Optimization Techniques for Energy Consumption in Sensor Networks – Survey

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ABSTRACT
Advances in sensor networks has revealed several low energy sensors which are used to monitor the surroundings in our environment such as plants, factory instruments, transportation, energy, medicines etc. In this paper, an algorithm is proposed which helps in the enhancement of the network lifetime using clustering. Clustering is the method of forming groups of sensor nodes into clusters to preserve the energy. Each cluster has a leader node referred to as a cluster head. The proposed algorithm is an extension to the LEACH algorithm and attempts to reduce the workload on a cluster head. This paper also focuses on the challenges and impact of energy consumption in sensor networks. Further work emphasizes on future direction with its scope. Results are encouraging for researchers of this domain.

Keywords
Sensor Networks, Energy Consumption, Clustering.

1. INTRODUCTION
A sensor network is defined as a group of electronic devices which are used to record physical conditions such as temperature, pressure, humidity, speed, chemical compositions of objects, sound intensity and various compounds present in the environment. The network may be wired or wireless. Due to the advancements in this field wireless sensor networks are promised to be more efficient and therefore in this paper, a wireless sensor network is discussed. Such type of a network contains small, lightweight devices which are referred to as sensor nodes. These devices consist of the following hardware: a microcontroller, transceiver, transducer or sensor, a small RAM or flash memory, a power source, an analog to digital convertor [1-3]. The work of the sensor node is to gather the information and communicate with the other nodes present in the network and process the data. This processing of data and storing the output is performed by the microcontroller. Microcontroller is the most effective and common controller and is best suitable for this job as it uses low power consumption and has low cost of manufacturing. The transceiver performs two basic functions, that is, receiving the commands from the central computer and transmitting the data to that computer. It uses radio frequency to accomplish this task of transmission. These devices either use flash memory or RAM for the storage purpose. Flash memories are most commonly used as they are cost efficient. The work of the transducer or sensor is to generate electrical signals based on the sensed physical effects from the location. These signals are digitized by the analog to digital converter. Then the microcontroller processes and stores the sensed output in the flash memory Sensors can be of two types, passive or active. Passive sensors are self powered whereas active sensors needs continuous source of energy. The major work of the sensor is to monitor the physical conditions and they can be of several types, such as, passive infrared, thermal, magnetic etc [1].

An important aspect for the development of the sensor network is the power consumption control. There can be few variations in power source. Batteries are used which are generally the main source for providing power supply. They can either be rechargeable or non rechargeable by collecting solar energy from environment. It is also possible to plug the devices into a power outlet to be used in indoor applications (refer Fig.1).

1.1 Characteristics
The characteristics of the components of sensor nodes are listed as below [2].

I. Microcontroller: It behaves as the central controlling device due to its properties of low power consumption. Microprocessors can also be used instead of microcontroller but it is not preferable as they consume high voltage. A microcontroller controls the functionality of the components of node. Different architectures of microcontroller are used in diverse locations depending on the applications. Power consumption and cost efficiency are its major characteristics.

II. Transceiver: It can be either idle, receiving or sending state. Transceivers are used for providing path for the communication between sensor nodes and the base station. Frequency, data rate, transmission power and power consumption are its characteristics. Radio frequency is the most preferable. Data rates can be low or high according to the application. Transmission power determines the signal strength of the transmitted data.

III. Sensors: A sensor can be accurate depending upon its input and output interface. Sensors also play an important role in the power consumption.

IV. Power supply: Batteries are the main source of power supply which can be rechargeable and non rechargeable. Voltage range should be chosen according to the battery.

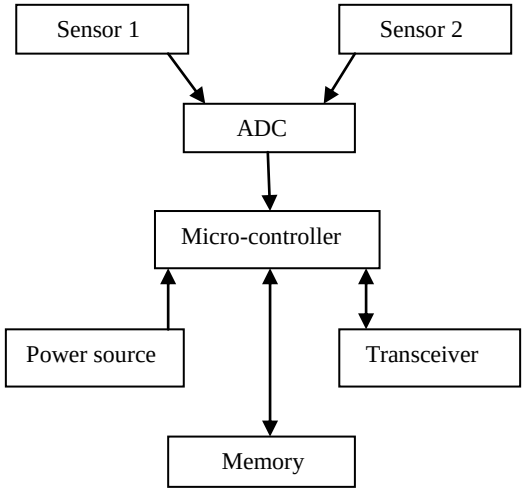

Figure 1: Architecture of a sensor node

1.2 Challenges

Certain issues such as power management, energy, design and security constraints have been encountered in the sensor nodes due to various factors which are further discussed [4][5].

I. Energy constraints and power management: In sensor nodes, the main source of power is obtained through batteries. These batteries can be either rechargeable or non rechargeable. The processing of data and communication among nodes requires the consumption of energy. Therefore the batteries are frequently recharged (in case of non rechargeable batteries) or replaced. Also, the sensor nodes have limited processing power and storage space.

II. Design constraints: It deals with the sensor's hardware constraints in order to create a node with desirable components. The hardware constraints are related with the size and complexity of the node and its limited storage space. In an adhoc deployment, where the sensor nodes are randomly distributed in a particular area, the nodes should be able to adapt and maintain itself with respect to the changes in the environment. These features of maintenance and adaptation must be designed and implemented in such a way that they do not consume excessive energy.

III. Security issues: In sensor networks, it is necessary to protect the data from unauthorized access. It is prone to attacks due to its broadcast communication environment. Sensor nodes can also be physically damaged.

IV. To overcome above discussed factors, various techniques and methods are used which are discussed in this paper. To reduce the energy consumption, a sensor node must perform all the data processing locally and minimize the communication among nodes.

1.3 Applications

Sensor network are widely used in the following fields:

- Monitoring of weather conditions: The occurrences of natural disaster around the world causes damage to human lives and property. A monitoring and alarm system is required to notify the changes in weather (such as temperature, moisture, vibrations etc) which would help to prevent the damage. Wireless sensor networks can be implemented for this purpose. The sensor nodes are installed in different places and are required to have good battery backup. Therefore it is essential to control the energy consumption of a node [6].
- Agriculture monitoring: Sensor networks are used in agriculture due to their high performance and low cost. The sensor nodes are distributed in the field where they capture information based on the physical phenomenon such as chemical compositions. Due to the limited power resources, it is important to conserve energy through an appropriate optimization technique [7].
- Medical monitoring: Wireless sensor networks can be used to track the condition of a patient's health in healthcare departments. It is used to decrease the workload and obtain accurate results. The sensor nodes are attached to the patient's body where they monitor the physiological parameters (such as blood flow, blood pressure, body temperature etc). The data collected by the nodes are transmitted to the base station which further sends it to the local computer for analysis. The difficulties faced in this process are the power consumption, interference from other devices in medical environment and size [8].
- Vehicle and traffic monitoring: The sensor nodes are installed in the roadbed for detecting and collecting traffic information (such as vehicle speed, vehicle length, number of vehicles etc). The information collected by the nodes can be used for the process of decision making in case of road blockage or heavy traffic. The nodes are able to detect the vehicles by change in earth's magnetic field. The major drawback of this system is the limited energy source [9].
- Coal mine monitoring: To detect the amount of gas, water and dust particles in underground coal mines, sensor nodes are randomly deployed which would ensure safe working environment. They can detect variations which occur due to underground collapses. To work for a longer period of time, it is essential for a node to conserve energy. Maintaining the network connectivity in extreme areas is also a challenge [10].
- Video surveillance: Passive infrared sensors are used here and are deployed in low cost surveillance systems (for a car or alarm system). These sensors are used to trigger the video cameras and capture the data. Here power consumption can be an issue along with the security threats [11].
- Habitat monitoring: Due to human presence, there have been noticed potential impacts on plants and animals in field conditions. Human interference changes the behavioral patterns of the animals and effects the plants also. Therefore, to minimize human disturbances, sensors can be deployed on these areas to monitor the animal and plant behavior. It is proved to be an economical method. The difficulty faced here is the management of power consumption [12].

2. LITERATURE REVIEW

Yu Yang, Bhaskar Krishnamachari et. al. [13] have focused their research on the design constraints for sensor nodes in a cluster based approach used for the optimization of the network. The issues mentioned by the researchers are to figure out the activity of the nodes in the cluster which requires the need for an efficient mechanism to maintain the information

of the cluster at the cluster head. In this research few techniques are proposed for energy efficient allocation of the nodes. The goal here is to maximize the lifetime of a network till the first node fails. A 3 phase heuristic approach is used where phase 1 involves the partitioning of the tasks among nodes with a specific execution order. In phase 2, a greedy policy is used to find the assignment of the groups of tasks. In phase 3, the voltage and communication activities are adjusted.

Prabhudutta Mohanty et. al. [14] has highlighted the security threats in wireless sensor networks (WSN). In WSN, it is highly essential to protect the data from unauthorized access. The researchers mention the lack of consideration of security aspects when protocols are proposed for routing and data gathering. Most of the proposed security solutions are based on the symmetric key cryptography. The researchers discuss the various issues associated with data gathering threats.

Vinay Kumar, Sanjeev Jain et. al. [5] have discussed the various clustering routing algorithms to preserve the energy consumed by nodes in a sensor network. They focus on maximizing the network lifetime of the WSN. This can be achieved by performing routing in such a way that would reduce the amount of energy consumed. The objective of the research here is to present a survey on clustering algorithms that have been discovered in the literature of WSN to guide the researchers of this domain.

Clustering can be a very effective optimization technique for energy consumption in a network. It is a very efficient method for preserving the lifetime of a network in sensor networks. To support the scalability, nodes are grouped together to form clusters. High energy efficiency can be accomplished with the help of clustering. Each cluster has been appointed with a leader referred to as the cluster head (CH). The job of the cluster head is to perform in-network data aggregation [15] [16].

In network data aggregation:

- Transmitting data is a lot more expensive than processing it. Therefore to lengthen the network lifetime, minimize the amount of data that needs to be transmitted.
- Removes data redundancy.

A CH is responsible for gathering the data from nodes and sending it to the base station. The sensor nodes periodically transmit the data to the corresponding CH nodes. The CH aggregates the data and transmits it to the base station directly or through intermediate communication with other CH nodes. The CHs are periodically re-elected to balance the energy consumption among the nodes.

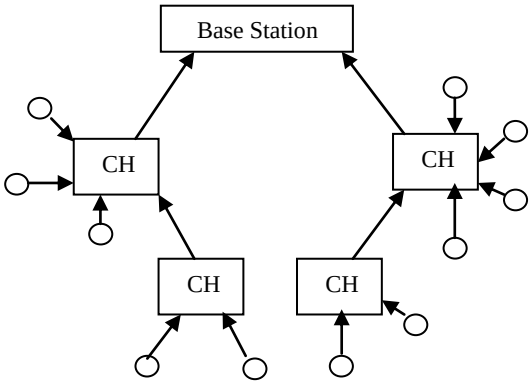

Figure 2: Data communication in a cluster network

In clustering, the selection of the cluster head has a major influence on the network lifetime. So there are several approaches through which the appropriate CH is appointed. Several approaches have been introduced to appoint the appropriate CH.

Cluster of nodes can be formed by using different approaches. The simplest approach would be to form a cluster of those nodes which have similar type of sensors that is, nodes which are sensing the same phenomenon. Such type of cluster is termed as a homogeneous network. This would provide a systematic method of communication. Now among that cluster, a cluster head can be elected which is closest to the base station. A variety of protocols have been developed for prolonging the lifetime of a network and for routing the correct data to the base station. In this paper the main focus is on decreasing the overload on the network so as to improve the performance [19].

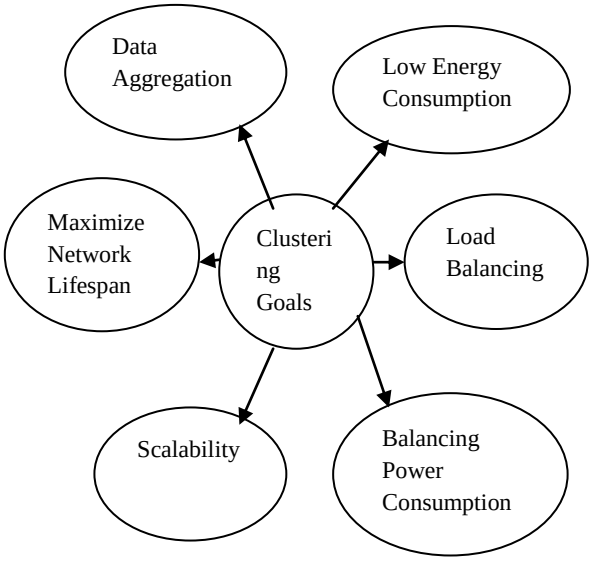

Figure 3: Goals of clustering

3. PROPOSED PROBLEM

The major problem faced by a sensor network is the depletion of energy which may cause the early failure of the nodes and network. It is essential to adopt an optimization technique which might overcome the deficiency of energy consumption. In clustering, a cluster head (CH) acts as an intermediating node for the communication between the nodes and base station. So the energy consumed by the cluster head can be very large. Due to this reason, a CH may fail in a short period of time. A failure of a CH would hinder the communication process and is a major setback of the network performance. Problems caused due to a failed CH:

- Short network lifetime
- Increase in cost
- Performance reduction
- Increase in complexity
- Low connectivity

After the failure of a CH, it is important to re-elect a new node as a CH. This requires strategies and protocols for an appropriate selection of CH. It is important to reduce the load on a CH.

4. EXISTING SOLUTIONS

To overcome the discussed problem, various methods have been deployed. The selection of an appropriate CH is the major concern. A CH can be appointed using different strategies. An ideal cluster head should fulfill the following criteria:

1. Highest residual energy
2. Shortest distance from the base station
3. Maximum number of neighboring nodes

A method for electing a CH is to select that node which is close to an ideal cluster head. Some of the protocols used for cluster formation and electing cluster heads are discussed as follows:

- LEACH (low energy adaptive clustering hierarchy). It is a self adaptive protocol and uses round as a unit. It has two main phases in each round which are, setup stage and steady stage. In the setup stage, all the nodes decide to become the CH or not. In the steady stage, the CH is appointed. The decision of CH is determined by percentage of CH in the network and how many times the node becomes a CH. If the value of that node is less than the threshold value then the node becomes the CH [17] [18].
- HEED (Hybrid energy efficiency distributed clustering). It is based on two factors. First one is the residual energy and the second one is the cost of communication. The CH appointed by this strategy has high average residual energy [19].
- DWEHC (distributed weight-based energy efficient hierarchical clustering protocol). It uses only one factor which is the residual energy on a node. For this purpose, it defines a weight factor. The node which has the highest weight is elected as a CH [19] [20].
- EEHC (energy efficient heterogeneous clustered). It is similar to the DWEHC algorithm. The CH is elected based on the weighted election probabilities according to the residual energy on node [19].
- PEGASIS (power efficient gathering in sensor information system). It is an extension of LEACH. Each node communicates with each other (thus forming chains) and become a leader for the communication with the base station.

The proposed algorithm is an extension to the LEACH algorithm. Several protocols such as TEEN (threshold sensitive energy efficient sensor network protocol), HEED (Hybrid energy efficiency distributed clustering) etc. are based on the LEACH protocol.

5. THE PROPOSED SOLUTION

The focus of this approach is to prolong the lifespan of a network where the distribution of nodes is homogeneous. The goal is to minimize the control overhead on clusters and thus decrease the energy consumption. This would increase the network scalability and efficiency. The goal can be achieved by decreasing the overload on the cluster head so as to increase its durability and thus minimizing the chances of failure.

5.1 Basic Assumptions

- The distribution of nodes in a region is organized in a random manner.
- All sensor nodes are homogeneous and have energy constraints.
- The location of the base station would be setup at the centre of the field and it will have no energy constraints like the nodes.
- The locations of the nodes are known to the base station.
- All nodes have same energy level and assume 100 nodes.

The work of a cluster head is to aggregate the data and communicate with the nodes and base station. The communication, whether inter- cluster or intra- cluster, consumes most of the energy of the cluster head (CH). If the energy consumption is more, then the chances of a CH to fail also increase due to the overhead. In the proposed algorithm CH is elected randomly according to the LEACH algorithm. The work of a CH is divided in order to balance the energy consumption by appointing a primary node.

5.2 Steps

1) The base station (BS) virtually divides the network into regions (say 5) for the appropriate and uniform selection of the CH.
2) One node from all the regions is randomly selected as the CH according to LEACH protocol.
3) The CH now broadcasts a cluster message to all the nodes asking them to join the cluster. A cluster message consists of sender's address, receiver's address, and identification tag and data message.
4) The nodes accept the request of joining the cluster, based on the distance between the node and the CH. Then it sends the acknowledgement message to the CH informing the joining of the node to the cluster.
5) After the formation of the cluster, the CH appoints a node which is nearest to it as the primary node.
6) The work of the primary node is to share the load on the CH. The primary node broadcasts its identity to all the other nodes in the cluster. The other nodes will collect their independent data and send it to the primary node.
7) The primary node would gather all the data from the node aggregate it and then compress it. This would remove the data redundancy and decrease the data size. It sends the aggregated data to the CH.
8) The CH receives the data from the primary node and then sends it to the base station.

5.3 Flowchart of the Proposed Algorithm

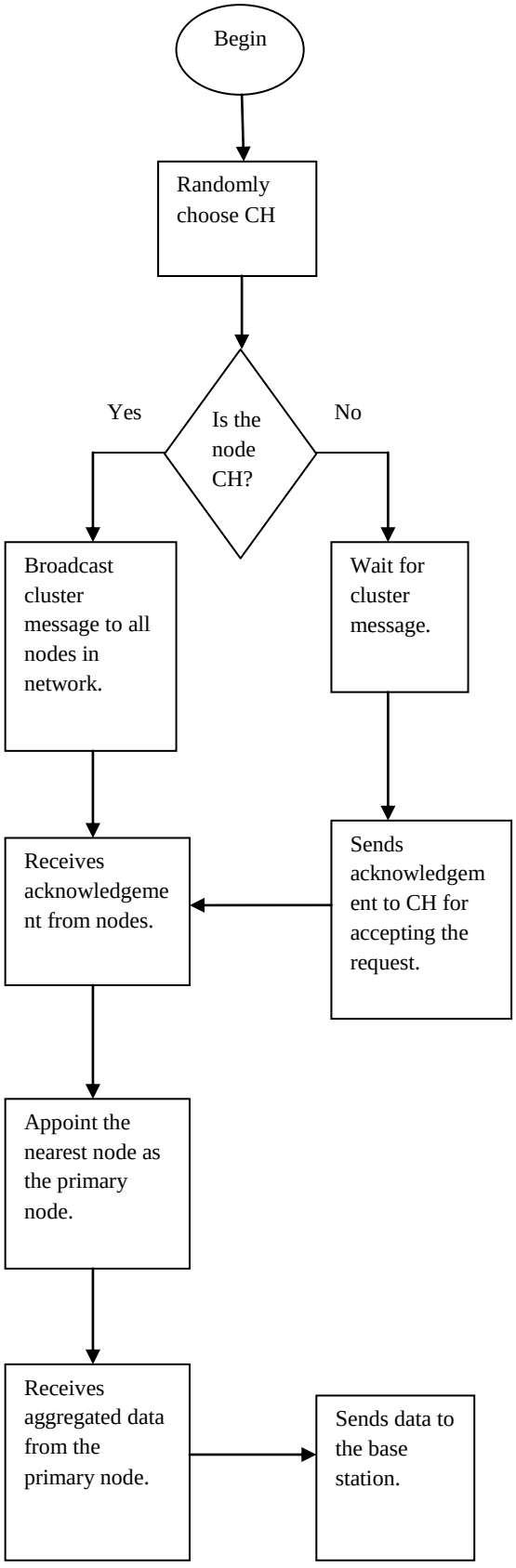

Figure 4: Working of cluster head

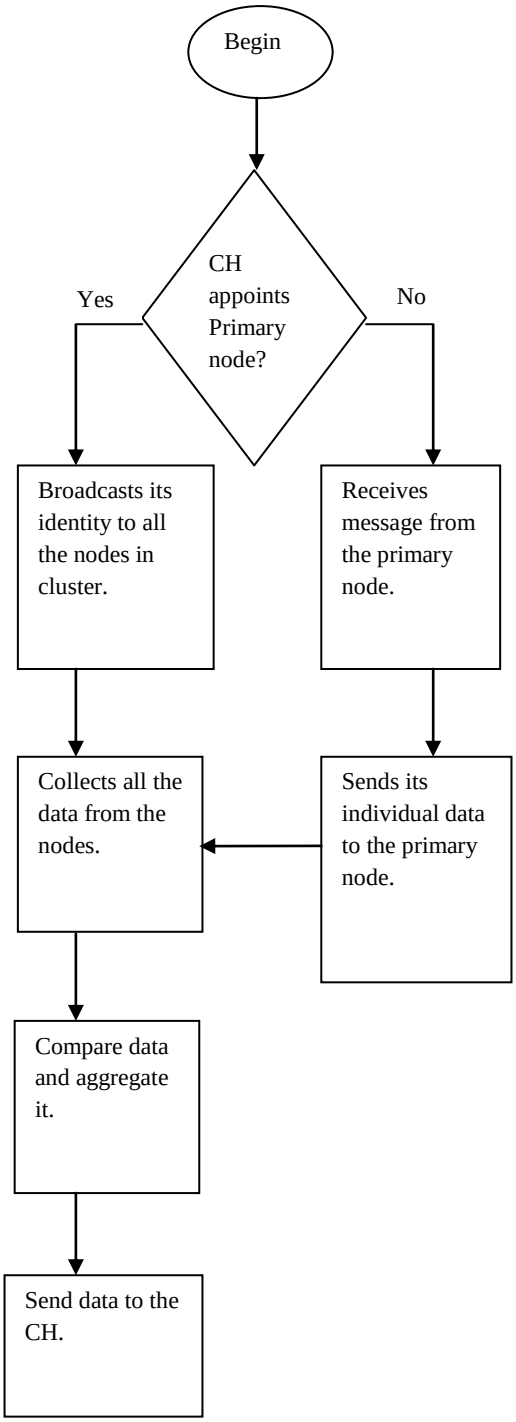

Figure 5: Working of primary node

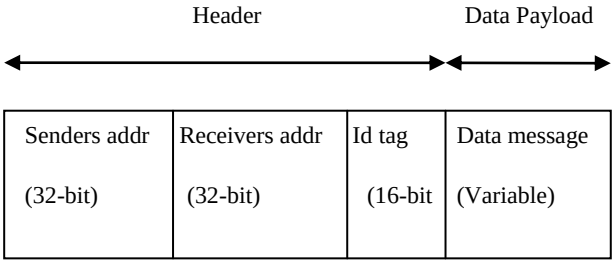

Figure 6: Frame format of broadcast messages

6. WORK ANALYSIS

In randomly selection of clusters, the clusters are formed more frequently. In new proposed algorithm, the network lifetime is extended as the overload on a CH is reduced. An example is further discussed to show the energy on a CH. If the energy of a CH is more then it will work for longer period of time [21].

6.1 Scenario Taken with the Absence of Primary Node

• Number of nodes in the network: 100

• Clusters formed randomly can be of any size (say 10, 20, 40, 15, 15).

• Energy consumed by CH for receiving or transmitting data and performing data compression is 50nJ/bit.

• Messages send with the speed of 10kb/ms.

• Assume that after data compression, the energy of a CH to send the data to the base station is reduced to half.

• Energy level of CH= (Ec*data packet*number of cluster nodes)+ Residual energy

= (Ec*data packet*number of cluster nodes) + (Ec *data packet*Number of cluster nodes)/2

= (50*10-9 *10*103*40) + (50*10-9*10*103*40)/2

= 30 mJ/ms.

6.2 Scenario Taken with the Presence of Primary Node

• Number of nodes in the network: 100

• Clusters formed randomly can be of any size (say 10, 20, 40, 15, 15).

• Energy consumed by CH for receiving or transmitting data and performing data compression by CH is 50nJ/bit.

• Messages send with the speed of 10kb/ms.

• Assume that after data compression, the energy of a CH remains same.

• Energy level of CH= (Ec*data packet*number of cluster nodes)+ Residual energy

= (Ec*data packet*number of cluster nodes) + (Ec *data packet*Number of cluster nodes)

= 2 *(50*10-9*10*103*40)

= 40 mJ/ms

Here, Ec refers to energy consumed. Number of cluster nodes is taken to be 40 for this example. Therefore, from the above analysis it is clear that the energy of a CH in scenario 2 is greater than that of CH in scenario 1. So the chance of a CH to work longer is more in 2nd scenario. This implies that the lifetime of the sensor network can be increased.

7. CONCLUSION AND FUTURE WORK

In this paper, an algorithm is proposed to decrease the overload on a cluster head and prolong the sensor network lifetime. This is achieved by introducing a primary node and dividing the work of CH between them. Due to this, the energy on CH is retained for a longer span of time. It would avoid the re-election of CH frequently. Battery power on a CH would also increase as its work overload is decreased. Also, the main characteristics required to make a sensor node for implementing a wireless sensor network have been discussed. This field of work has the scope of inventing and discovering new optimization techniques for the sole purpose of preserving energy consumption in a network.

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