Wireless Sensor Networks (WSN)

by Aashish Siotra

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Chapter 1
Introduction

In this chapter, an overview of Wireless Sensor Network is provided. The architecture of wireless sensor network, various components of WSN are discussed in detail.

1.1 Wireless Sensor Networks (WSN)

Over the past few years, we have seen exponential increase in computer processing power while the size and price have decreased considerably. With such revolution, computers with embedded sensors have become economical. Thus, the limitations of sensor networks have become a keen area of interest for the researchers. In this project some of the limitations of wireless sensor networks are addressed. In real world, senses help living beings to interact with each other by gathering information of some particular attribute and then some action is performed based on this information. Similarly, there are devices which measure physical attribute like temperature, humidity etc. from the real world and then react based on the data received. This sensory data is provided with the help of Wireless Sensor Network (WSN). In WSN, there are large numbers of sensor nodes and at least one sink or base station. Sensor nodes are equipped with at least one sensing device and transceiver. Various physical attributes like temperature, pressure, noise, motion etc. can be monitored by these sensing devices. The collected information is then sent to the base station or sink using the transceivers. Thus, we can say that basic building blocks of WSN are Wireless sensing and Data networking.

The sensing nodes are generally deployed at remote areas mostly at very difficult terrains which are inaccessible, and these nodes operate with the help of battery. It is also desirable that sensor nodes are small in size. Because of these factors [1] sensor nodes have lot of constraints like limited power supply, limited memory, communication range. Nodes which run out of battery are referred to as Dead nodes and such nodes don't contribute to the WSN. These factors make WSN topology very dynamic as number of active nodes may differ considerable with time. All these constraints are challenges which need to be taken care of while designing WSN.

In this project two algorithms are proposed to overcome shortcomings of WSN:

1. A priority-based routing algorithm for WSN.
2. An Energy efficient cluster Head selection algorithm.

First, we will briefly explain WSN components and various energy efficient routing algorithms.

1.2 WSN Components

There are two main components in WSN architecture [2][15]:

1. Sensor nodes
2. Base Station

Wireless Sensor network can be shown as:

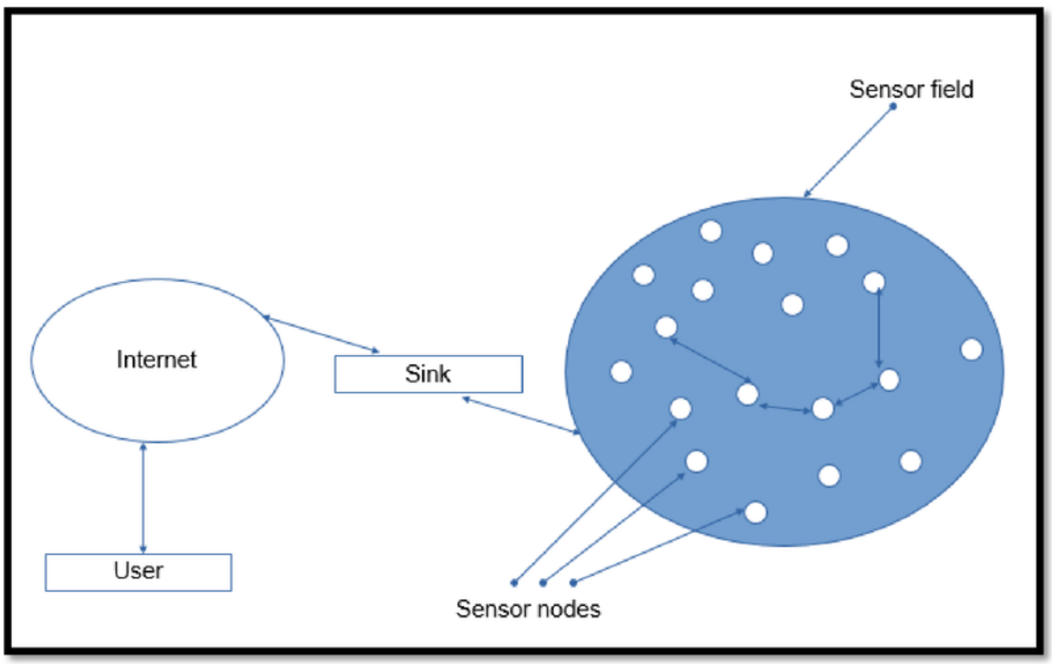

Fig1.1 Wireless sensor network architecture

1.2.1 Sensor Nodes

The basic role of the sensor node is to sense, process and finally transmit the data to the desired destination. Sensor node has following elements:

a. Sensing unit

b. Processing unit

c. Transceiver unit

d. Power unit

a. Sensing unit:

Sensing unit are the hardware devices that measures the physical attributes like temperature, humidity, pressure or other attributes for which it is deployed. Sensing unit monitors the environment. They continuously keep on taking measuring the attributes and send the data to processing unit. Sensing unit are designed in such a way that they can operate autonomously without any need for manual intervention. These are electronic devices and operate with the help of a power supply through battery.

b. Processing unit:

Processing unit receive the data from the sensors. The size of the data received from sensors can be very large and it can have lot of redundant data. So, directly transmitting this data can consume lot of energy and resources, thus making our system very inefficient in terms of energy and lifetime. Thus, the data is first processed, the redundant data is removed, and data compression is performed so that less energy is consumed for data transmission to final destination.

c. Transceiver unit:

The sensor units are mostly deployed in remote areas where we don't have the feasibility of wired network. Thus, the data need to be transmitted wirelessly. Both transmitter and receiver are combined in a single unit called transceiver which is used for wireless communication. Wireless sensor networks generally use license free frequencies for radio communication. It is to be noted that data transmission in wireless sensor network is most expensive task in terms of energy. Most of the energy in system is consumed for data transmission only. Thus, the transceivers are completely shut down when not transmitting the data.

d. Power unit:

All the units in the sensor nodes are electronic units only. They need energy for operation. A continuous energy supply is provided with the help of power unit which is mostly a battery. Because of remote deployment of sensor nodes, it is not feasible to change the battery unit. The battery should have sufficient capacity to last longer while keeping size constraints in mind.

The senor nodes are desired to be small and have battery constraint as well. We can add other units in sensor nodes which will add more functionality to our sensor node, but it will increase the size and will also consume more power which is not desired. Thus, we have the trade-off between functionalities and size of sensor node. The additional functional units can be added but we have to make sure that the size doesn't increase too much, and the power consumption is also less.

A sensor node can be shown as:

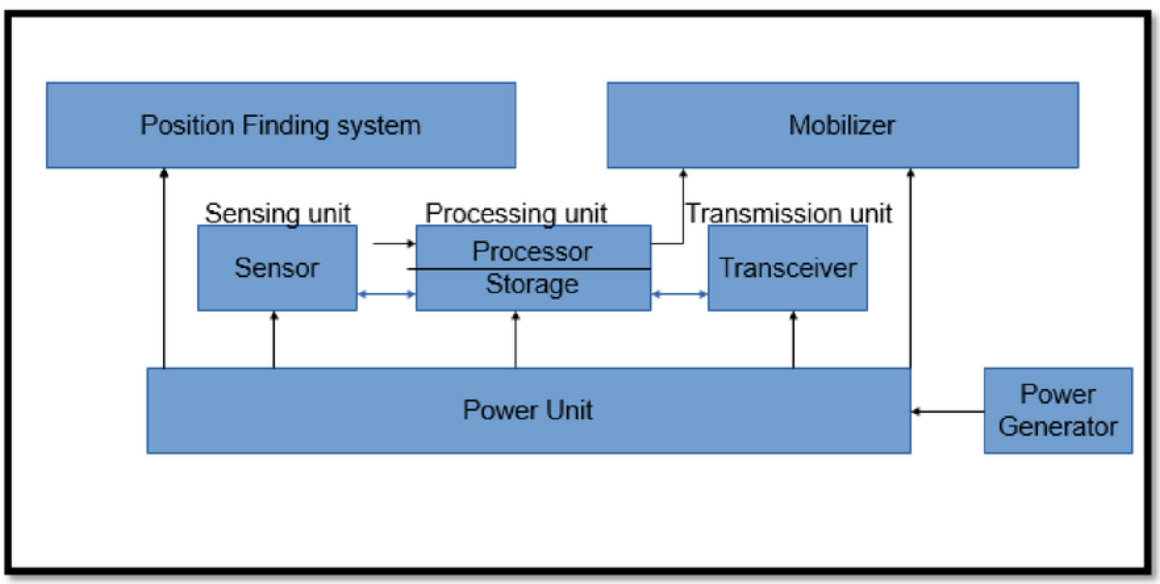

Fig 1.2 Components of a sensor node

1.2.2 Base Station

Base station links WSN to other networks. Base stations are generally static and have continuous power supply. Thus, we don't have battery constraints with base stations. Also, base stations don't change position, once deployed. Since all the sensor nodes need to communicate with the base station, position of base station becomes very important. Network planning phase takes care of base station deployment position.

1.3 Application of WSN

The development of wireless sensor networks was originally motivated by military applications such as battlefield surveillance. Recent developments in this technology have made these sensor nodes available in a wide range of applications like:

1. Military operations
2. Area monitoring
3. Transportation
4. Health Application
5. Environmental sensing
    a. Air pollution monitoring
    b. Forest Fire detection
    c. Greenhouse monitoring
    d. Landslide detection
6. Industrial monitoring
7. Agriculture sector

1.4 Energy-efficient Routing Algorithms

We can broadly categorize energy efficient routing algorithms [15] as follows: data centric routing algorithm, location-based routing algorithm and hierarchical routing algorithm. In data centric [3] routing, a route from source to destination is found with the help of meta data before any actual data transmission. This helps to eliminate redundant data transmission in the network. Location based routing algorithms [3] need actual GPS based location information for every sensor node. In Hierarchical routing [3], sensor network is divided into clusters. A cluster head (CH) is selected in each cluster which collects the data from its members, aggregated the data and may also optionally process the data before sending it to base station or sink. This approach is energy efficient but also relatively complex as compared to other approaches.

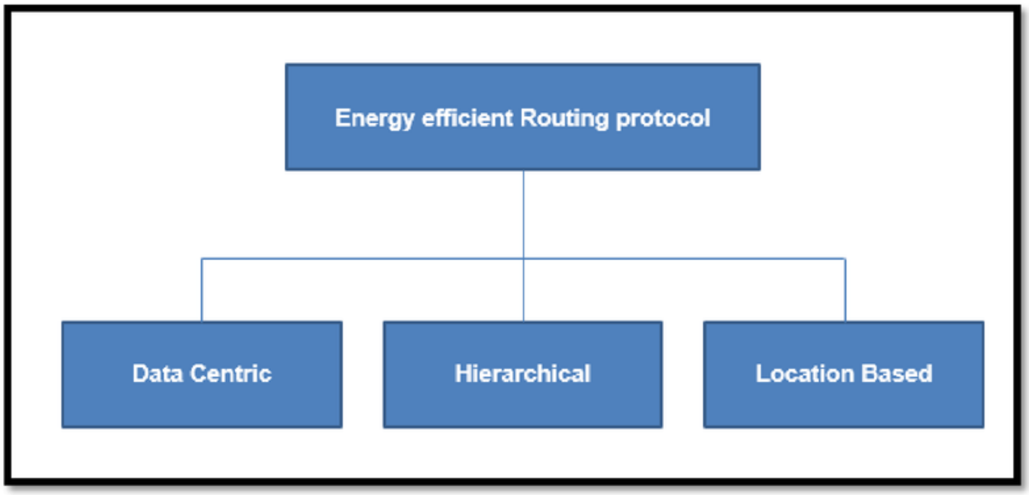

Fig 1.3 Energy efficient routing protocol

1.4.1 Data Centric

Data centric protocols are query-based protocols in which the naming of the data is done. The attribute-based naming is done to specify properties of data. The base station sends query to a certain area for some particular data and waits for the reply from concerned nodes. Sensor nodes collect the particular requested data as per query from the area of interest and sends to base station. Attribute based naming helps in reducing number of transmission, hence minimizing transmission cost. SPIN was the first data centric protocol.

1.4.2 Hierarchical

This is used for energy efficient routing. In hierarchical protocols, higher energy nodes are used for data processing and data transmission over large distance; low energy nodes perform sensing in area of interest and send data to higher energy node which is placed at relatively small distance thus transmission cost of low energy nodes is reduced. E.g. LEACH [4], TEEN [5], APTEEN [6].

1.4.3 Location Based

Location based routing protocols need GPS (Global Positioning System) based location information of all the sensor nodes. An optimal path for data transmission is formed based on the location information thus reducing transmission cost. e.g. Geographic and Energy Aware Routing (GEAR)

Chapter 2

Literature Review

The needed detailed literature survey, to get preliminary knowledge and search scope of investigation, to implement Low energy adaptive clustering hierarchy, is explained in this chapter. This Report presents study of energy efficient routing algorithm, LEACH, and its general purpose.

LEACH algorithm as explained in [7], is the hierarchical routing algorithm. The core idea in LEACH is to share the load among the nodes by randomly choosing cluster heads. This algorithm helps in balancing the energy consumption among the nodes thus prolonging network lifetime. There are other variants of LEACH such as LEACH-C as explained in [24]. In LEACH-C, the base station plays the more dominant role in selecting the CH. All the nodes share their current energy and location information to the BS. Now, the BS selects the CH for current round based on the average energy and location of each node. In this, BS relies heavily on position of each node and the use of GPS increases energy consumption in the system which is the major shortcoming of this algorithm. In LEACH-C there can be some cases in with BS selects node with low energy as CH based on position. This will result cause the low energy node to die early. To overcome this shortcoming, M. Tripathi proposed LEACH Centralized Efficient (LEACH-CE) algorithm [13]. LEACH-CE ensures that node with higher energy is selected as CH. There is another variant of LEACH called Energy Efficient LEACH (EE-LEACH). As explained in [25], EE-LEACH introduces relay nodes to transfer the CH data to BS. So, the CH doesn't directly send data of cluster nodes to BS, rather CH sends data to some relay node which then further sends data to BS. This algorithm avoids the data transmission over long distance thus saving transmission energy but the major shortcoming is that some delay is introduced because of relay nodes.

There are other energy efficient WSN protocols like Hybrid, Energy-Efficient, Distributed Clustering Approach, HEED [14]. In HEED, intra cluster transmission energy is taken into consideration for choosing CH. HEED is based on the assumption that each sensor node can control its transmission power. In this, average minimum reachability power (AMPR) is calculated for each node. AMPR for some node 'i' in some cluster is the mean of minimum power required by each node in this cluster to reach node 'i'. Now, the cluster with minimum AMPR is selected as CH. The major drawback of this algorithm is communication overhead to calculate average minimum reachability power for each node.

Threshold-sensitive Energy Efficient sensor Network protocol (TEEN) [5] is reactive hierarchical WSN protocol. In TEEN sensor nodes don't transmit data to BS continuously, rather BS sets two threshold know as hard threshold and soft threshold for the parameter that the nodes are measuring. So, the nodes transmit data only when the sensed data is more than hard threshold and also whenever the change in sensed data is more that soft threshold. It saves the transmission cost considerably. By keeping the soft threshold value low, the transition of the sensed parameter can be studied more closely but that will result in increase in number of transmissions. Thus there is a trade-off between soft threshold value and number of transmissions. If the value of sensed parameter is lower than the hard threshold, transmitters of the sensor nodes remain off thus saving energy. The major drawback of this algorithm is that if the value of sensed parameter remains lower than hard threshold then the network will not capture any information at all. Thus some important information can be lost in this protocol.

Adaptive Periodic Threshold-sensitive Energy efficient sensor Network protocol (APTEEN) [6] is the best combination of reactive and proactive protocols. It incorporates best features of both protocols. In APTEEN apart from threshold, sensor nodes keep on sending data periodically also. The periodicity in APTEEN can be changed as per application needs. Thus it overcomes the shortcomings of TEEN protocols as it minimizes the chances of information loss at sensor nodes.

2.1 LEACH Protocol

Low Energy Adaptive Clustering Hierarch [7] (LEACH) is a hierarchical clustering algorithm for WSN. It was introduced by W. Heinzelman. LEACH arranges the nodes in the network into small clusters [16] and chooses one of them as the cluster-head [11]. Node first senses its target and then sends the relevant information to its cluster-head. Then the cluster head aggregates and compresses the information received from all the nodes and sends it to the base station. Because of data computational overhead and high transmission cost to send data to base station, cluster head uses more energy as compared to other nodes. So, we can't use a single node for cluster head for long time, as it may become dead. LEACH randomly cluster head nodes so that overhead is evenly distributed. After number of experiments it was found that LEACH is most efficient if we choose 5% of total number of nodes as cluster head. LEACH protocol is used when sensor nodes constantly need to monitor sensor area. The data collection is centralized at the base station and the data is sent by sensor nodes periodically.

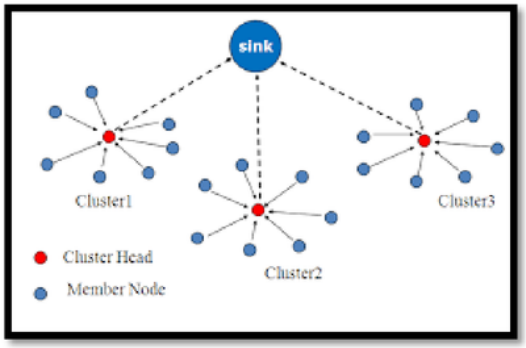

Fig. 2.1 Clustering in LEACH protocol

2.2 LEACH Operation

Leach operation can be divided into two phases:

1. Setup Phase
2. Steady Phase

In the setup phase, the clusters are formed and a cluster-head is chosen for each cluster. While in the steady phase, data is sensed and sent to the central base station. The steady phase is longer than the setup phase. This is done to minimize the overhead cost.

Setup Phase: In this phase, we have predetermined fraction of nodes [8], f, select themselves as cluster head according to a threshold value, Th(N). Threshold value is calculated from f, current round(c) and the set of nodes that have not become cluster head in last 1/f rounds as:

$$Th(N) = \begin{cases} \dfrac{f}{1 - f\left(c \bmod (1/f)\right)}, & if N \in G \\ 0, & otherwise \end{cases} \quad [1]$$

where G is set of nodes that have not become CH in last 1/f rounds.

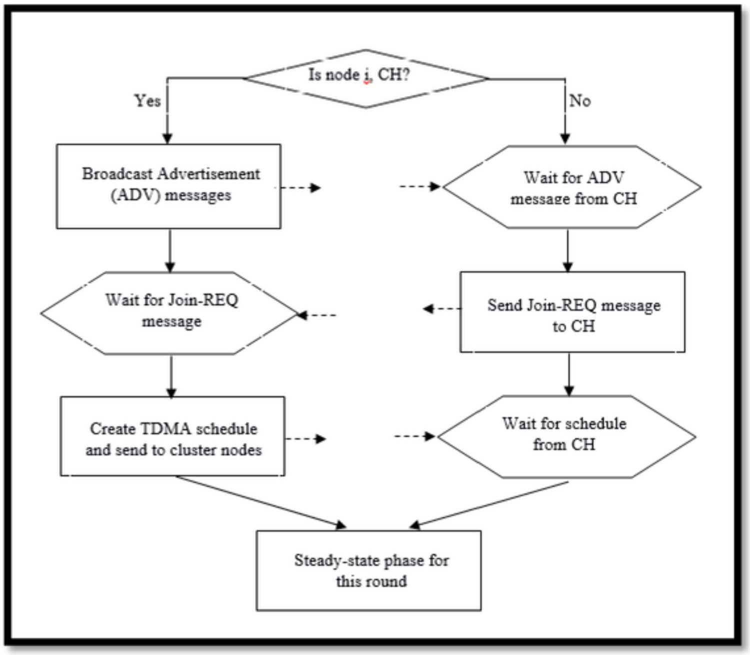

Fig 2.2 Setup phase in LEACH protocol

All the nodes who want to be the cluster head select a value randomly between 0 and 1. The node becomes the cluster head for current round if the random value chosen is less than threshold value. Each cluster head broadcasts an advertisement message. This message is invitation from the cluster head to other nodes to join their cluster. The non-cluster node decide to join a cluster based on the strength of advertisement signal. Acknowledgement message is sent by the non-cluster node to their respective cluster heads. All the non-cluster nodes, sending acknowledgement message to a particular cluster head becomes member of that cluster. The cluster nodes sends the sensed data to the cluster head as per time slot allotted to them by cluster head. Cluster head allocate time slots using TDMA scheduling [9]. The cluster head of current node can become cluster head again only after all other nodes become cluster head.

Steady Phase: Cluster nodes are already allocated time slots to send their data to cluster node in setup phase. So, in steady phase cluster nodes senses the data and transmit the same to cluster head as per their allocated timeslot. The role of the cluster head is to aggregate the data from all cluster nodes and send it to base station. After a certain predefined time, setup phase is repeated again and new cluster heads are chosen so that the load of cluster head is distributed equally among all the nodes.

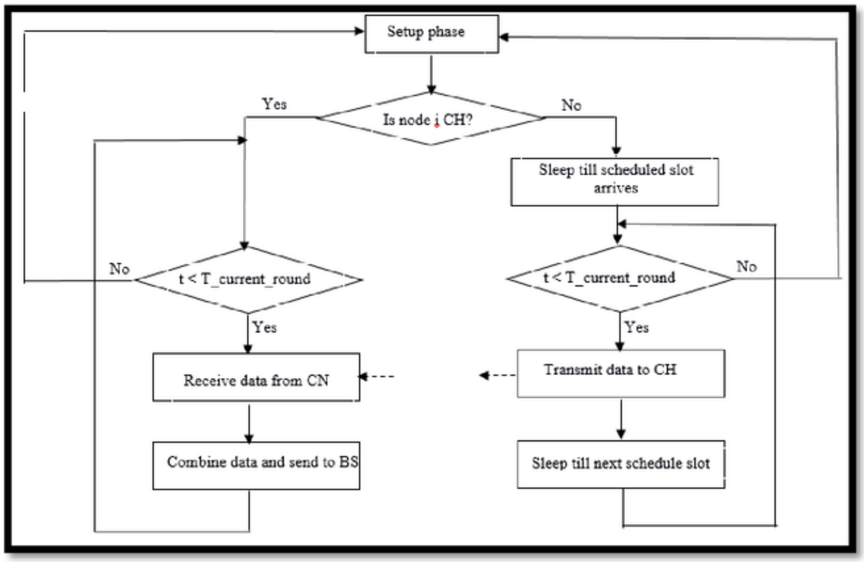

Fig 2.3 Steady phase in LEACH protocol

2.3 Assumptions

We have taken the following assumptions while describing LEACH protocol:

1. The base station is reachable from every node
2. The computational power of strong enough to support different MAC protocols.
3. Cluster nodes always have data to transmit.
4. All nodes have almost same energy at the start of each round.

2.4 Motivation

Many WSN protocols are derived from hierarchical based LEACH protocol [17]. It is energy efficient protocol for sensor environment. According to this protocol, for every round, new cluster head is elected. In a particular cluster all the cluster nodes collect data and send the data to cluster head which then further sends the data to base station. The sensors are deployed to capture some change in physical attributes so that the change can be detected from remote location. But in present scenario all the data is treated as same. Even if some node detects the required change it will keep on reporting the data same as other nodes in which no change is detected. So, the sensor nodes don't differentiate between the data that they sense. Our proposal is to differentiate the critical data or change from normal regular data so that physical change for which the sensor is deployed can be detected. Also, we are suggesting an energy efficient and robust Cluster head selection [11] [13] algorithm.

2.5 Objective

In this project, two algorithms are proposed and implemented for WSN as:

1. A priority-based energy efficient protocol which works as:
    a. The sensor nodes will continuously sense the data.
    b. A priority bit will be added in the data.
    c. If the sensed data is regular or normal data (within predefined normal range) then the priority bit will be set to low or 0.
    d. If the sensed data is critical (above or below the predefined normal range), mark the priority bit as High or 1.
    e. Send data to cluster head along with priority bit.
2. An Energy efficient cluster Head selection algorithm which works as follow:
    a. Every node which wants to become cluster head will transmit its energy.
    b. All other nodes will listen to the potential cluster head nodes and will calculate their distance from cluster head nodes.
    c. Now all nodes know the distance from potential cluster head nodes and also the energy of Cluster head nodes.

d. The aim is to select cluster head which is at minimum distance(d) and also the energy(e) of cluster head is desired to be high.
e. So, rather than considering only one factor for cluster head selection, we will take ratio of 'd' and 'e' i.e. R = d/e.
f. Potential cluster heads, with minimum 'R' will be selected as cluster head.

Both algorithms are explained in detail later in the document.

2.6 Methodology

The above said objective is achieved in following phases:

Initial phase: A detailed literature survey was done from eminent journals like IEEE, and Springer. This provided the basic and conceptual knowledge of the domain. Various Wireless sensor network protocols were studied in detail along with their features and limitations to find the area of improvement that can be explored. The research areas were identified in wireless sensor networks. From the literature survey one major challenge was identified in wireless sensor network which is to increase the lifetime of network. Sine the power supply is limited, the protocols used must be highly energy efficient. So, we worked on providing algorithms that will help in increasing network lifetime in wireless sensor networks.

Implementation Phase: First the already implemented LEACH protocol is run on network simulator tool NS2 [18][19][20] . The existing algorithm is modified as per proposed solution. Then our desired changes are added to existing implementation. The final program is run successfully in NS2.

Simulation and Analysis: The modified code is tested with different inputs randomly generated by the program. The results are analyzed to verify the desired changes.

Chapter 3

Project Work

3.1 Problem Definition

LEACH because of its energy efficient approach is one of the finest clustering protocol for WSN. But we can point our one of the drawback of LEACH protocol. Also, the cluster head selection algorithm can be further enhanced. The physical nodes are deployed to detect the change in the physical attribute. In LEACH, we treat all the data as same, whether it is normal sensed data or the desired change that we wish to capture. Thus, it doesn't explicitly detect the event or the change. Thus, our problem statement is that this protocol is unable to differentiate between normal regular data and the data that is sensed in case of any event or change.

3.2 Proposed Solution

The proposed solution has impact in both setup phase and steady phase. In setup phase, the cluster head selection algorithm is improved. Cluster head selection is performed based on energy of node and the distance of node from other cluster nodes. The idea is to make cluster head selection algorithm more efficient by selecting cluster head which is having energy above threshold and at the same time nearest to the node so that transmission cost of cluster nodes can be reduced. If transmission cost of cluster nodes is reduced, overall energy consumption in wireless sensor network will be reduced and the lifetime of network will increase. In steady phase, the sensor data is classified as regular data or priority data. Priority bit is set to 1 in case of priority data.

Setup Phase: In our proposed solution, we are first changing the cluster head selection algorithm in setup phase of the LEACH protocol.

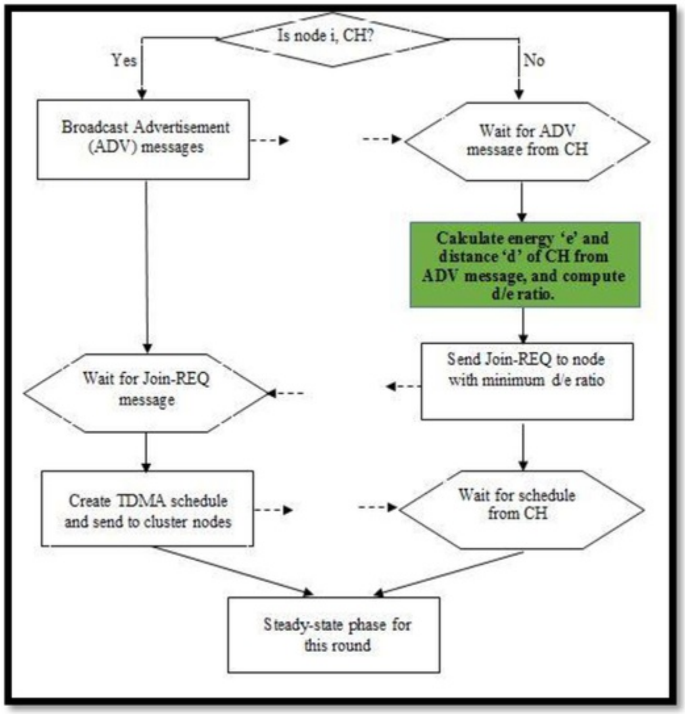

Fig 3.1 Flowchart of Setup phase in proposed solution

In setup phase, first the nodes which can be cluster head are identified. Those potential cluster head nodes then send ADV message to all the nodes. Normal nodes compute the energy of CH and its distance with the help of ADV message. Now, the desired CH must have large energy and also its distance should be least. So, the node will compute the ratio, r = d/e and will send Join-REQ to CH with minimum r value. Thus, the node will select CH which is near and having high energy as well.

Steady Phase: The Steady phase has been modified in our solution to solve the problem statement. First, a normal range is predefined for the physical attribute that the sensor is sensing. Suppose the sensor is sensing the temperature, then we will predefine the normal temperature range say 15 degrees centigrade to 45 degrees centigrade. Now, if the sensor senses data within this range it will be marked as normal data or low priority data. In case, temperature sensed is less or more than the defined range, that data will be marked as High priority data. In such cases priority bit will be set before sending the data to CH.

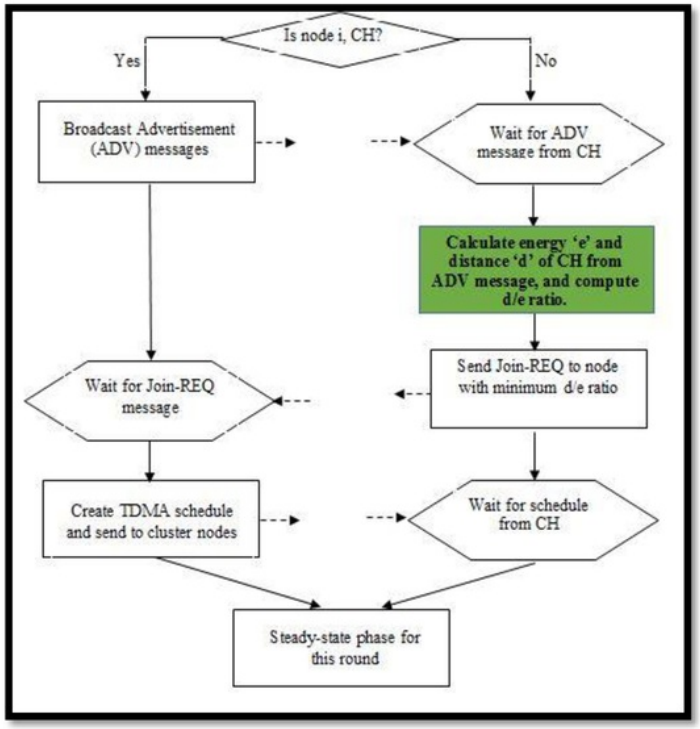

Fig 3.2 Flowchart of Steady phase in proposed solution

The cluster head transmits the priority data to the base station with priority bit high. Thus, appropriate action can be taken at base station based on priority of data received.

Chapter 4

SIMULATION SETUP AND RESULT ANALYSIS

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In this chapter, Network Simulator(NS2) software used for deploying WSN is presented. Simulation of LEACH routing protocol and LEACH with proposed solution for WSNs are discussed in detail along with result and result analysis.

4.1 Simulation tool

NS2 tool [18] [19] [20] [21] has been used for simulation purpose. We have calculated network lifetime, energy efficiency and throughput with the help of simulations. NS2 tool along with system configuration are briefly explained below.

NS2 [10] is packet level simulator by which we can simulate different kinds of protocols. It can simulate both wired and wireless networks. It helps in simulating network behavior by creating different topology and also provides log events to analyze and understand the network. Tcl (Tool Command Language) is used in NS2 tool for writing scenarios.

4.2 Tool and System configuration

We have run our simulation on Linux based system using Network simulator tool. Details about tool and system configuration are:

OS: Ubuntu 14.04

NS2 version: NS2.34

System configuration: 32-bit system.

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4.3 Assumptions and parameters

The simulation assumed that there are sensor nodes are randomly and densely scattered in a two-dimensional square field, and the sensor network has the following properties:

1

1. Sensor nodes are static and unaware about their non-rechargeable i.e energy constrained, and always have data to send.

2. There is only one sink in the field, which is deployed randomly.

3. A node is considered dead when it is not capable of transmitting data to the sink.

4. It is assumed that the probability of signal collision and interference in the wireless channel is ignorable and the radio transmitter, radio amplifier and data fusion unit are the main energy consumers of a sensor node.

5. Transmission power varies depending upon the distance between node and receiver.

Parameters	Value
Network area (in meters)	100x100
Number of Nodes	100
Location of Sink	50,50
Initial Energy of each node	2 Joule
Maximum simulation Time	3600sec
Routing Protocol	LEACH

Table 4.1 Simulation parameters and value

4.4 Implementation

For LEACH simulation purpose the data sent by each node comprised of node id, the time at which the data was sent. In our solution, we have assigned priority to the nodes whose energy has become poor than 0.5 Joule. Now in modified solution, the data sent by node includes node id, time at which data was sent and the priority bit. As already discussed, energy efficient WSN deployment is not an easy task due to large number of parameters, i.e., energy parameters and cluster head selection then their data transmission procedure. NS2 programming platform is used for coding of LEACH and the proposed enhancement.

4.5 Results

We have already discussed the phases of proposed solution in **"3.2 Proposed solution"**. The simulation results for proposed solution are obtained from NS2 tool simulation. Now we will present our simulation output and will show various steps mentioned in proposed solution:

******************* **Setup Phase** *******************
Step 1: Total 100 nodes created at random position, Node id: (x,y); where id =1,2...100 and x,y<100 Node 100 is Base Station
Output file: Creating sensor nodes Node 0: (65.745973803916002,92.581722416254564) Node 1: (21.008649990432268,92.380389195112684) . . Node 99: (44.071560420129238,10.71598111219517)
Step2: Nodes calculate the threshold value and Cluster head is selected based on threshold value. In our simulation result Node 3, node 23 and node 50 are selected as Cluster Head node.
Output file: THRESH = 0.050000000000000003 node id= 12 12: Is a cluster head at time 0 . THRESH = 0.050000000000000003 node id= 22 22: Is a cluster head at time 0 . THRESH = 0.050000000000000003 node id= 43 43: Is a cluster head at time 0
Step3: Cluster Heads broadcast their Advertisement(ADV) messages
Output file: Cluster Head 43 broadcasting ADV at time 1.4057081571806728e-06 Cluster Head 12 broadcasting ADV at time 1.887486428901314e-05 Cluster Head 22 broadcasting ADV at time 0.00012535849822934645
Step4: All nodes receive ADV message.
Output file: aash: 86 rcvd ADV_CH from 43 at 0.00022741270962858162 aash: 3 rcvd ADV_CH from 43 at 0.00022742454572024579 . . aash: 91 rcvd ADV_CH from 12 at 0.0004208933594781542 aash: 24 rcvd ADV_CH from 12 at 0.00042089374872477026

. . aash: 68 rcvd ADV_CH from 22 at 0.00070337523961579173 aash: 83 rcvd ADV_CH from 22 at 0.00070337884837130729
Step5: Nodes will join the CH based on e/d ratio in ADV message received.
Output file: 0: Current cluster-head is 22, code is 3, dist/energy is 10.000224999062345 1: Current cluster-head is 12, code is 2, dist/energy is 24.000539997749627 . . 3: Current cluster-head is 43, code is 1, dist/energy is 3.0000674997187033 10: Current cluster-head is 12, code is 2, dist/energy is 17.500393748359105 . . 58: Current cluster-head is 43, code is 1, dist/energy is 7.5001687492967584 62: Current cluster-head is 22, code is 3, dist/energy is 9.5002137491092284
Step6: All nodes send JOIN-REQ to their selected CH node
Output file: 0: sending Join-REQ to 22 (dist = 10.000224999062345) at time 0.74640611094989162 aash: 22 received notice of node 0 at time 0.74674417696770223 1: sending Join-REQ to 12 (dist = 24.000539997749627) at time 0.70417048053278886 aash: 12 received notice of node 1 at time 0.70450863764304616 . . 3: sending Join-REQ to 43 (dist = 3.0000674997187033) at time 0.52277617748830474 aash: 43 received notice of node 3 at time 0.52311419632586786 10: sending Join-REQ to 12 (dist = 17.500393748359105) at time 0.53980685621872493 aash: 12 received notice of node 10 at time 0.5401449718616721 . . 58: sending Join-REQ to 43 (dist = 7.5001687492967584) at time 0.27407219427625845 aash: 43 received notice of node 58 at time 0.27441024307835143 . . 62: sending Join-REQ to 22 (dist = 9.5002137491092284) at time 0.96649434989308114 aash: 22 received notice of node 62 at time 0.96683241179639345
******************STEADY PHASE*******************
Step7: Cluster head nodes broadcast TDMA schedule to cluster nodes which will send data as per schedule
Output file:

aash: 12 sending TDMA schedule: 36 41 28 27 24 70 42 47 69 85 30 53 56 32 99 61 13 17 67 39 26 45 52 98 29 95 21 93 37 2 15 76 10 79 66 40 48 80 23 1 44 84 50 57 33 38 9 63 74 46 89 54 64 91 87 78 97 73 92 4 55 96 72 at time 1.004872 . . aash: 22 sending TDMA schedule: 14 68 83 71 11 20 60 0 35 62 at time 1.004872 . . aash: 43 sending TDMA schedule: 31 59 25 34 75 8 58 6 5 90 51 81 82 3 49 94 77 16 18 19 7 65 86 88 at time 1.004872
Step8: Cluster node start sending data to CH based on TDMA schedule
Output file: aash: 58 sending data {58 , 1.2097540488020928 , 0} to 43 at 1.2097540488020928 (dist = 7.5001687492967584) . . aash: 0 sending data {0 , 1.2415620660178106 , 0} to 22 at 1.2415620660178106 (dist = 10.000224999062345) . . aash: 62 sending data {62 , 1.3087620619033122 , 0} to 22 at 1.3087620619033122 (dist = 9.5002137491092284) . . aash: 3 sending data {3 , 1.4449540188375627 , 0} to 43 at 1.4449540188375627 (dist = 3.0000674997187033) . . aash: 10 sending data {10 , 2.0883461156429468 , 0} to 12 at 2.0883461156429468 (dist = 17.500393748359105) . . aash: 1 sending data {1 , 2.3235461571102571 , 0} to 12 at 2.3235461571102571 (dist = 24.000539997749627)
Step9: CH received data from cluster nodes
Output file: aash: CH 12 received data (53 , 61.376218060671718 , 0) with priority 0 from 53 at 61.408556121343437 . . aash: CH 22 received data (6 , 141.54485807407355 , 0) with priority 0 from 6 at 141.57719614814707 . .

aash: CH 43 received data (19 , 1.6123140333243924 , 0) with priority 0 from 19 at 1.6446520666487849
Step10: CH performs computation and send data to BS
Output file: aash: CH 12 must now perform comp and xmit to BS. aash: compute_energy = 0.00024000000000000003 aash: Node 12 sending {{12 , 61.408556121343437 , 0}} to BS at time 61.417488170379897 . . aash: CH 22 must now perform comp and xmit to BS. aash: compute_energy = 0.00034000000000000002 aash: Node 22 sending {{22 , 141.57719614814707 , 0}} to BS at time 141.57863930993986 . . aash: CH 43 must now perform comp and xmit to BS. aash: compute_energy = 0.00038000000000000002 aash: Node 43 sending {{43 , 1.6446520666487849 , 0}} to BS at time 1.6491250478206876
Step11: BS receives data from CH nodes
Output file: BS Received data 12 , 61.408556121343437 , 0 from 12 at time 61.449826587671119 This represents data from nodes: 52 55 92 15 24 47 2 50 95 75 36 53 12 . . BS Received data 22 , 141.57719614814707 , 0 from 22 at time 141.61097763015351 This represents data from nodes: 81 3 71 62 82 83 11 60 86 68 25 35 18 20 19 14 6 22 . . BS Received data 43 , 1.6446520666487849 , 0 from 43 at time 1.7137514149347488 This represents data from nodes: 75 25 22 18 0 20 60 82 14 3 68 35 62 86 11 6 71 83 19 43
Step12: Step 1 to step 11 continue for multiple rounds, till maximum execution time is exhausted or all nodes are declared dead.
Step 13: Later in the execution as the energy of nodes becomes poor(less than 0.5 Joule), priority bit is set to 1
Output file: aash: 49 sending data {49 , 21.241690060472298 , 1} to 34 at 21.241690060472298 (dist = 19) aash: 79 sending data {79 , 21.041370177543907 , 1} to 72 at 21.041370177543907 (dist = 54) . . aash: CH 34 received data (49 , 21.241690060472298 , 1) with priority 1 from 49 at 21.2740281209446 aash: CH 72 received data (79 , 21.041370177543907 , 1) with priority 1 from 79 at 21.073708355087817 .

.
aash: CH 34 must now perform comp and xmit to BS.
aash: compute_energy = 0.00022000000000000001
aash: Node 34 sending {{34 , 21.374828162225647 , 1}} to BS at time 21.375072672385588

aash: CH 72 must now perform comp and xmit to BS.
aash: compute_energy = 0.00042000000000000002
aash: Node 72 sending {{72 , 21.712108207690708 , 1}} to BS at time 21.720496061104708.
.
.
BS Received data 34 , 21.374828162225647 , 1 from 34 at time 21.407411131768093
This represents data from nodes: 18 31 11 25 94 58 81 49 82 3 6 34

BS Received data 72 , 21.712108207690708 , 1 from 72 at time 21.75283461426212
This represents data from nodes: 41 79 78 67 57 45 84 73 87 33 17 13 80 4 26 76 44 28 69 37 30 72

Step 14: Total energy consumed in network, total data sent and total number of alive nodes are computed at fixed interval of time:

At 20:
Total Energy = 60.315191117759788
Total Data = 1673
Total Alive = 95

At 40:
Total Energy = 92.857644992718392
Total Data = 3778
Total Alive = 85

At 60:
Total Energy = 102.66525147632635
Total Data = 5855
Total Alive = 80

At 80:
Total Energy = 114.76532158473185
Total Data = 8223
Total Alive = 76
.
.
At 180:
Total Energy = 179.89786886719503
Total Data = 16705
Total Alive = 33

At 200:

Total Energy = 186.91843615880794
Total Data = 17694
Total Alive = 25

At 220:
Total Energy = 188.78624322424446
Total Data = 18535
Total Alive = 22

At 260:
Total Energy = 195.50887080163554
Total Data = 19913
Total Alive = 8

At 270:
Total Energy = 197.31383940635803
Total Data = 20094
Total Alive = 6

.
.

At 274.99999999999403:
Total Energy = 198.07119377510566
Total Data = 20192
Total Alive = 4

Simulation complete.

Total energy at beginning of simulation = number of nodes X energy of each node.
where, total number of nodes =100
energy of each node = 2 Joule

Therefore, Total energy at beginning of simulation = 100 X 2 = 200 J

In the end of simulation, we can see that total energy consumed in network is 198.07 Joule, and total Data sent is 20192 and total alive nodes at end of simulation is 4.

Table 4.2 Simulation Results

4.6 Result Analysis:

The results obtained with proposed algorithm are shown in table above. The result analysis is done with respect to total network lifetime, total alive nodes in network, and throughput of the wireless sensor network. These parameters are briefly defined below:

Network Lifetime [12]: In our simulation starting energy of all nodes was 2 Joule. The nodes whose energy becomes 0 are declared as dead nodes. Dead nodes don't contribute anything to the network and those nodes are considered as useless. Wireless sensor network is considered as alive until base station can receive data from the sensor nodes in the network. Network lifetime of any wireless sensor network is desired to be high.

Alive nodes: A node is alive if it can transmit sensor data to its cluster head or to the base station directly. Initially all nodes are alive nodes with 2 Joule of energy each. As sensor nodes keep on sensing data and transmitting the same to base station or cluster head, its energy keeps on decreasing. When the energy [22][23] of a node becomes 0 or so low that it can't transmit to any cluster head or to base station, it is declared as dead node. Thus, as simulation progresses, total alive nodes in network keeps on decreasing. For any wireless sensor network, it is desired that there are more number of alive nodes and the nodes should die gradually enhancing network lifetime.

Data Transmission (Throughput): All the sensor nodes send data to the cluster head or to base station directly. The cluster head receives data from all alive cluster nodes, combine the data and send to base station. Total data received by the base station is called throughput or data transmission in the network. Wireless sensor network is expected to receive maximum data from the sensor field, so data transmission or network throughput is desired to be high.

4.7 Result Comparison:

The result obtained with proposed algorithm are compared with that of original LEACH algorithm. It is found that network performance has improved with proposed algorithm. Network lifetime has improved which will have direct impact on number of alive nodes and network throughput because more network lifetime means more alive nodes which will further ensure that throughput is increased. Results of proposed solution are compared in terms of network lifetime, number of alive nodes and network throughput in detail below.

4.7.1 Network Lifetime Comparison: From the data given below it can be seen that network life time has increased in proposed solution.

Network lifetime with original LEACH algorithm = 251 secs.
Network lifetime with proposed algorithm = 275 secs.
Percentage improvement = **9.5%**

Network life has improved with proposed solution because both Cluster Head's energy and distance is taken into consideration in setup phase while cluster head selection. More preference is given to those nodes who have energy greater than threshold set for cluster head with lesser distance, thus, less transmission cost will be involved giving more network lifetime.

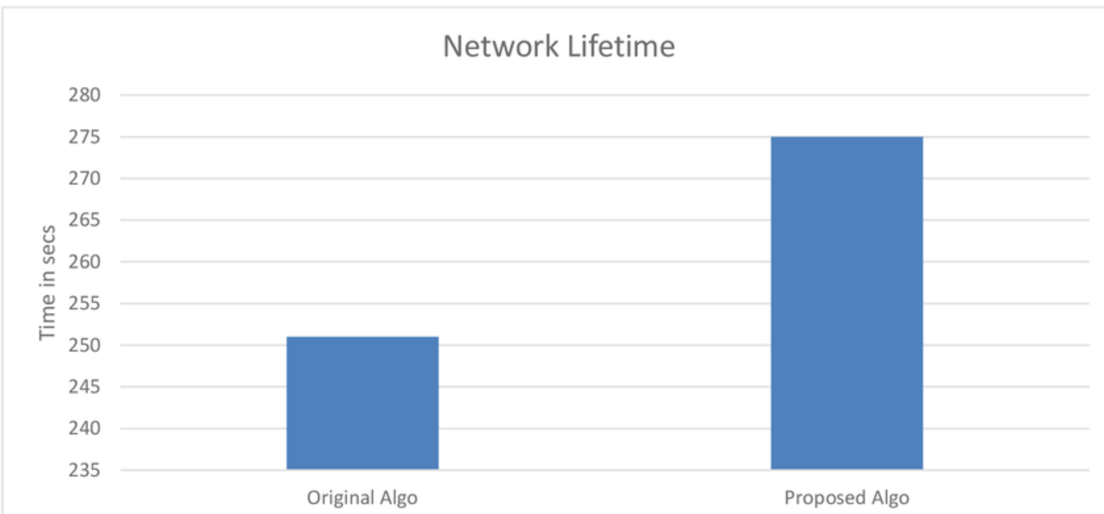

Fig 4.1 Network Lifetime Comparison with original algorithm

34

4.7.2 Energy Consumption Comparison: Energy consumption in proposed algorithm has been compared with that in original algorithm. At the beginning of simulation every node has 2 Joule of energy. There are total 100 nodes, thus total energy in network at beginning is 2 X 100 = 200 J. As sensor node collect data and data transmission takes place in network, energy of nodes and thus total energy of network keeps on decreasing. Total energy consumed in the network is calculated at specific intervals of time. The energy consumed in proposed algorithm is compared with that in original algorithm and is shown graphically below:

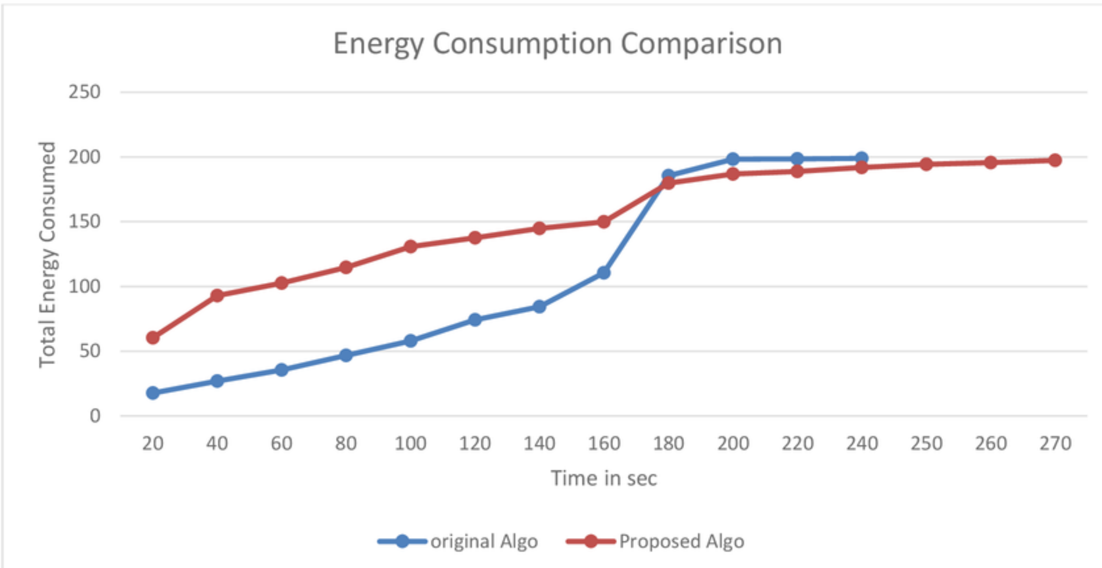

Fig 4.1 Energy Consumption Comparison with original algorithm

Observation from the Energy Consumption Comparison: The following conclusion can be drawn from the energy consumption comparison graph shown above:

1. As the simulation progresses and number of alive nodes become sparsely distributed and less in number, network energy consumption abruptly increases in original algorithm. In original solution, only energy is taken into consideration for selecting cluster head. Now when number are alive nodes are less which means the distance between nodes is more, when a cluster head is selected only based on energy, the transmission cost for all nodes can increase in case the selected cluster head is at some far distance. So, although cluster head had maximum energy, total energy consumption increased drastically because of transmission cost of each node to distinctly located cluster head.

   This shortcoming is overcome in proposed algorithm. Cluster head is selected not only on the basis of energy, but distance is also taken in consideration. Node with energy above threshold and minimum distance is selected as cluster head which reduces transmission cost of cluster nodes. Thus, we didn't find any abrupt increase in network energy consumption in proposed solution.

2. At the beginning of the simulation, energy consumption is higher in case of proposed solution. This is simply because more computation is taking place in each node for cluster head selection. But as the simulation progresses and network becomes sparse the proposed algorithm becomes more robust and efficient. The cluster head, selected in proposed algorithm help in reducing energy consumption later during simulation, thus overall decreasing energy consumption and increasing network lifetime.

4.7.3 Alive node Comparison: Nodes whose energy get reduced to 0 are considered as dead nodes. Dead nodes don't contribute to the network and are useless. Thus, more the number of alive nodes, better the system. Energy in nodes keeps on decreasing because of data collection, data processing and transmission. Alive nodes in the network were determined at different interval of time. Alive node in proposed algorithm is compared with that in existing algorithm and the graph is shown below:

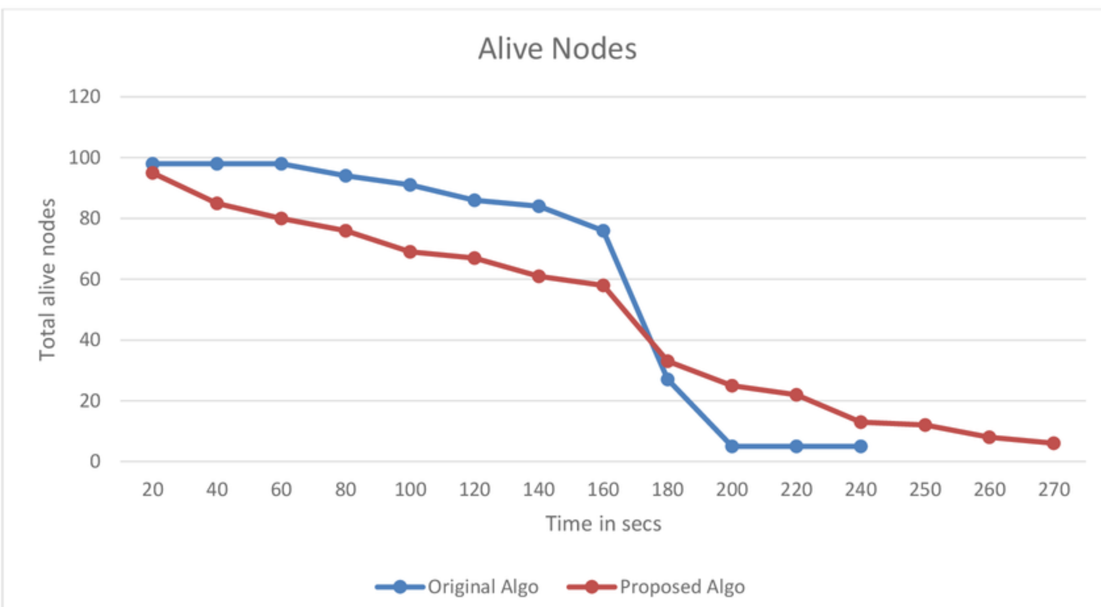

Fig 4.2 Alive Nodes comparison with original algorithm

Observation from Alive nodes comparison: The following observation can be drawn from the alive nodes comparison graph shown earlier:

1. There is abrupt decrease in number of alive nodes in original algorithm when network becomes sparse and nodes die very quickly after that. This behavior is observed because when number of alive nodes becomes less, a node with high energy but larger distance from cluster nodes can be selected as cluster head, thus the transmission cost of all the nodes will increase leading to more dead nodes in network. This has been overcome in proposed algorithm. Since cluster head is selected on base of energy and distance so performance of network remains even throughout the lifetime of network. There is no drastic change in number of alive nodes.

2. In the beginning of the simulation, number of alive nodes are less in proposed algorithm as compared to original algorithm. All the nodes must do more computation in cluster head selection, so energy consumption is more in proposed algorithm, but this consumption is uniform throughout the network lifetime and there is not abrupt change in number of alive nodes in network. The network can achieve more lifetime and dies gradually.

4.7.4 Throughput Comparison: All the sensor nodes collect data and send it to the cluster head or to the base station directly. Total data received by base station is called network throughput. The throughput in original algorithm is compared with that in proposed algorithm and comparison is drawn in graph.

Total throughput in original algorithm = 19151

Total throughput in proposed algorithm = 20192.

Total improvement in throughput = **5.4%**

Observation from Alive nodes comparison: Throughput is more uniform in proposed solution. This can be achieved because nodes die gradually in proposed solution. There is no abrupt change in number of alive nodes, and because of more network lifetime more throughput is achieved in proposed solution.

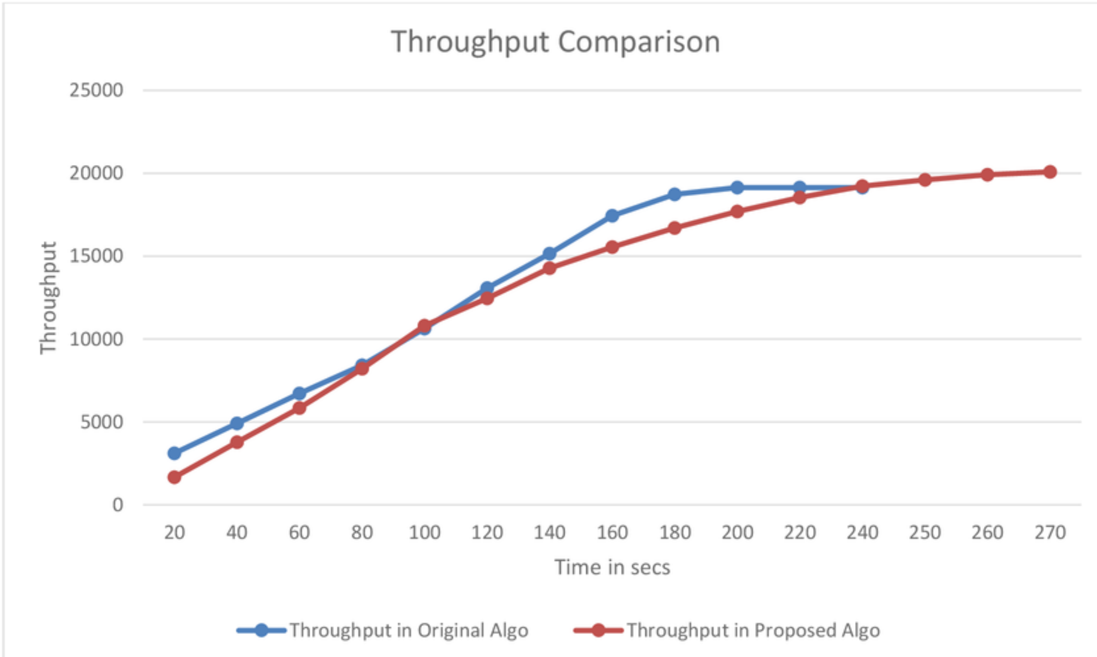

Fig 4.3 Throughput Comparison with original algorithm

4.8 Benefits of proposed changes

The new cluster head selection algorithm takes into consideration both energy and distance of cluster head from node. Thus, the algorithm is more robust and helps in increasing lifetime of network. As described earlier, with increase in network lifetime we have more network throughput and the decrease in number of alive nodes is smooth, gradual and uniform. This makes our wireless sensor network more reliable as it won't die abruptly. Also, it differentiates the priority data from the regular data. Wireless sensors monitor continuously, and we need continuous data from the sensors to form the pattern of physical change in parameter that we are studying. So, if we consider an algorithm which sends only changed pattern, it won't be helpful as we will not be able to find the pattern in change. So we need all data as well and with approach we are able to differentiate between priority data and regular data at the same time we are not dropping any regular data. Based on the priority data received, some audio/visual warning can be played at Base station or the monitoring station so that the necessary action can be taken. This will have its application in all various fields in which energy efficient algorithm is used in WSNs

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

From the test results shown above, we can see that we have enhanced the functionality of energy efficient protocol by using priority in data which is sensed. Also, the cluster head selection algorithm is more robust as it takes into consideration both distance and energy to select cluster head. This enhancement can be used in variety of applications and will make our application more useful. Also, we are not adding much computational cost to the existing algorithm and hence the energy efficient benefits of the algorithm stay.

5.2 Future Scope

The work done here can be extended and further enhancements can be added to make our protocol more robust and useful. Some of the areas in which we can work further are:

1) Extend this concept in case of mobility. In this project, we have considered the sensor nodes to be static. We can study the behavior if sensor nodes have mobility.
2) Rather than assigning 0 or 1 priority to the data, we can include fuzzy logic and can give some continuous value to our priority like very low, low, normal, medium, high, very high and critical.

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