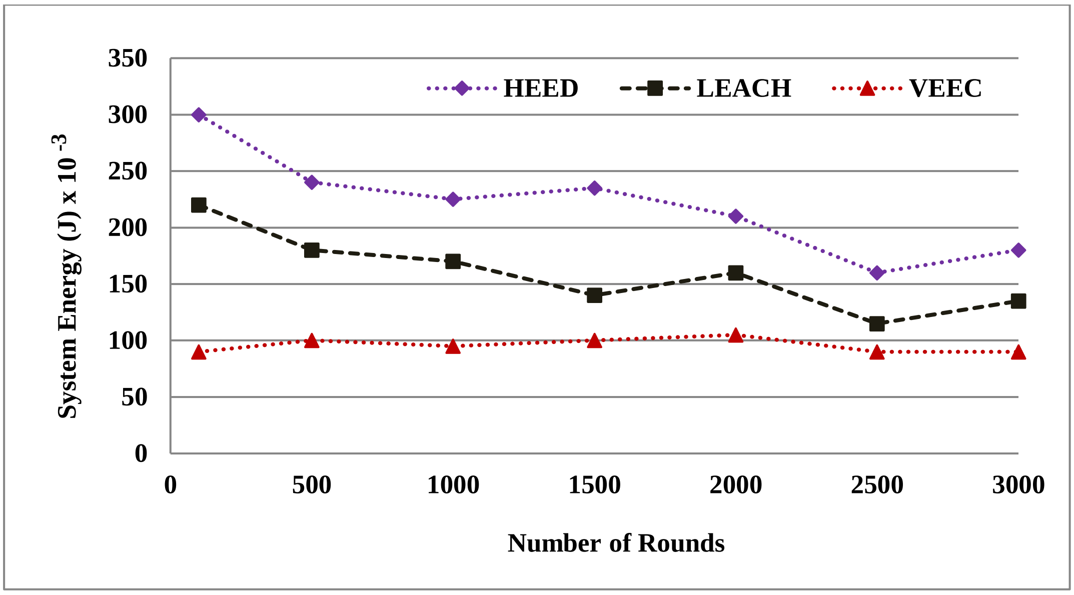

Figure 3.6 Comparison of proposed methodology with LEACH and HEED (Normalized Total System Energy Consumption)

In case of LEACH and HEED, the resulting curve is steeper with increased slope which is generally not preferable. But in VEEC, the slope of the curve is almost minimum. Thus it could be clearly seen that, VEEC shows reduction in total system energy consumption compared to LEACH and HEED.

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This is because of VEEC avoiding unnecessary communications during cluster-setup, with the help of relay nodes and by variable transmission power.

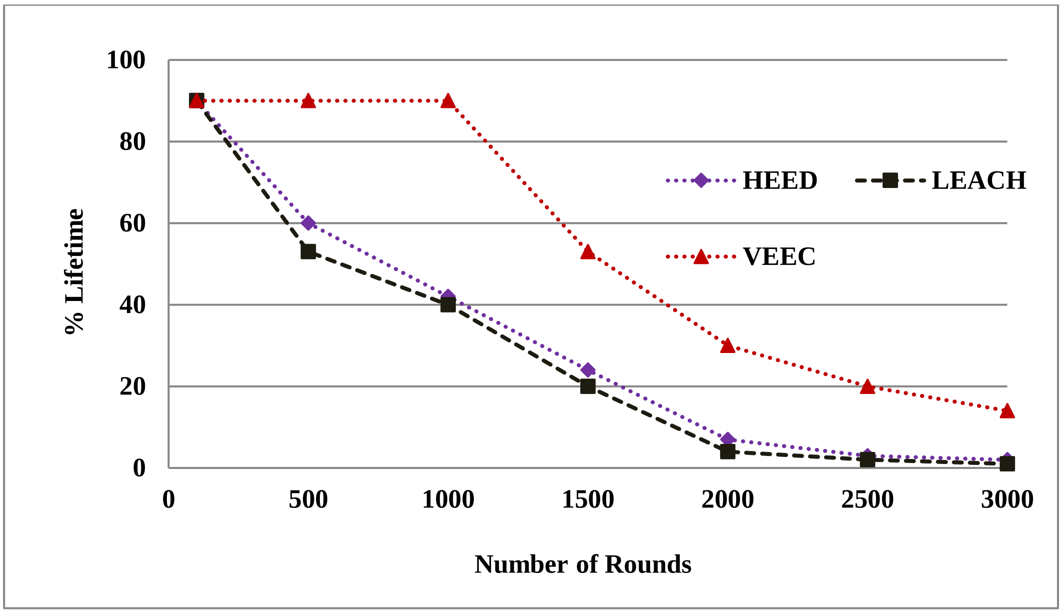

Figure 3.7 Lifetime Comparison of LEACH, HEED and VEEC

Figure 3.7 depicts the network lifetime for particular number of rounds for all the three algorithms. Initially in 100 rounds, 90% of the sensor nodes are alive for all the three algorithms. In 1000 rounds, the percentage lifetime of VEEC is 90% but in case of LEACH and HEED the percentage lifetimes are reduced to 40% and 42% respectively. In 2000 rounds, almost all the nodes die for the two existing algorithms, but VEEC shows a great improvement in lifetime till the end of the process. A moderate difference of 25.57% and 23.43% is seen in VEEC with respect to LEACH and HEED in terms of average network lifetime. The proposed algorithm VEEC shows better improvement in network lifetime when compared to LEACH and HEED. This is because of the distinctive features applied for VEEC which have been discussed in the preceding sections. This evidently shows that VEEC based clustering methodology could be effectively employed for wireless sensor network systems where network lifetime and energy efficiency is a primary criterion.

DISCUSSIONS

Average Communication Energy

Average communication energy is the average of total energy spent during communication in the network over a stipulated interval of time or after particular number of rounds. In LEACH, a sensor node communicates only with the nearest CH. When there is less number of CHs these CHs will be heavily loaded and the communication distance between cluster nodes and CH increases. The CH should announce its status to all the nodes in the network during cluster-setup phase. When more number of CHs are elected, a node have to receive communication from many CHs in the network in order to select the nearest CH. All these communications will lead to increased communication energy by both CHs and cluster nodes.

Basically HEED was proposed to avoid the random selection of CHs. Though LEACH was more energy efficient, the main drawback is the random selection of cluster head. In HEED, the selection of cluster head is on the basis of residual energy and the communication cost of the sensor nodes. During the initialization phase, initial CH percentage will be given to the nodes. Every node tries to become a CH. There is no control for CH selection in the initialization phase and hence more energy is consumed even more than that of LEACH. Also in the repetition phase, until CH is found with least communication cost the process will be iterated. These iterations use more communications between the nodes and CH. These two phases make the algorithm complicated in terms of communication energy from the beginning of cluster formation.

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The proposed algorithm is based on the concept of single message per node for cluster-setup. A random PCH node sends one message for every cluster nodes requesting their NID and residual energies. These nodes on sending their details, the PCH compares the residual energy of the cluster nodes with its own residual energy and if any node has higher residual energy than that of PCH, that particular node is elected as CH. The characteristic feature of VEEC is that the nodes having lower energy than CH never tries to become a CH, thereby unnecessary communications are avoided. In LEACH and HEED, more energy is wasted during communication due to imbalance in the number of CHs and due to several phases for cluster-setup.

Total System Energy Consumption

It is the sum total of energy consumed during communication, processing, etc., which is the total energy consumed for entire clustering mechanism by the whole sensor network. It tries to distribute the loading of CHs to all nodes in the network by switching the cluster heads from time to time. Due to two-hop structure of the network, a node farther from CH will have to consume more energy than a node nearer to CH. This introduces an uneven distribution of energy among the cluster members, affecting the total system energy.

The uneven distribution of energy among the cluster members is avoided in HEED as the CH selection is mainly on the basis of residual energy and communication cost. A node with highest residual energy and communication cost becomes a CH, thus the random selection of CH is avoided. But in repetition phase, more number of iterations are carried out in order to find a node with best communication cost. This is a peculiar drawback of HEED.

In the proposed algorithm, lesser communication energy is required which could be understood from the simulations. It uses the concept of variable-transmission power in which the transmission power is variable from the lower edge to the higher edge based on the layers. Also with the property of relay nodes, more energy utilization for routing the aggregated data from CH to base station is avoided. But the two existing algorithms use direct communication between the CH and BS, which is generally long-haul in nature. From the simulation, it is also clear that the slope of LEACH and HEED algorithms are maximum, hence consuming the available energy easily when compared to VEEC. Also in the proposed algorithm, separation among the layers is optimized to use optimum power for each layer.

Network lifetime

Network lifetime is basically related to node death rate. Node death rate is the measure of the number of nodes die over a time period, from the initiation of the process. When the data rate increases the node death rate also increases. The networks formed by LEACH show periodical variations in the data collection time. This is due to the selection function dependent on the number of data collection process. Since the CH selection of LEACH is a function of the number of completed data collection processes, the number of cluster varies periodically. The same condition prevails also in HEED due to increased data collection. This increases the node death rate. The proposed algorithm uses limited data collection process by using limited messages in cluster-setup phase. In all the three algorithms, the cluster size is variable but in order to compensate this, the proposed algorithm uses variable transmission power. Also the proposed algorithm has an excellent control over the number of connections between the cluster nodes, CH and relay nodes. In LEACH and HEED, there is no control over the number of connections, which increases the data collection time, thereby increasing data rate and node death rate. The proposed algorithm shows prolonged network lifetime when compared to LEACH and HEED to a great extent.

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SUMMARY

In this module a well distributed clustering algorithm VEEC has been proposed. Based on single message for cluster-setup, variable transmission power and relay nodes, the algorithm VEEC has been formulated to form efficient clusters in wireless sensor network. The algorithm is analysed and the performances are compared with the two existing clustering algorithms LEACH and HEED.

The proposed distributed clustering algorithm depicts much reduction in average communication energy when compared to the two existing clustering algorithms. The performance of the proposed algorithm shows a drastic reduction in the total system energy consumption. Nevertheless, the proposed algorithm VEEC greatly prolongs the overall network lifetime of the wireless sensor network system.

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Module 4

DISTRIBUTED CLUSTERING USING HIERARCHICAL APPROACH

INTRODUCTION

In wireless sensor network it becomes impossible to recharge or put back the dead batteries of the sensor nodes. When a quantity of sensor nodes in WSN is drained, their functioning is stopped thereby causing progressive deconstruction of the network. Hence the protocol should be so designed, that minimum energy should be consumed during sensing, processing and communication. Three layers of protocol stack involved in the functioning of wireless sensor network are the physical, data link and network layers. The physical and data link layers deals with energy awareness, wireless communication hardware, duty cycle issues, sensor system partitioning and energy aware protocols. The network layer finds the energy-efficient route and reliably transmits the data from sensor nodes to the base station.

Since wireless sensor nodes are power-constrained devices, long-haul transmissions should be kept to minimum in order to expand the network lifetime. Thus, direct communications between nodes and the base station are not intensely encouraged. An effective methodology to perk up efficiency is by arranging the network into several clusters, with each cluster electing one node as its leader or cluster head. The aggregated data will then be transmitted

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to the base station directly or by multi-hop fashion by the cluster head. In such an arrangement, only cluster heads are required to transmit the data over longer distances. The remaining nodes will need to do only short-distance transmission.

Clustering mechanism is basically classified into centralized, distributed and hybrid clustering. Hierarchical methodology could be employed for all these clustering mechanisms. When energy efficiency is a major criterion during clustering, hierarchical methodology could be more effective. The cluster heads all over the wireless sensor network will be divided into different levels (hierarchy or tier). First level cluster heads will transfer the aggregated data to the second level cluster heads. The second level cluster heads will transmit the data to third level cluster heads. The cluster head at the final level only will be forwarding all the data to the base station. By following this hierarchical approach, energy wastage can be avoided to a larger extent. This module gives a profound description about energy-efficient hierarchical distributed clustering algorithm (EHDCA) for efficient formation of clusters in wireless sensor network.

HIERARCHICAL CLUSTERING METHODOLOGIES

The major hierarchical clustering algorithms for wireless sensor network are LEACH, Threshold sensitive Energy Efficient Network (TEEN) and Scaling Hierarchical Power Efficient Routing (SHPER). The initial stage of TEEN protocol is the formation of clusters. In this mechanism, every cluster member nodes becomes a cluster head for a particular time interval referred as cluster period as formulated by (Manjeshwar and Agarwal 2001).

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Dionisis et al (2008) proposed SHPER protocol which includes base station and sensor nodes which are arbitrarily dispersed over a restricted region of attention. The base station and all the nodes are found to be stationary. The end users can access the data from the base station, which is situated far away from the sensing field. Every cluster nodes are grouped together into separate clusters. Within every cluster, one node is elected to be the cluster head. The cluster head election in SHPER is purely based on residual energy. The cluster heads that are nearer to the base station, which could correspond with the base station with rational power utilization, is considered to be the highest level cluster head. Similarly, the cluster head which is located far away from the base station is considered to be the lowest level cluster head.

The operation of SHPER protocol includes two main phases namely the initialization phase and steady state phase. During the initialization phase, the base station decides which node should be a cluster head. The nodes other than the cluster head becomes member nodes. Each cluster head along with some cluster nodes are grouped together to form a specific cluster. The base station sends the ID of each cluster heads which are newly elected. Additionally, each sensor node decides the cluster to which it belongs and informs its cluster head on being the member of that cluster. The cluster head informs the member nodes regarding the time when they have to transmit. Accordingly, data is collected by the cluster head and aggregated, further being transmitted to the base station during the steady state phase.

LIMITATIONS OF THE EXISTING METHODOLOGIES

LEACH protocol is less-effective when periodic transmissions are unnecessary, thus causing useless power consumption. The election of

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cluster head is based on priority, and hence there is a possibility that the weaker nodes to be drained, when they are elected as cluster heads as frequently as the stronger nodes. Moreover, the protocol is based on the suppositions that every nodes start with identical energy capacity in every election round and all the nodes can transmit with sufficient power to the base station if needed. However, in several cases these assumptions are found to be unrealistic.

TEEN protocol has been developed for reactive networks so as to take action for abrupt changes in the sensed attributes. TEEN is appropriate for time critical applications, but not suitable for applications where periodic reports are required.

In case of SHPER, the election of cluster head is purely based on the base station. Hence unnecessary transmissions occur between the base station and cluster heads. Also the base station should keep track on the sensor nodes in order to decide which node has the highest residual energy, thereby causing increased power consumption.

FEATURES OF THE PROPOSED EHDCA METHODOLOGY

In the existing techniques, the election of cluster heads and cluster nodes are entirely done by the base station. Hence they are prone to additional power consumption. The proposed work mainly considers that the cluster head to be completely responsible for all the process including the election of new cluster heads and member nodes. The cluster head calculates the power consumed by the nodes, which normally depends on the available power at the nodes, and the distance between nodes and the cluster head.

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Two different thresholds are employed namely hard threshold and soft threshold to reduce the number of transmissions during data aggregation. Generally, hard threshold is the smallest possible values of an attribute to activate a sensor node to switch on its transmitter and transmit the data to the cluster head. Soft threshold is a little change in the value of the sensed attribute that activates the node to switch on its transmitter and transmit the data. The former tries to diminish the number of transmission by letting the nodes to transmit only when the sensed attribute is ahead of a critical value. Similarly, soft threshold additionally trims down the number of transmissions when there is small or no change in the value of sensed attribute. For each cluster change, the values of both the thresholds could be altered, facilitating the user to manage the trade-off between energy efficiency and data accuracy. The nodes transmit the sensed data to the cluster head. The distinctive feature of this method is that, the residual energy is transmitted along with the sensed data by the nodes to the cluster head. The cluster head only transmits the aggregated data to the base station.

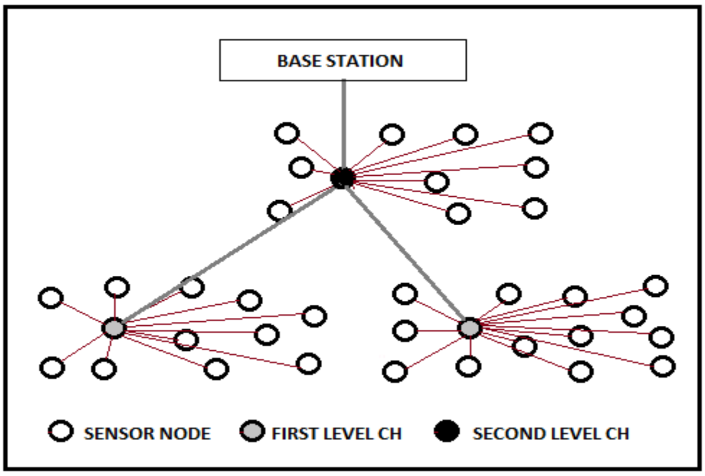

Figure 4.1 Hierarchical clustering Architecture of EHDCA

Figure 4.1 shows the hierarchical clustering architecture of the proposed EHDCA methodology. Every process such as initialization, formation of

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clusters, election of cluster heads and monitoring the residual energy is done exclusively by the cluster head. Store and forward technique is followed at the cluster head, so that the sensed attribute along with the residual energy is collected from the cluster nodes, stored at the cluster head and further the aggregated data alone is forwarded to the base station. Since the BS has no direct link with the cluster nodes, unnecessary transmissions are avoided thereby minimizing enormous energy consumption.

BASIC CONCEPT OF THE PROPOSED METHODOLOGY

As described in the preceding sections, the cluster nodes need to be evenly distributed over the entire network for reducing energy utilization. In the proposed EHDCA methodology, the redundant formation of cluster heads is greatly avoided. The proposed EHDCA methodology incorporates set-up phase and steady state phase. Figure 4.2 depicts the timeline concept of the proposed methodology.

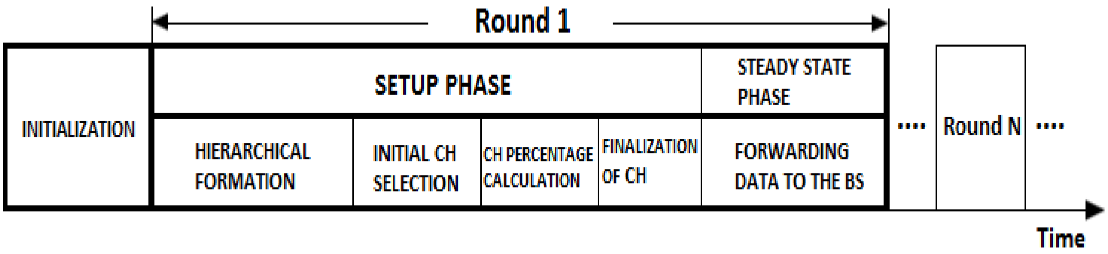

Figure 4.2 Timeline of the proposed Methodology

The Set-up Phase

The chief actions during the set-up phase are the hierarchical layer formation, election of candidate nodes, initial selection of cluster heads, calculating the percentage of cluster heads, scheduling at each cluster, finding cluster head for CH-to-CH data transmission and finalization of the CH.

During set-up phase, every node initially decides whether it could become a candidate node for the current round. An advertisement message has been used to elect the CHs. Every candidate nodes broadcast an advertisement message within its transmission limit. The advertisement range is twice the maximum distance to cover other levels. This choice is based on the available strength of the signal of the advertisement message.

When all the nodes have decided their respective clusters, the sensor nodes start transmitting its data to their suitable cluster head. The cluster head on receiving all the messages from the sensor nodes that would like to be incorporated in the cluster, and based on the number of sensor nodes contained in the cluster, the cluster head creates a schedule and allocates every node with a time slot for data transmission.

For this sole reason, every cluster head makes use of two-way handshake technique containing messages like Request (REQ) and Acknowledgement (ACK). Each and every cluster head broadcasts a REQ message within its own advertisement range.

When the cluster head receives this REQ message, it transmits an ACK message back to the cluster head that has transmitted the REQ message. The node that transmitted REQ message on receiving the ACK message, it chooses this cluster head which transmitted the ACK message as the next successive hop. If the cluster head could not find the upward cluster head it decides the base station as the next hop.

The Steady-State Phase

In EHDCA, the steady state phase is similar to other cluster-based schemes. The main activities done in this phase are sensing and transmission of the sensed data. Each sensor node performs sensing operation and transmits the data to its respective cluster head during its assigned time schedule.

When every data has been received, the cluster head carries out data aggregation in order to further reduce the amount of data for communication. Each cluster head finally transmits the aggregated data to the base station along the CH-to-CH routing path which has been constructed during the set-up phase.

After every data has been transmitted, the network returns back to set-up phase again and the next successive round begins by electing fresh candidate nodes.

PERFORMANCE EVALUATION

The performance of the proposed EHDCA clustering methodology has been evaluated through simulations for 30 wireless sensor nodes and the results have been compared with LEACH. All the simulations have been carried out using NS-2. The sensor nodes are considered to be immobile (stationary) with uniform initial energy level of 1 Joule. The sensor nodes are thoroughly prepared with every possible power control capabilities. The base station has sufficient energy and energy scarcity does not occur at any cost.

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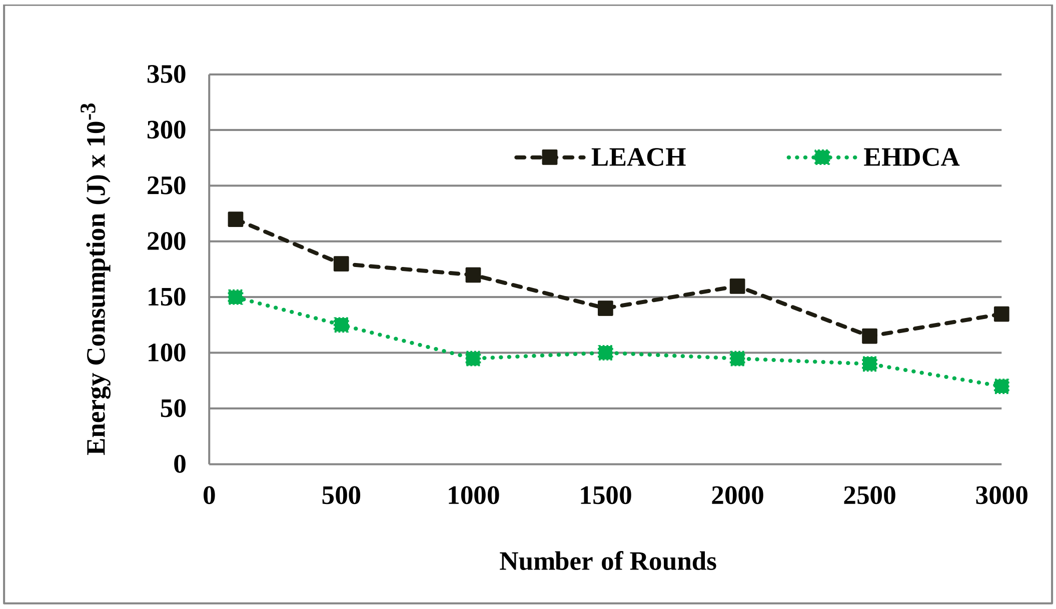

Figure 4.3 Total energy consumption in LEACH and EHDCA

Figure 4.3 shows the total energy consumption for each round for both LEACH and EHDCA. Initially at 100 rounds, the total energy consumption is 0.22 Joules and 0.15 Joules for LEACH and EHDCA respectively. Similarly for 3000 rounds, the energy consumption is 0.135 Joules and 0.07 Joules for LEACH and EHDCA respectively. The average energy consumption is 0.160 Joules for LEACH and 0.104 Joules for EHDCA.

EHDCA shows 35% reduced energy consumption when compared to LEACH. This is because, the proposed EHDCA methodology reduces needless creation of cluster heads and utilizes the CH-to-CH routing path, and thereby unnecessary energy utilization is avoided.

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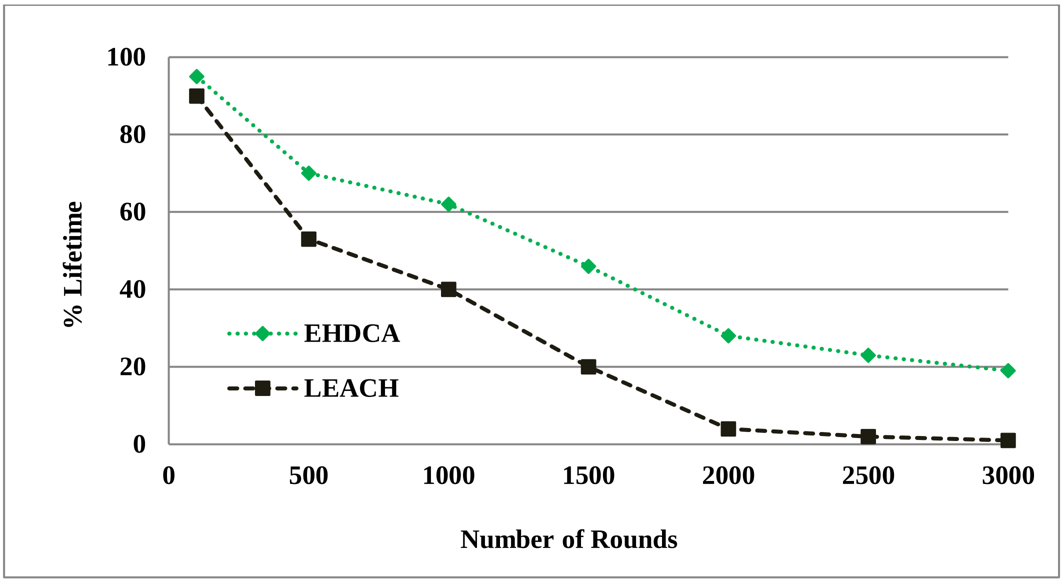

Figure 4.4 Percentage Lifetime in LEACH and EHDCA

Figure 4.4 shows the percentage lifetime for particular number of rounds for both LEACH and EHDCA. Initially in 100 rounds, the percentage lifetime of LEACH is 90% and that of EHDCA is 95%. Similarly in 3000 rounds, the percentage lifetimes of LEACH and EHDCA are 1% and 19% respectively. At an average, EHDCA shows 19% improvement in lifetime when compared to LEACH. This clearly shows that the proposed EHDCA methodology has enhanced lifetime when compared to LEACH, because of the hierarchical concepts employed in the proposed methodology.

Figure 4.5 shows the percentage backbone energy consumption against number of rounds for both LEACH and EHDCA. The backbone energy consumption is lesser in EHDCA when compared to LEACH for all the successive rounds. The average percentage backbone energy consumption in LEACH and EHDCA is 23.57% and 14.71% respectively. EHDCA shows 37.59% reduced backbone energy consumption when compared to LEACH. This is mainly because LEACH uses random CH selection mechanism and direct forwarding of data to the BS by the cluster head. But EHDCA employs hierarchical method for cluster formation and the aggregated data

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is not directly forwarded to the base station. Thus, it could be clearly seen that the proposed methodology is highly efficient in terms of backbone energy consumption when compared to LEACH.

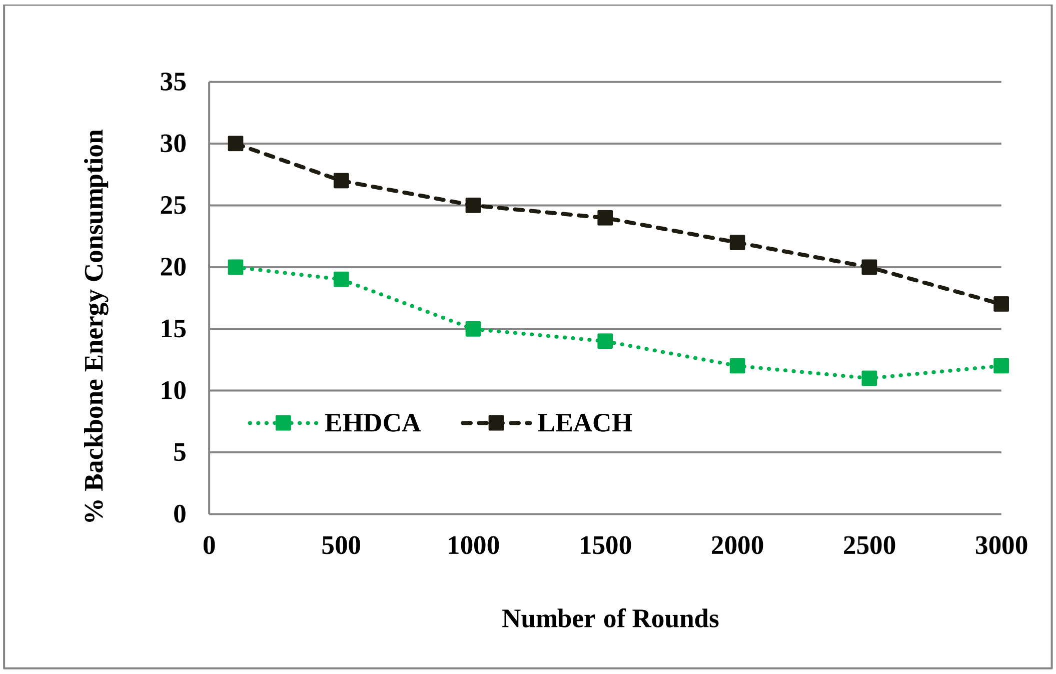

Figure 4.5 Backbone Energy Consumption in LEACH and EHDCA

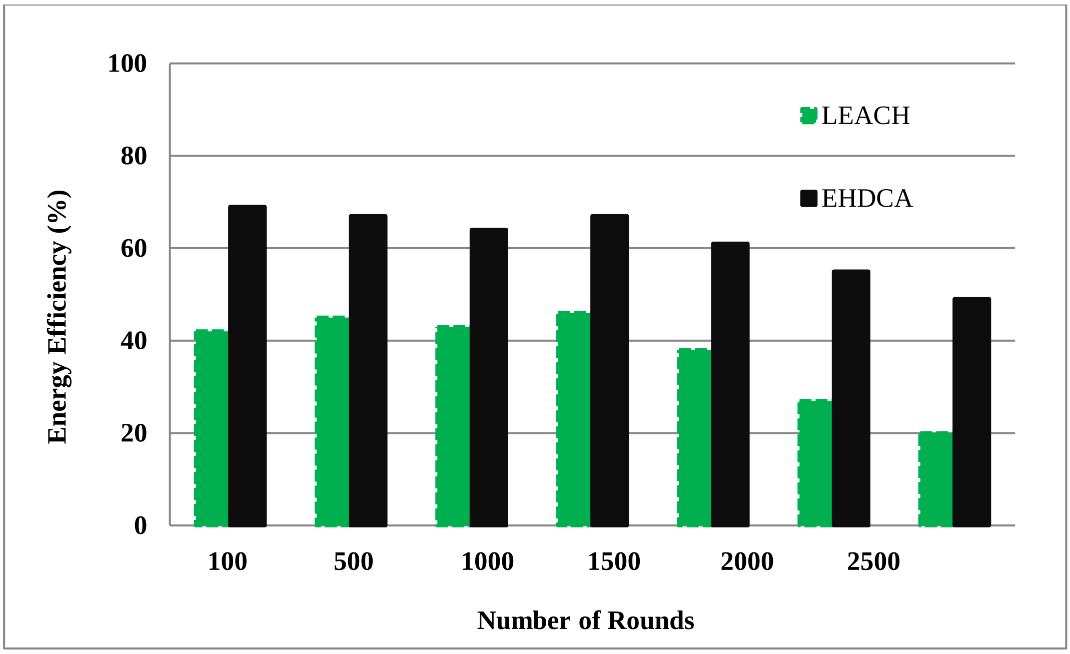

Figure 4.6 Energy Efficiency Comparison in LEACH and EHDCA

Figure 4.6 shows the energy efficiency comparison of both ECDCA and LEACH. Initially in 100 rounds, the energy efficiency is 42% and 69% for LEACH and EHDCA respectively. Similarly in 3000 rounds, the energy efficiency is 20% and 49% respectively for LEACH and EHDCA. Throughout the process, the energy efficiency is better in EHDCA when compared to LEACH. Thus, it could be clearly understood that the proposed EHDCA mechanism is a well-distributed and energy-efficient clustering mechanism, and could be employed for effective clustering of sensor nodes in wireless sensor network.

SUMMARY

This module is concerned with the proposal of EHDCA methodology for static wireless sensor network. This methodology employs hierarchical architecture for cluster formation. The peculiar feature of this technique, compared to the existing techniques is that the election of cluster head, cluster nodes and monitoring of residual energy is purely done by the cluster head. Since base station does not involve in these processes, unnecessary energy wastage for long distances communication is avoided, thereby reducing energy usage to much extent. Simulation results clearly show that the proposed EHDCA methodology depicts an excellent reduction in backbone energy consumption and total energy consumption. Nevertheless, the energy efficiency in EHDCA is improved to a great extent. It is noted that the first node death and final node death are greatly delayed, thereby the overall lifetime of the wireless sensor network is improved by the proposed EHDCA methodology.

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Module 5

MOBILITY ASSISTED CLUSTERING METHODOLOGY

INTRODUCTION

Wireless sensor network is gifted for accessing real-world information about the physical environments. Few deployments of wireless static sensor network are done using Berkley smart dust, μ-Adaptive multi-domain power aware sensors and wireless integrated sensor networks. In static wireless sensor network, few parameters like mobility is not considered thereby mobility becomes the next evolutionary criterion to be carefully considered. The dynamic environment of wireless sensor network introduces exclusive confronts like data management, accuracy, coverage, security and software configuration. One of the vital contemplations in wireless sensor nodes is the route maintenance when the node moves. The conservative protocols for static sensor network are to be optimized carefully when mobility is introduced. To learn the performance of these protocols, the mobility patterns and mobility metrics have to be subjectively considered.

In this module, an enhancement over the LEACH-M protocol has been anticipated, which is appropriate for mobile wireless sensor networks (MWSN). The proposed clustering algorithm, the mobility assisted dynamic clustering algorithm (MADCA) has been well-evaluated to support mobility. This is a hierarchical one, and the concept of cluster head panel has been employed in the proposed algorithm to minimize re-clustering time and energy consumption. By employing these techniques to the proposed algorithm, energy efficiency and life time of the sensor nodes have been found to be greatly prolonged.

RELATED WORKS IN MOBILE WIRELESS SENSOR NETWORK

This section briefly outlines the related works in mobile wireless sensor network and LEACH protocol improvements. In general, the mobility of sensor nodes perks up the sensing coverage as worked out by (Liu et al 2005). Few techniques like the Robotic Fleas project in Berkeley, the Robomote and the Parasitic Mobility attempts to facilitate mobility in wireless sensor network as demonstrated by (Laibowitz and Paradiso 2005). The data mule technique could be used to powerfully gather the data by reducing data delivery latency with bare minimum energy consumption in mobile sensor network (MSN) as formulated by (Anastasi et al 2007; Ekici et al 2006).

One real world application of MSN is the Adaptive Sampling and Prediction (ASAP) in which a fleet of undersea mobile sensor nodes manages and collects the measurements of ocean without any human intervention. An adaptive navigation system has been devised, in which the sensors equipped on vehicles is capable of collecting the real time traffic information and exchanging them among the neighbouring vehicles as formulated by (Huifang et al 2007). A mobility management service layer in the Sensor-Net Protocol has been implemented, which is a cross layer approach and the mobility information is stored in a database so that it is noticeable across all the layers as illustrated by (Ali et al 2006). A novel idea called the network dynamics has been investigated to crack the mobility management issue which is a previous effort to devise the laws that oversee mobility annoyed by classical dynamics as investigated by (Ma et al 2008). Ultimately, the mobility of sensor nodes is of immense significance and there is rising research inclination towards leveraging the sensor node mobility to augment the network performance in terms of energy efficiency, lifetime and fault tolerance.

Enhancements on LEACH Protocol

LEACH motivated the proposal of several other descendant protocols which attempts to perk up the cluster head selection process as illustrated by (Yang and Sikdar 2007; Zhixiang and Bensheng 2007). LEACH protocol does not support sensor node mobility. In mobile environments, an agent based data collection methodology has been investigated, where a mobile agent efficiently processes the data and reduces the total energy expended by the network as worked out by (Jeong et al 2008). A novel methodology LIMOC has been proposed, which is a system to augment the lifetime of the sensor network in which the moving cluster heads work together intelligently with each other to route the data to the distantly located base station as illustrated by (Banerjee et al 2007).

The improvement over LEACH to sustain mobility has been pioneered as LEACH-Mobile (LEACH-M) which was brought out by (Do-Seong and Yeong-Jee 2006). The fundamental idea in LEACH-M is to verify whether a mobile sensor node is capable of communicating with a particular cluster head. LEACH-M uses the similar set-up process as used in the basic LEACH protocol. Sensors elect themselves to be local cluster heads at any given time with a definite probability. These cluster head nodes broadcast their condition to other nodes in the sensor network. Every node determines to which cluster it wants to fit-in by deciding the cluster head that requires the least amount of communication energy. When every sensor nodes are prearranged into clusters, each cluster head forms a TDMA schedule for the sensor nodes in its cluster for collecting the sensed data. The wireless components of each non-CH node is turned off at all times excluding its transmit time, thereby reducing the energy dissipated by individual the sensor nodes. The aggregated data is then forwarded to the base station by the cluster head.

SYSTEM MODEL AND PROBLEM STATEMENT

The System Model

The sensor nodes are all similar in hardware, software and capabilities. Initially all the sensor nodes have equal amount of initial energy of 1 Joule, but after some time of operation, the nodes may be left with unequal energy levels. The sensor nodes as well the base station are moderately mobile. The base station is highly reliable and resourceful. After deployment of sensor nodes in the field, the field is logically partitioned into clusters. The base station forms these clusters and each cluster contains one cluster head node and two supporting deputy cluster head (DCH) nodes. Communication takes place in hierarchical fashion from sensor node to the base station through the cluster head. The communication between a cluster head node and base station will be in multi-hop fashion depending on the situation. The selection of nodes for various roles such as cluster head or deputy cluster head will be carried out at the base station level.

The Problem Statement

The key aim of this work is to design an energy efficient clustering algorithm for mobile wireless sensor network that operates in unattended and sometimes in hostile environments. As the sensor nodes are resource constrained (specially limited energy and limited on-board storage), the algorithm should consume low power and should not burden the nodes with

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storage overhead. The algorithm should ensure that connectivity is maintained in the network and in presence of link or node failure it should be capable of offering all alternate routes without allowing much degradation in throughput level at the base station. Most importantly, the lifetime of the wireless sensor network should be prolonged.

THE PROPOSED MADCA METHODOLOGY

In this section, the mobility assisted dynamic clustering algorithm (MADCA) has been investigated for effective clustering in mobile wireless sensor network, where both the sensor nodes as well as the base station are mobile. The objective of the proposed algorithm is to improve the lifetime of sensor nodes in the network. In the existing algorithm (LEACH-M), the sensor nodes keeps on sensing the data and sending the data to its cluster head, and this cluster head sends the data only when the base station comes in range with the cluster head. In the proposed algorithm, the sensors start sensing the data only when the base station comes in range with the cluster head. The algorithm manages the energy efficiency of the routes as well as the reliability of the routes. The data packets are routed through multiple hops in order to minimize the transmission energy requirement at the sender nodes. This help to trim down large amount of energy and also the battery life of the sensor nodes get increased.

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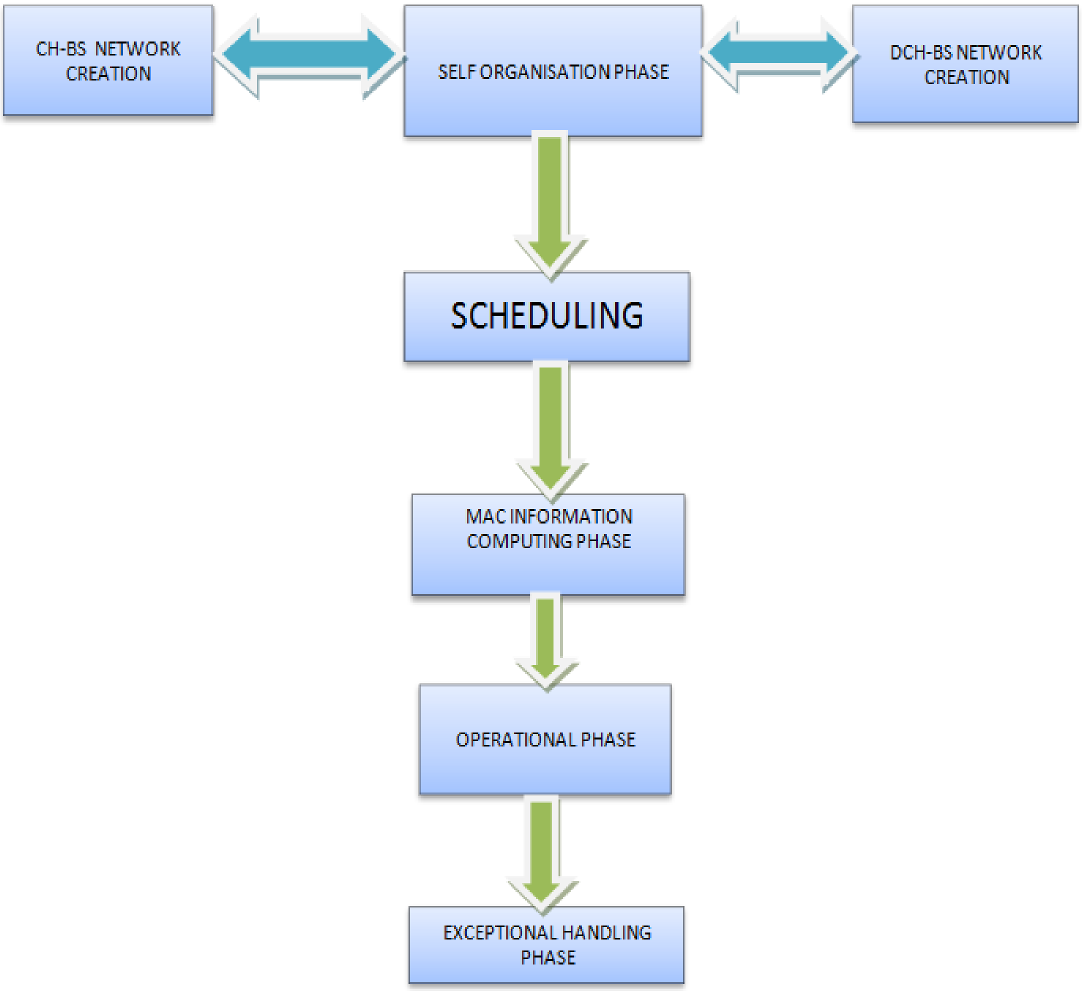

Figure 5.1 Flowchart of Proposed Clustering Methodology (MADCA)

After the deployment of sensor nodes, the base station groups different sensor nodes into clusters. Each cluster contains one cluster head node and two deputy cluster head nodes. There are three criteria to select the cluster head: the energy efficiency of the sensor node, the mobility of the sensor node and the accessibility to the neighbouring sensor nodes. This arrangement is also called as cluster head panel. The sensor nodes send the data to their respective cluster head. At the CH level, data aggregation has been carried out to remove data redundancy and then the CH forwards the aggregated data to the base station. The DCH nodes do several cluster management tasks such as mobility monitoring and also remain ready to act as intermediate hop in the presence of fault. The DCH nodes are also called as cluster management nodes. Figure 5.1 shows the flowchart of the proposed MADCA clustering methodology for mobile wireless sensor network.

If the base station observes that the arrival of data packets is lesser than a threshold value, then it informs the respective CH to check the connectivity with its cluster members. The CH considers this as feedback from the base station and accordingly checks the current connectivity with its cluster members. If the connectivity status of the cluster members with the cluster head is very poor, the base station decides to shift the charge of cluster head to another suitable member from the cluster head panel already determined or to one of the deputy cluster heads depending on the situation. If this new CH also goes out of the range of the base station, the sensed data from the sensor nodes will be forwarded to the cluster head of nearest cluster, thereby the data will be forwarded to the base station. If this CH also goes out of range with the base station, then the data from the first CH and the data collected from this CH will be forwarded to the next nearest CH. In this situation, this CH sends the data of all the three cluster heads. Since the base station keeps on collecting the data, data aggregation will be done by the CH to remove data redundancy.

The Self-Organization Phase

After the deployment of wireless sensor nodes, the first phase is the self-organization phase. During this phase, clusters are formed and cluster head gets finalized. The current cluster head and deputy cluster heads are also selected by the base station. Initially, the base station collects the current location information from each sensor nodes and then forms a sensor field map. Based on the velocity of a sensor node, the base station prepares a rough estimate of the zone in which the sensor node is going to be in the next time interval. The value of the next time interval can be set manually depending on the type of application and this value is critical as most of the computations e.g., cluster setup validity period, medium access slot, etc., are dependent on the next time interval. Using this information, the base station computes the topology. Once the base station creates the sensor field map, it forms the clusters. The cluster formation approach is quite simple. The basic idea is to maintain geographically uniform distributed clusters, so that the coverage is uniform and also the cluster head nodes are uniformly distributed over entire sensor field. Therefore, the entire sensor field is geographically and uniformly divided into multiple clusters. After formation of clusters, the base station identifies a set of suitable nodes which can take the role of cluster head and deputy cluster heads. This selection is based on cumulative credit point earned from the three parameters namely the residual energy level of the node, degree of the node and mobility level of the node.

The user can use a suitable normalization function to compute the cumulative credit point earned by a sensor node through these three non-homogeneous parameters. An ideal node suitable for CH role should have higher residual energy, higher degree and low mobility. The base station then prepares the cluster head panel consisting of nodes having cumulative credit point above the threshold value. This threshold value can be set manually at the time of implementation, also depending on the type of application and normalization function. The node with highest credit point is selected as the current cluster head. The next two nodes in the list with second and third highest credit points are selected as deputy cluster heads for the same cluster.

The Role of Cluster Head Node

The cluster head is responsible for collecting data from every sensor nodes. After data collection, the CH carries out data aggregation on the collected data to remove data redundancy. The aggregated data is sent to the base station either directly or in multi-hop fashion based on the communication pattern distributed by the base station.

The Role of Deputy Cluster Head Node

The DCH keeps monitoring the sensor nodes in their cluster and keeps on checking the mobility pattern of the sensor nodes. They are also referred as cluster management nodes, as they take the major responsibility in collecting the current location information from the cluster members and communicating it to the base station. Moreover, in the event of immediate link or node failure in the route of CH towards the base station, the cluster head seeks the aid of one of the deputy cluster head nodes to forward the data to the base station.

The Use of Cluster Head Panel

The cluster head panel is selected initially and remains valid till re-clustering process is initiated. If the current cluster head drops out the connectivity with most of its clusters members, due to which throughput at the base station degrades, the cluster head might be asked to relinquish the charge of cluster headship. Even a cluster head node might drain out its energy beyond a threshold value and becomes useless, whereas in this situation a new cluster head is necessary. Under such circumstances, the base station gives the charge of headship either to one of the two deputy cluster heads or to a node from within the cluster head panel. This saves huge cost and time

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involved in the process of selecting a cluster head. An instance of shifting the charge of cluster headship from CH to DCH is very important, as the base station also instructs the sensor nodes to join the DCH as their new CH.

SIMULATION RESULTS AND ANALYSIS

The effectiveness of the proposed clustering methodology has been validated through simulation. The results and the evaluated values have been compared with a well-evaluated distributed clustering algorithm (LEACH-M).

Table 5.1 Simulation Parameter Setup for MADCA

Simulation Parameter	Values
Network Topology	500 x 500 m^2
Number of mobile nodes	30
Data packet size	4000 bytes
Control packet size	550 bytes
Initial energy	1 Joule
Transmitter power	31.32 mW
Receiver power	35.28 mW
Ideal power	712 mW
Sleep power	144 mW
Mobility Model	Random Way Point Model
Radio Model	First Order Radio Model
Sensor Node Deployment	Random Deployment

Simulation Settings

For simulation purpose, a sensor network of 30 nodes is randomly deployed over a field of dimension 500 x 500 m^2 area. The sensor nodes move in random directions. The simulation has been executed for a period of 1800 seconds. All the sensor nodes are assumed to have equal amount of initial energy. The initial energy of the sensor nodes are considered to be 1 Joule. All the simulation works have been carried out using NS-2. Table 5.1 exhibits the parameters needed for conducting simulation works.

Experimental Results

The simulator consists of different modules such as deployment module, topology construction module, mobility management module, medium access control module, routing module, energy expenditure computing module and throughput computing module. The performance of the proposed algorithm has been evaluated against LEACH-M in terms of average communication energy, network lifetime and node death rate. Figure 5.2 shows the performance evaluation of the proposed MADCA algorithm with LEACH-M, in terms of the average communication energy. Initially at 100 seconds, the average communication energy of LEACH-M is 0.17 Joules and that of MADCA is 0.13 Joules. Similarly at 1800 seconds, the average communication energies of LEACH-M and MADCA are 0.28 Joules and 0.18 Joules respectively. At an average, the proposed MADCA algorithm shows a reduction of 29.05% in terms of average communication energy when compared to LEACH-M. Thus the average communication energy is found to be reduced linearly in MADCA, when compared to the existing LEACH-M algorithm, which is mainly because of the above mentioned novel features employed in the proposed MADCA algorithm.

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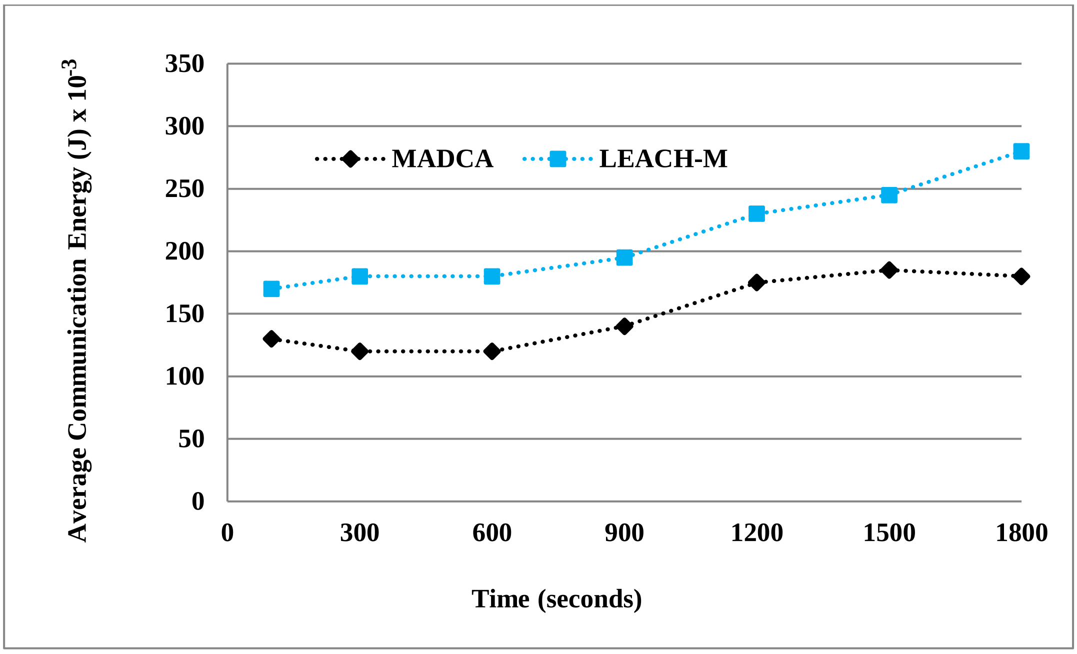

Figure 5.2 Average Communication Energy of LEACH-M and MADCA

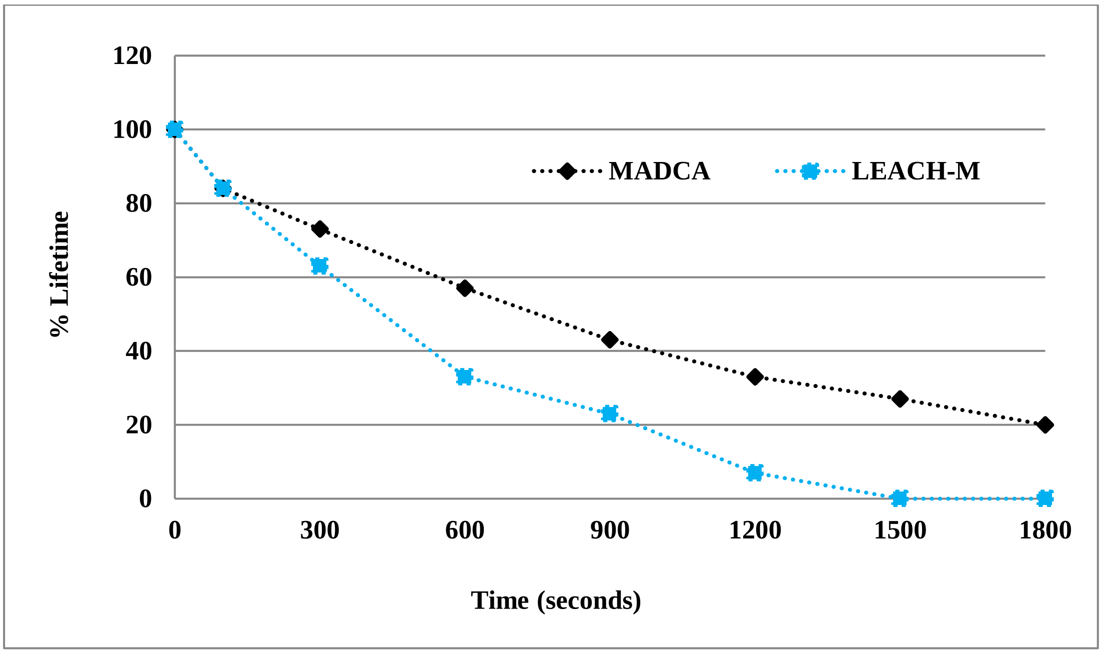

Figure 5.3 Lifetime comparison of LEACH-M and MADCA

Figure 5.3 shows the lifetime comparison of both LEACH-M and MADCA algorithms. At 100 seconds, the lifetime of both LEACH-M and MADCA

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are 84%. The network lifetime falls rapidly in LEACH-M, but in MADCA the network lifetime reduces slowly. In 1500 seconds, the lifetime of LEACH-M drops to 0%, but in MADCA the lifetime is 27%. At an average, MADCA shows 15.87% improvement in network lifetime when compared to LEACH-M. This lifetime improvement is mainly due to the novel concepts employed in MADCA methodology.

Figure 5.4 depicts the comparison of node death for both LEACH-M and MADCA. At 100 seconds, the number of node death is only 5 nodes for both LEACH-M and MADCA. Node death is drastic in LEACH-M and at 1500 seconds every nodes die. But in MADCA, the node death is less and even at the end of simulation (1800 seconds) 6 nodes are still alive. Thus, MADCA shows reduced node death when compared to the existing LEACH-M clustering methodology.

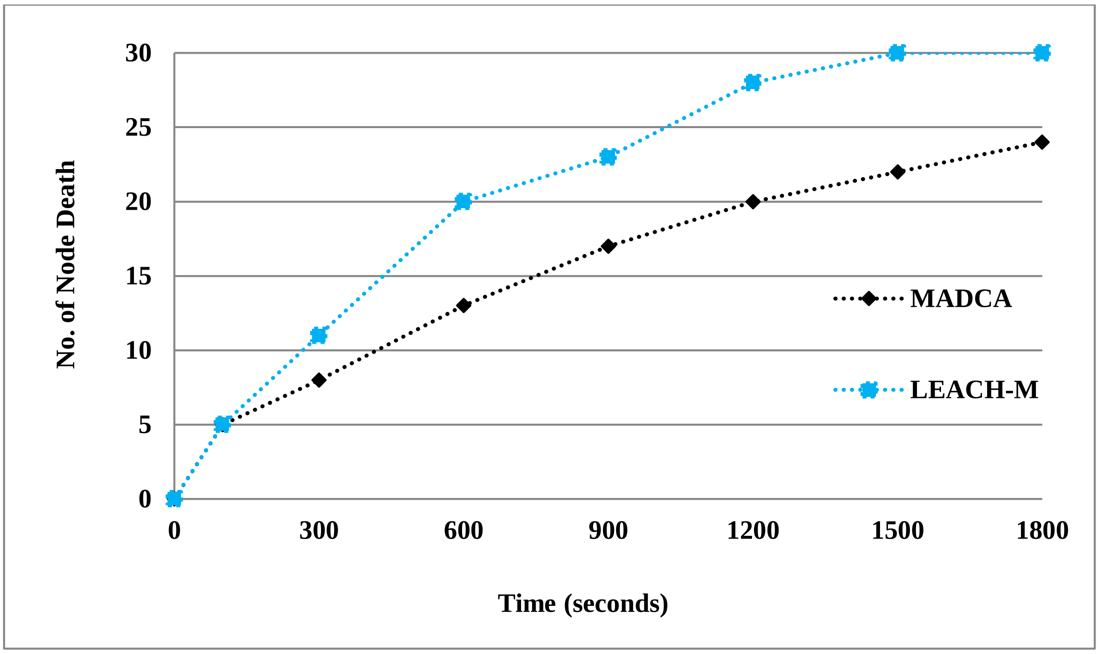

Figure 5.4 Node death versus Time (LEACH-M and MADCA)

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SUMMARY

In this module, a dynamic clustering algorithm for mobile wireless sensor networks, the MADCA has been proposed. The proposed clustering methodology MADCA is hierarchical, dynamic and energy-efficient algorithm for mobile wireless sensor network. MADCA forms multiple clusters with each cluster having one cluster head and two deputy cluster heads. The sensor nodes start collecting the data only when the base station comes in range with the cluster head. The performance of the proposed algorithm has been evaluated through simulations and the results have been compared with the existing LEACH-M algorithm. MADCA shows drastic reduction in average communication energy when compared to LEACH-M. The network lifetime has been found to be greatly prolonged in MADCA. The node death has been found to be greatly reduced in the proposed algorithm. Thus the proposed clustering methodology has been found to be greatly useful when both the sensor nodes as well as the base station are mobile.

Module 6

RESULTS AND DISCUSSIONS

INTRODUCTION

Distributed clustering plays a vital role in attaining energy efficiency in wireless sensor network. The proposed distributed clustering methodologies HEECA, VEEC and EHDCA have been well evaluated using simulations particularly for static wireless sensor network. Also, the proposed algorithm MADCA has been analysed for mobile wireless sensor network. This module gives a detailed analysis over the simulation results attained for all these proposed distributed clustering methodologies for various parameters for static wireless sensor network. The parameters considered for analysis include throughput, energy efficiency, residual energy, energy consumption, number of cluster heads selection, number of packets delivered to the base station and network lifetime.

RESULT ANALYSIS

Figure 6.1 reveals the comparison of percentage network lifetime against number of rounds for HEECA, VEEC, EHDCA, O-LEACH, HEED and LEACH. In general, network lifetime is the time until the first node or group of nodes in the sensor network runs out of energy or it is the quantity of time for which a wireless sensor network would be completely

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operative. This metric is commonly used in wireless sensor network literature to reflect the time span from the initial exploitation of the network to the first loss of coverage.

Table 6.1 Tabulated values for lifetime against Number of Rounds

Number of Rounds		100	500	1000	1500	2000	2500	3000
% Lifetime	HEECA	90	80	72	65	58	48	44
	VEEC	90	90	90	53	30	20	14
	EHDCA	95	70	62	46	28	23	19
	O-LEACH	90	72	62	43	24	20	14
	HEED	90	60	42	24	7	3	2
	LEACH	90	53	40	20	4	2	1

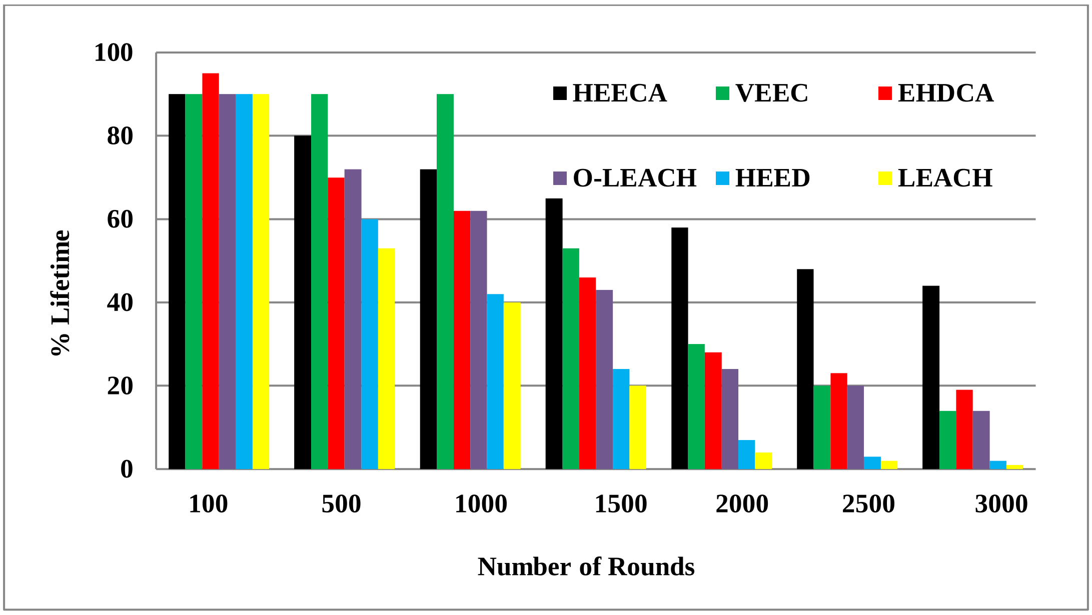

Figure 6.1 Percentage Network lifetime Comparison

The network setup or methodology that minimizes the maximum node load is the one that will guarantee the maximum network lifetime. At an average, HEECA shows 50% and 29% lifetime improvement over HEED and O-LEACH respectively.

A moderate difference of 25.57% and 23.43% is seen in VEEC with respect to LEACH and HEED in terms of average network lifetime. At an average, EHDCA shows 19% improvement in lifetime when compared to LEACH.

Figure 6.1 clearly reveals that till 1000 rounds, the network lifetime of VEEC is much better (90%) when compared with other methodologies. So, in cases where the number of rounds is limited to be less than 1000 rounds the proposed methodology VEEC is highly preferable.

Only in the proposed methodology HEECA, the percentage lifetime varies in a better and steady manner (90% to 44%) till 3000 rounds compared to all other methodologies. In situations where the network lifetime has to be maintained linearly without sudden drops, the proposed methodology HEECA could be employed.

The average network lifetime is 65.28% for HEECA, 55.28% for VEEC and 49.0% for EHDCA. An improvement of 15.31% is shown by HEECA when compared to VEEC and 9.62% improvement when compared to EHDCA.

Among all the proposed methodologies, HEECA shows an excellent and improved average network lifetime.

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Table 6.2 Tabulated values for throughput against Number of Rounds

Number of Rounds		100	500	1000	1500	2000	2500	3000
% Throughput	HEECA	40	38	37	45	50	47	49
	O-LEACH	32	30	26	38	40	36	37
	HEED	22	26	18	23	25	24	26
	LEACH	27	22	20	36	33	30	24

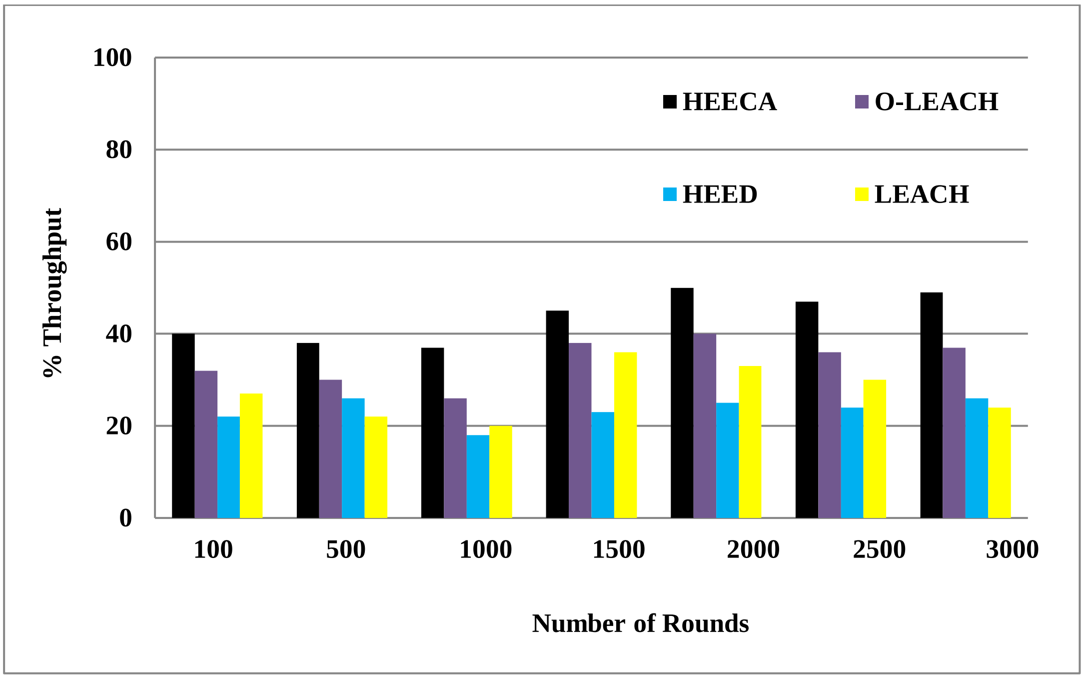

Figure 6.2 Percentage throughput Comparison

Figure 6.2 shows the comparison of percentage throughput against number of rounds for HEECA, O-LEACH, HEED and LEACH. Throughput is the number of messages fruitfully delivered per unit time and is controlled by the available bandwidth, obtainable signal to noise ratio and hardware limitations. The average throughput value is 43.71% for HEECA, 34.14% for O-LEACH,

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23.42% for HEED and 27.42% for LEACH. At an average, 46% improvement is shown by HEECA over HEED, 22.0% over O-LEACH and 37.26% over LEACH. Thus among all the existing and proposed methodologies, HEECA depicts an excellent improvement in throughput.

Table 6.3 Tabulated values for Energy Efficiency for Number of Rounds

Number of Rounds		100	500	1000	1500	2000	2500	3000
% Energy Efficiency	HEECA	70	67	64	67	61	59	55
	EHDCA	69	67	64	67	61	55	49
	O-LEACH	40	35	30	17	12	8	5
	HEED	55	49	45	49	38	25	21
	LEACH	42	45	43	46	38	27	20

Figure 6.3 shows the comparison of percentage energy efficiency against number of rounds for HEECA, EHDCA, O-LEACH, HEED and LEACH. In the proposed algorithms HEECA and EHDCA, the energy efficiency is maintained at a maximum optimal value.

In O-LEACH, the energy efficiency shows a sudden decrease with the number of rounds. At an average, the energy efficiency of HEECA is 63.28%, that of EHDCA is 61.71%, that of O-LEACH is 21.0%, that of HEED is 40.28% and that of LEACH is 37.28%. HEECA depicts maximum energy efficiency when compared to EHDCA, O-LEACH, HEED and LEACH.

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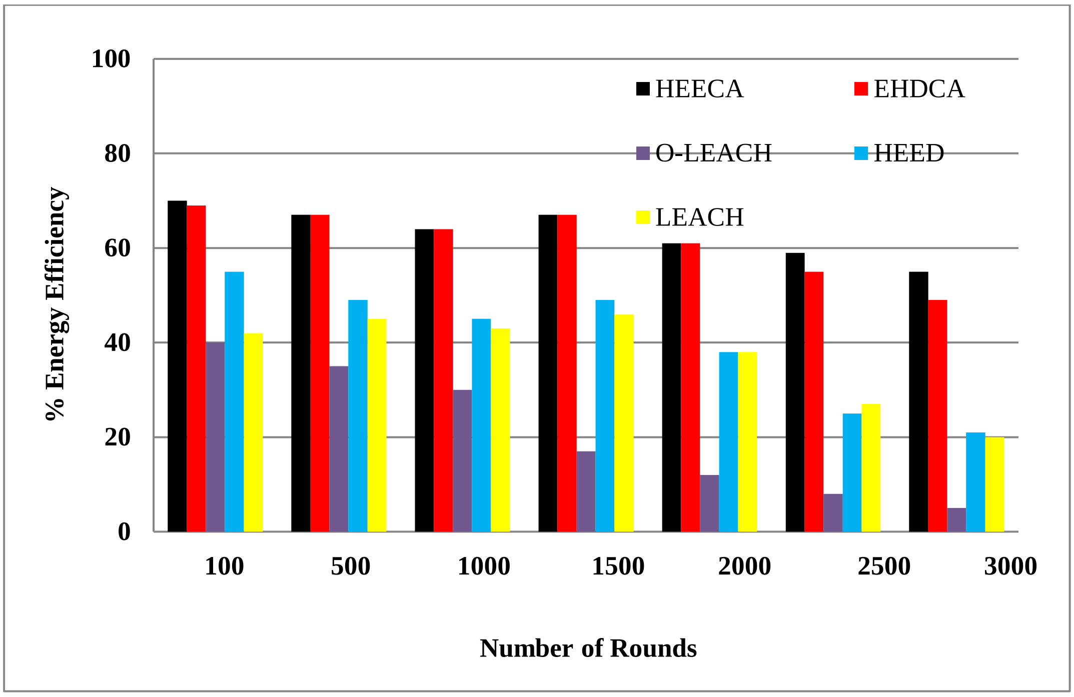

Figure 6.3 Percentage Energy Efficiency Comparison

At an average, the proposed algorithm HEECA shows an improvement of 2.48% in comparison with EHDCA, 66.81% improvement in comparison with O-LEACH, 36.34% improvement in comparison with HEED and 41.08% improvement in energy efficiency when compared to LEACH.

Thus when energy efficiency is a vital area of focus, the proposed algorithm HEECA could be employed. Figure 6.4 depicts the comparative analysis of energy consumption against number of rounds for HEECA, VEEC, EHDCA, O-LEACH, HEED and LEACH. For any sensor network to have prolonged network lifetime, one basic criterion is to have reduced energy consumption by the sensor nodes.

The proposed algorithms VEEC, EHDCA and HEECA depict lower energy consumption when compared to O-LEACH, HEED and LEACH.

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Table 6.4 Values for Energy Consumption for Number of Rounds

Number of Rounds		100	500	1000	1500	2000	2500	3000
Energy Consumption (Joules)	HEECA	0.225	0.21	0.19	0.175	0.16	0.14	0.125
	VEEC	0.09	0.1	0.095	0.1	0.105	0.09	0.09
	EHDCA	0.15	0.125	0.095	0.1	0.095	0.09	0.07
	O-LEACH	0.33	0.275	0.24	0.25	0.26	0.22	0.24
	HEED	0.3	0.24	0.225	0.235	0.21	0.16	0.18
	LEACH	0.22	0.18	0.17	0.14	0.16	0.115	0.135

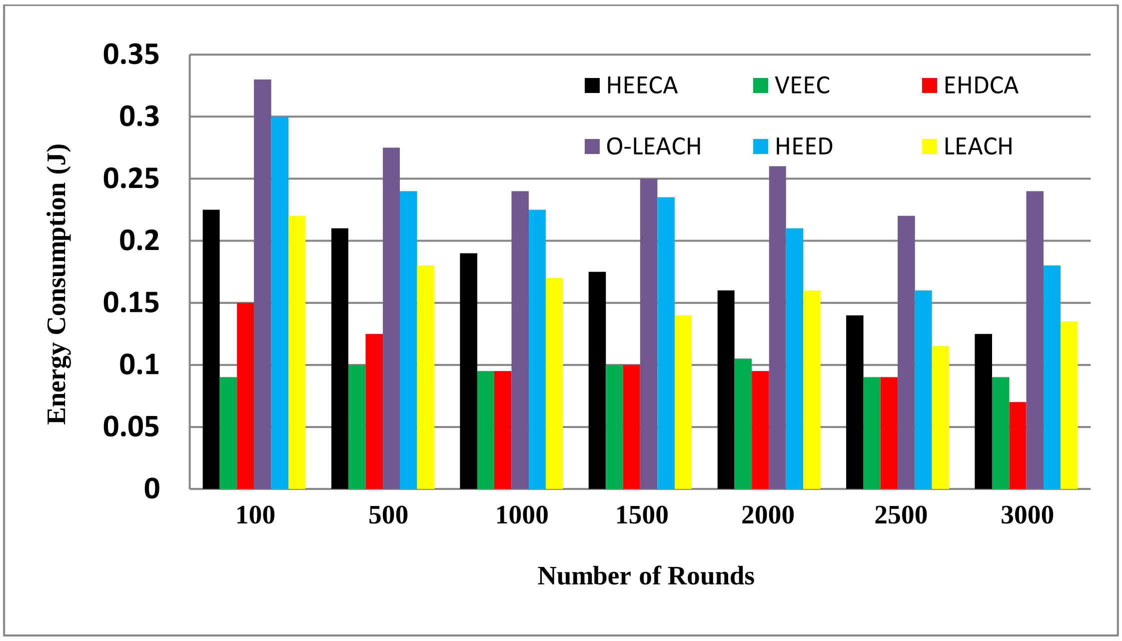

Figure 6.4 Energy Consumption Comparison

The average energy consumption of VEEC is 0.096 Joules, that of EHDCA is 0.104 Joules, that of HEECA is 0.175 Joules, that of O-LEACH is 0.259 Joules, that of LEACH is 0.160 Joules and that of HEED is 0.221 Joules. The proposed algorithm VEEC shows an improvement of 82.0% when compared to HEECA and 7.29% when compared to EHDCA. Thus, among the proposed methodologies VEEC clustering mechanism shows reduced energy consumption.

SUMMARY

Various distributed clustering mechanisms have been proposed in this research work for the betterment of few parameters like throughput, energy efficiency, residual energy, energy consumption, number of cluster heads selection, number of packets delivered to the base station and network lifetime. The simulated values obtained from the previous modules have been integrated together in this module. Various comparisons have been carried out to find the best algorithm for every parameter. Among every methodologies discussed, HEECA shows an excellent improvement in network lifetime. Also, among all the clustering methodologies, HEECA depicts an excellent improvement in throughput. When energy efficiency is a vital area of focus, the proposed algorithm HEECA is highly effective. VEEC clustering mechanism shows reduced energy consumption among all the distributed clustering methodologies.

Module 7

CONCLUSION AND FUTURE DIRECTIONS

CONCLUSION

The distributed wireless sensing systems open up entirely new ways and issues for scientists and engineers to monitor the environmental phenomena and react to them. Among many hurdles needed to be overcome, energy utilization in communication links is one major issue of concern. A detailed introduction to wireless sensor network, their features, advantages and limitations have been elaborated in this thesis. Also, the design issues and real-world applications of wireless sensor network have been discussed in a well-structured manner. The methodology of clustering and the manner by which the cluster head gets elected have been discussed in detail. A literature survey of available clustering algorithms for wireless sensor network has been clearly discussed. The different classifications of distributed clustering techniques, the manner by which the clustering process is carried out and the way by which the cluster head gets rotated has been functionally elaborated.

A distributed clustering methodology for evaluating the clustering parameters of two separate wireless sensor network fields, the hybrid energy efficient clustering algorithm (HEECA) has been proposed, in which the optical fiber link in the existing method is replaced by distributed relay nodes for connecting two separate WSN fields. Based on three novel techniques: zone based transmission power (ZBTP), routing using distributed relay nodes

(DRN) and rapid cluster formation (RCF), the proposed clustering methodology has been well-evaluated for efficiency against two distributed clustering algorithms O-LEACH and HEED. HEECA shows better lifetime improvement in comparison with O-LEACH and HEED. The residual energy of the sensor nodes are also more when compared to O-LEACH and HEED. The energy consumption of the proposed algorithm HEECA is much reduced when compared with the existing methodologies. The throughput and energy efficiency is also found to be improved when compared to O-LEACH and HEED. Moreover, HEECA selects cluster head 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 energy-efficient wireless sensor network. The distributed relay nodes used in HEECA effectively connects two separate wireless sensor network fields with reduced packet loss in comparison with the existing O-LEACH algorithm with an optical fiber link.

A distributed clustering methodology, the variable power energy efficient clustering (VEEC) has been proposed. Based on single message for cluster-setup, variable transmission power and relay nodes, the algorithm VEEC has been formulated to form efficient clusters in wireless sensor network. The algorithm has been analysed and the performances are compared with LEACH and HEED. The proposed methodology VEEC shows much reduction in average communication energy when compared to LEACH and HEED. VEEC shows reduced system energy consumption when compared to the existing methodologies. Nevertheless, the proposed algorithm exhibits prolonged network lifetime and can be effectively employed in wireless sensor networks where energy efficiency is a vital concern.

The proposal of an energy efficient hierarchical distributed clustering algorithm (EHDCA) for static wireless sensor network has been carried out.

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The main feature of this technique, compared to the existing techniques is that the election of cluster head, cluster nodes and monitoring of residual energy are purely done by the cluster head. Since the base station does not involve in these processes, unnecessary energy wastage for long distance communication is avoided, thereby reducing power consumption to much extent. The performance of the proposed methodology has been compared with LEACH. The proposed algorithm EHDCA displays reduced energy consumption when compared to LEACH. EHDCA depicts an excellent improvement in network lifetime when compared to LEACH. The proposed algorithm EHDCA shows reduced backbone energy consumption when compared to LEACH. It is noted that the first node death and the last node death are delayed, thereby the overall network lifetime is prolonged.

A dynamic clustering algorithm for mobile wireless sensor network, the mobility assisted dynamic clustering algorithm (MADCA) has been proposed. The proposed methodology MADCA is hierarchical, dynamic and energy efficient algorithm for MWSN. In MADCA, there are multiple clusters, with each cluster having one cluster head and two deputy cluster heads. The sensors start collecting the data only when the base station comes in range with the cluster head. The performance of the proposed algorithm has been evaluated and compared with LEACH-M. The proposed MADCA methodology shows an excellent reduction in average communication energy. The network lifetime has been greatly improved when compared to LEACH-M. Thus, the proposed MADCA methodology has been found to be greatly useful in terms of energy usage and lifetime, when both the sensor nodes as well as the base station are mobile.

A consolidated analysis of the simulation results from all the proposed methodologies have been carried out. When a wireless sensor network has to be developed in which energy efficiency is a concern, the proposed

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methodology HEECA could be employed. For networks where mobility is an intense issue, the proposed methodology MADCA could be employed. When throughput is the focus of analysis for wireless sensor network, the proposed methodology HEECA could be employed. Where networks have to be constructed with prolonged network lifetime, the proposed HEECA methodology could be employed. When two separate wireless sensor network have to be effectively connected together, the clustering methodology HEECA could be employed. When reduced energy consumption by the sensor nodes is an intense issue, the proposed methodology VEEC could be employed.

FUTURE DIRECTIONS

As a future direction, these proposed clustering algorithms shall be incorporated with some real-world applications like building automation, enemy tracking in military, forest fire detection and environmental monitoring. Distributed clustering algorithms based on biologically inspired social insect colonies shall be developed. This work shall be extended towards wireless sensor actuator network, where some control actions could be taken on the basis of the sensed phenomenon, which could become a door-opening scheme for agricultural applications. More distributed clustering algorithms shall be developed for mobile wireless sensor network. Future works may also concentrate on the improvement of other parameters like routing, sleep-awake scheduling, delay-minimization and quality-of-service. The simulation works in this thesis have been carried out only using the network simulator (NS-2), but in future the simulation works shall be carried out using other available simulation tools like JSIM, REAL, OPNET and NETSIM. The modified versions of the distributed clustering algorithms contained in this thesis could be formulated for heterogeneous wireless sensor network. As a future work, the output from the sensors will be incorporated with the internet with IP connectivity for global monitoring. A methodology that reduces sensor network failure shall be developed which will be viable for harsh environmental applications. A distributed clustering methodology shall be developed for static and mobile wireless sensor network with excellent security. A distributed clustering methodology that reduces energy hole while clustering shall be investigated in future.

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