MULTIHOP CLUSTERING ALGORITHM FOR LOAD BALANCING IN WIRELESS SENSOR NETWORKS.

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Abstract: The paper presents a new cluster based routing algorithm that exploits the redundancy properties of the sensor networks in order to address the traditional problem of load balancing and energy efficiency in the WSNs.The algorithm makes use of the nodes in a sensor network of which area coverage is covered by the neighbours of the nodes and mark them as temporary cluster heads. The algorithm then forms two layers of multi hop communication. The bottom layer which involves intra cluster communication and the top layer which involves inter cluster communication involving the temporary cluster heads. Performance studies indicate that the proposed algorithm solves effectively the problem of load balancing and is also more efficient in terms of energy consumption from Leach and the enhanced version of Leach.

Keywords: cluster based routing, efficient intercluster routing, energy efficient routing, coverage based routing.

1. INTRODUCTION

Due to the recent development in the field of micro electrical mechanical systems (MEMS) [Min, Cho, Shih, Bhardwaj and Sinha, 2001] [Rabaey, Ammer Patel and Roundy, 2000] radio communication has made it possible to form small tiny nodes with the capability of sensing, computing and communication in a short range. These nodes can perform the sensing collaboratively which if monitored by a sensor will not give precise results. They are capable to form an autonomous intelligent network which does the unattended management. Technology review at MIT and Global Future say that sensor technology is one of the ten emerging technologies that will change the world [Werff, 2003]. A WSN consists of nodes with sensing, computing and communication capability connected according to some topology and a sink to communicate with the outside world. The network is capable of monitoring activities and phenomenon which can not be monitored easily by human beings, such as site of nuclear accident, some chemical field monitoring or environment monitoring for longer period of time. The general characteristics of these networks are [Haenggi, 2005] continuously changing topology due to the scheduling of the nodes in a network into different states, such as sleep or wake up states and dying nodes in the network, dense deployment of the network, autonomous intelligent network management, multi hop communication, limited node energy [Akyildiz, Su, Cayirci and Sankarasubramaniam, 2002] and limited bandwidth. Due to the short range of the radio communication and the fact that consumption of energy is proportional to the square of the distance making communication multi hop instead of direct communication will save energy. In WSNs each node tries to perform computation on data locally so data to be forwarded condenses, because computation is less expensive then data transmission in WSNs. For example to calculate the median of data sample at node is much efficient than to transmit the sample data and calculate the median at sink. WSNs are data centric networks and because of the sheer number of nodes it is not efficient to give a unique identification number (ID) to sensor nodes. The nodes are usually referred to as the type or the range of data they are dealing with [Al-Karaki and Kamal, 2004]. These networks are highly application specific so the architecture of protocol operation varies from application to application. One routing algorithm might be good for periodic monitoring while it may not perform well where it will have continuous data sensing.

The rest of this paper is organized as follows. Section 2 briefly describes the applications of the WSN in various fields. Section 3 gives a brief overview of the various clustering algorithms. Section 4 includes a detailed survey of the related research. The proposed algorithm is discussed in section 5.Section 6 discusses the simulation and its results Finally Section 7 concludes the paper.

2. APPLICATIONS

This section describes a few areas where WSNs can be used effectively. According to [Akyildiz, Su, Cayirci and Sankarasubramaniam, 2002] WNS are able to monitor wide range of applications which include Temperature, Humidity, Pressure, Lightning conditions, Soil makeup, Presence of objects, Mechanical stress, Speed, direction and size of objects. Typical applications include surveillance and battle space monitoring [Haenggi, 2005] by military, agricultural and environmental. For example researchers at UC Berkeley and the College of the Atlantic in Bar Harbour deployed sensors on Great Duck Island in Maine. These networks monitor the microclimates in and around nesting burrows used by the Leach's Storm Petrel. The goal was to develop a habitat monitoring kit that enables researchers worldwide to engage in the non-intrusive and non-disruptive monitoring of sensitive wildlife and habitats [Szewczyk, Anderson, Polastre, Culler and Mainwaring, 2002]. Engineering applications include maintenance in a large industrial plant or monitoring of civil structures, regulation of modern buildings in terms of temperature, humidity etc. Other applications include forest fire detection, flood detection [Bonnet, Seshadri and Gehrke, 2000] etc.

3. CHALLENGES AND ISSUES IN CLUSTERING THE WSNs

Despite the tremendous potentials and its numerous advantages namely distributed localised computing, communication in which failure of one part of the network does not affect the operation in other part of the network, longer area coverage, extreme environment area monitoring, WSNs pose various challenges to research community. This section briefly summarise some of the major challenges faced while clustering the wireless sensor network.

3.1. Network deployment

Node deployment in WSNs is either fixed or random depending on the application. In fixed deployment the network is deployed on predetermined locations whereas in random deployment the resulting distribution can be uniform or not uniform. In such a case careful management of the network is necessary in order to ensure entire area coverage and also to ensure that the energy consumption is also uniform across the network.

3.2. Heterogeneous network

The WSNs are not always uniform. In some cases a network is heterogeneous consisting of nodes with different energy levels. Some nodes are less energy constrained than others. Usually the fraction of nodes which are less energy constrained is small. In such type of network the less energy constraint node are chosen as cluster head of the cluster and the energy constrained nodes are the worker nodes of the cluster. The problem arises in such network when the network is deployed randomly and all cluster heads are concentrated in some particular part of the network resulting in unbalanced cluster formation and also making some portion of the network unreachable. Also if the resulting distribution of the cluster heads is uniform and if we use multi hop communication, the nodes which are close to the cluster head are under a heavy load as all the traffic is routed from different areas of the network to the cluster head is via the neighbours of the cluster head .This will cause rapid dying of the nodes in the vicinity of the cluster heads resulting in gaps near the cluster heads, decreasing of the network size and increasing the network energy consumption. Heterogeneous sensor networks require careful management of the clusters in order to avoid the problems resulting from unbalanced cluster head distribution as well as to ensure that the energy consumption across the network is uniform.

3.3. Network scalability

When a WSN is deployed, some time new nodes need to be added to the network in order to cover more area or to prolong the life time of the current network. In both the cases the clustering scheme should be able to adapt to changes in the topology of the network. The key point in designing such management schemes should be if the algorithm is local and dynamic it will be easy for it to adapt to topology changes.

3.4. Uniform energy consumption

Transmission in WSNs is more energy consuming compared to sensing, therefore the cluster heads which performs the function of transmitting the data to the base station consume more energy compared to the rest of the nodes. Clustering schemes should ensure that energy dissipation across the network should be balanced and the cluster head should be rotated in order to balance the network energy consumption.

3.5. Multihop or single hop communication

The communication model that wireless sensor network uses is either single hop or multi hop. Since energy consumption in wireless systems is directly proportional to the square of the distance, single hop communication is expensive in terms of energy consumption. Most of the routing algorithms use multi hop communication model since it is more energy efficient in terms of energy consumption however, with multi hop communication the nodes which are closer to the cluster head are under heavy traffic and can create gaps near the cluster head when their energy terminates.

3.6. Attribute based Addressing

Due to the sheer number of nodes it is not possible to assign IDs to nodes in WSNs. Data is accessed from nodes via attributes not by IDs. This makes intrusion into the system easier and implementing a security mechanism difficult.

3.7. Cluster Dynamics

Cluster dynamics means how the different parameters of the cluster are determined for example, the number of clusters in a particular network. In some cases the number might be preassinged and in some cases it is dynamic. The cluster head performs the function of compression as well as transmission of data. The distance between the cluster heads is a major issue. It can be dynamic or can be set in accordance with some minimum value. In case of dynamic, there is a possibility of forming unbalanced clusters. While limiting it by some pre-assigned, minimum distance can be effective in some cases but this is an open research issue. Also cluster head selection can either be centralised or decentralised which both have advantages and disadvantages. The number of clusters might be fixed or dynamic. Fixed number of clusters cause less overhead in that the network will not have to repeatedly go through the set up phase in which clusters are formed. In terms of scalability it is poor.

4. RELATED WORK

Routing in WSNs is a challenging task firstly because of the absence of global addressing schemes; secondly data source from multiple paths to single source, thirdly because of data redundancy and also because of energy and computation constraints of the network [Younis and Akkaya, 2005]. The conventional routing algorithms are not efficient when applied to WSNs. The performance of the existing routing algorithms for WSNs varies from application to application because of diverse demands of different applications. There is a strong need for development of routing techniques which work well across wide range of applications.

Broadly the routing protocols are divided into two categories one is based on the network structure and the second is based on protocol operation. The network structures are further classified as flat network routing, hierarchal network routing and location based routing. The protocol operation can be classified as negotiation based, multipath based, query based, QoS based and coherent based routing. Remaining section briefly describes the routing protocols based on network structure and more specifically the hierarchal routing algorithms.

Cluster based routing in WSNs comes under the category of hierarchal routing. Hierarchal routing involves formation of clusters where nodes are assigned the task of sensing which have low energy and transmission task to nodes which have higher energy. The purpose is to perform energy efficient routing. The cluster heads may be special nodes with higher energy or normal node depending on the algorithm and application. The cluster head also performs computational functions such as data aggregation and data compression in order to reduce the number of transmission to the base station (or sink) there by saving energy. One of the basic advantages of clustering is that the latency is minimized compared to flat base routing and also in flat based routing nodes that are far from the base station lacks the power to reach it.

Clustering based algorithms are believed to be the most efficient routing algorithm for the WSNs. The basic principle of its efficiency is that it operates on the rule of divide and conquers. Clustering along with reduction in energy consumption improves bandwidth utilization by reducing collision. Work is currently underway on the energy efficiency in WSNs which will result from the selection of cluster heads, the distance between cluster heads, the size of the cluster and inter and intra cluster communication, the type of environment they are deployed in, the organization of the network into set up and steady phase are the main factors to consider for devising an efficient cluster based routing algorithm. In the next section we take a brief look at some of the common clustering algorithms.

Leach [Balakrishnan, Chandrakasan and Heinzelman, 2000] is one of the first hierarchal routing approaches for sensor networks. Most of the clustering algorithms are derived from this algorithm. This protocol uses only two layers for communication. One is for communication within the clusters and the other is between the cluster heads and sink. Here the cluster head selection is random and the role of cluster heads rotates so as to balance the energy consumption throughout the network. Clusters are formed depending upon the signal strength of the advertisement message each node receives. Node will go for the one which has the strongest signal and it also calculates the total number of cluster heads for the network. According to Leach work it is 5% of the entire network and their Simulation shows that Leach performs over a factor of 7 reductions in energy dissipation compared to flat based routing algorithm such as direct diffusion [Intanagonwiwat, Govindan and Estrin, 2000]. The main problem with Leach protocol lies in the random selection of cluster heads. In random selection of the cluster heads there exists a probability that the cluster heads formed are unbalanced and may be in one part of the network making some part of the network unreachable.

An extension of the Leach protocol uses centralized cluster formation algorithm for the formation of the clusters [Balakrishnan, Chandrakasan and Heinzelman, 2002].The algorithm execution starts from the base station where the base station first receives all the information about each node regarding their location and energy level and then it runs the algorithm for the formation of cluster heads and clusters. Here also the number of cluster heads is limited and the selection of the cluster heads is also random but the base station makes sure that a node with less energy does not become a cluster head. The problem with the Leach-c is that it is not feasible for larger networks because the nodes which are far away from the base station will have difficulty in sending their status to the base station and since the role of cluster heads rotates, therefore r the distant nodes would not reach the base station in time. This results in increase of communication latency and delay also amplifies.

The routing algorithm in Leach is based on two phases, the setup phase and the steady phase. In the set up phase cluster head are selected randomly. The steady phase is the data transmission phase.

Leach-f [Balakrishnan, Chandrakasan and Heinzelman, 2002] uses the ideas that if the clusters remain fixed and only rotate the cluster head role within the cluster this will save masses of energy and increase the system throughput as well, whereas the disadvantage is that lack of scalability within the network which means new nodes cannot be added.

Teen [Manjeshwar and Agrawal, 2001] is basically for time critical applications to respond to sudden changes in the sensed data. Here the nodes sense data is continuously compared with data transmission which is only when the data is in the interest range of the user. Here the cluster head uses two value thresholds, one is hard threshold and other is soft threshold. Hard threshold is the minimum value of the attribute that triggers the transmission from node to the cluster head and soft threshold is small change in the value of the sense attributes. The node will transmit only when the value of the attribute changes by an amount equal to or greater then the soft threshold. The soft threshold reduces transmissions further if there is no significant change of the value of the sense attribute. The biggest advantage of this scheme is its suitability for time critical application and also the fact that it significantly reduces the number of transmission and gives the user the control in the accuracy of the value of the attribute he is collecting by varying the value of the soft threshold.

Apteen protocol [Manjeshwar and Agrawal, 2002] is an extension to Teen which is a hybrid protocol for both periodic data collection and also for time critical data collection. Here the cluster head broadcasts four types of messages to the node. Values of the threshold, the attributes value and a scheduling scheme for the nodes TDMA allowing every node a single slot for transmission Simulation shows that Teen and Apteen performs better then Leach in terms of energy consumption. Out of the three Leach, Teen and Apteen, Teen performs better then the other two. The disadvantage is that since there is multilevel clustering in Teen and Apteen, they result in Complexity and overheads.

The protocol by [Gupta and Younis, 2003] presents a multi-gateway architecture to cover large area of interest without degrading the service of the system. The algorithm balances the load amongst the different clusters at clustering time to keep the density of the cluster uniform. The network incorporates two types of nodes: sensor nodes which are energy constrained and gateway nodes which are less energy constrained. Gateways maintain the state of the sensors as well as setup multi hop route for collecting sensor data. The nodes TDMA based MAC is used for communication with cluster heads. The disadvantage is that since the cluster heads are static and less energy constraint than the rest of the nodes and they are also fixed for the network life time therefore the nodes close to the cluster head will die quickly compared to other nodes, thus creating gaps near the cluster heads and decreasing the connectivity of the network. Also if the network is to be deployed randomly then there is a good probability that the resultant distribution of the cluster heads is unbalanced.

A centralized protocol is presented by [Muraganathan, Bhasin, Ma and Fapojuwo, 2005] with the base station being an important component with complex computational capabilities. The base station makes all the high energy consuming decisions like cluster head election, route calculations etc.This algorithm operates in two major phases. The first phase is the setup phase and the second is data communication. During the setup phase cluster formation, cluster head selection and a scheduling is done for each cluster. Also the base station receives energy from all the nodes and calculates the average amount of the energy produced and then decides on a set of nodes whose energy level are above the average value where cluster head will be chosen from this set. Step two is to group the remaining nodes in one of the cluster heads and then by iterative process algorithm forming clusters until the desired number of clusters is achieved. The process also ensures that the selected cluster heads are uniformly distributed. The data communication phase consists of the following activities

- Data gathering
- Data fusion
- Data routing

Simulation results show that BCDCP outperforms its comparatives leach, leach-c and PEGASIS also performing CH to CH routing scheme to transfer fuse data to base station. The drawback of the protocol is that it requires information about all the nodes in a network before the selection of cluster heads where in a larger network this approach would not work well since it uses a centralised approach for the management of the clusters.

The paper by [Hansen, Nolin and Bjorkman, 20060] looks at how much the energy consumption can be lowered in the sensor network by separating the cluster heads. The cluster formation same as in leach-c. To minimize energy consumption for the cluster nodes when transmitting data to the cluster head, this algorithm randomly chooses a node eligible for cluster head selection but also at the same time makes sure that nodes are serrated with a minimum separation distance from other cluster heads. The node should have energy level above the average energy level of the network to be eligible for cluster head. When the cluster head election process finishes then clusters are formed in the same way as in leach. Simulation results shows that the minimum separation distance improves the energy efficiency measured by the number of messages received at the base station. It also shows that it is 150% better when minimum separation distance is used compared to the one which does not use the minimum separation distance.

In [Israr and Awan, 2006] we presented the multi hop routing algorithm for inter cluster communication. The algorithms was a multilayer multi hop routing algorithm which worked on the principle of divide and conquer and was performing good in terms of load balancing and energy efficiency then leach. The algorithm was aimed at exploiting the redundancy property of the WSNs .It selects a small percent of nodes from the network and marks them as temporary cluster heads and uses these nodes to make the intercluster communication multi hop.

The problem with the algorithm was that it was selecting the temporary cluster heads randomly thus compromising occasionally on the area coverage of the network which it is monitoring. This modified version of the algorithm selects only those nodes as temporary cluster heads whose neighbors guarantees the area coverage of the node selected as temporary cluster head. Hereafter the algorithm forms two layers of communication, the bottom layer which comprise of nodes which sense data and participate only in intra cluster communication, the second layer will comprise of cluster heads and the temporary cluster heads. Both the layer communication is multi hop and we can make the following assumption about the network model as made by other models:

- The network comprise of 100 sensor nodes.
- All the nodes are homogeneous with same battery power and architecture.
- The network is deployed randomly in an area of 500 by 500 meter square area.
- We assume that the network is noise and error free.
- The energy consumption assumptions are as follow 50 nj/bit to run the circuitry of both transmitter and receiver and 100 Pj/bit to transmit.
- We have not made any assumptions about the network synchronization, the radio transmission range and about the control messages.
- Each node is aware of its location via some gps system or by using some localisation algorithm [Savvides,han and Stivastava,2001] also each node has information about their neighbours
- Each node also has information regarding its area coverage.

5. MCLB (MULTIHOP CLUSTERING ALGORITHM FOR LOAD BALANCING)

The MCLB comprise of two distinct phases, the setup phase and steady phase. During the setup phase Cluster Heads and temporary cluster heads are elected followed by the steady phase. The steady phase is the data transmission phase and is longer then the setup phase. In the setup phase, the algorithm first filters all the nodes in the network of which area coverage is covered by its neighbours. Area coverage of a neighbour is determined by using the tian and gorganas approach which states that if we combine the central angles of the sector drawn by touching points of the two areas and the node itself, therefore if the resultant angle is greater then or equal to 360 then the node sensing area is fully covered by its neighbours. Some times the sensing area is also covered in case if two adjacent nodes have different sensing range due to its different battery power. But we are not considering this type of area coverage in this simulation.

Figure 2. depicts the general operation of the formation of temporary cluster head. Here node 5's sensing area is completely covered by node 1, 2, 3 and 4 so node 5 becomes a temporary cluster head. The procedure runs for all the nodes in the network and terminates in O (n) time. As a result of this operation the network is divided into two layers the top layer and the bottom Layer. The top layer comprise of nodes whose sensing area is completely covered by its neighbours along with cluster heads, whereas the bottom layer comprise of the rest of the network nodes. Figure 3 shows the bottom layer of the randomly deployed network and Figure 4.shows the top layer of the network as a result of operations

described in Figure 2.where as the rest of setup phase of the algorithm is the same as that of leach in which a set of cluster heads are chosen at random. These cluster heads then broadcast an advertisement message. Depending on the message strength each node then decides to which cluster head it belongs. This phase uses the CSMA MAC protocol and during this period all the nodes are listening. The selection of the cluster head is dependent on the probability. During each cycle the cluster head selection is random and is dependent on the amount of energy a node has left and its probability of being not cluster head during the last r rounds. After this the data transmission phase starts. In this phase all nodes transmit data using TDMA based scheduling. When all the nodes within the cluster finish sending data the cluster head performs some computation on it and sends it to base station using multi hop communication involving temporary clusters and other clusters heads.

Table 1.Pseudocode of the MCLB

Start Setup phase

- The nodes whose sensing area coverage is covered by neighbours forms temporary cluster heads
- Select the desired number of CH for a round
- CH broadcast hello message
- Clusters are formed depending on signal strength a node receives from different CHs
- Nodes broadcast location, range and area they cover via hello message.
- Nodes build a table of their neighbours depending on the hello message they receive from neighbours.
- The temporary cluster heads and cluster heads forms the top layer of communication
- The sensor nodes forms the bottom layer of communication

End of Setup Phase

Start Steady Phase

Intra Cluster Communication

- Nodes start transmitting in their allotted time slot using TDMA. When all nodes in a cluster finish the CH transmission phase begins

Inter Cluster Communication

- Cluster Head performs computation on data
- Cluster Head also Transmit Data using multi hop Communication.
- Once all the Cluster Head finish the control returns to steady phase again

End of Steady Phase

Repeat Steady Phase

6. SIMULATION AND DISCUSSION

In this section we evaluate the performance of the MCLB. The deployment of the network is shown in Figure 1 .Figure 4 shows the top layer of the network without cluster heads. Figure 3 shows the bottom layer of the network. After formation of both layers, clusters are formed and transmission pahse starts. Figure 5 shows a general operation of the algorithm showing both multi hop inter cluster and intra cluster communication .The simulation was run for 2500 iterations. Figure 6 shows the comparison of the energy left in the network as the simulation progresses by the three algorithms. Form this fig it is obvious that the proposed algorithm performs better in terms of energy consumption compared to leach and extension to leach [Israr and Awan, 2006]. Also from the graph it is obvious that the proposed algorithm's energy consumption is uniform compared to leach and its extended version it also means that unbalanced clusters have no effect on the consumption of energy in this model. Figure 7 shows the distribution of dead nodes in Leach after the simulation ends. Figure 8 shows the distribution of dead nodes in the extended leach algorithm after the simulation ends and Figure 9 depicts the distribution of dead nodes in the proposed algorithm across the network after the simulation ends. From the comparison of three figures it is obvious that both in leach and its extended version, the number of dead nodes is far more then the proposed algorithm and also in leach and its extended version the dead nodes forms clusters .whereas compared to this the proposed algorithm efficiently balances the dead nodes across the network. Figure 10 shows comparison of the dead nodes as the simulation progresses

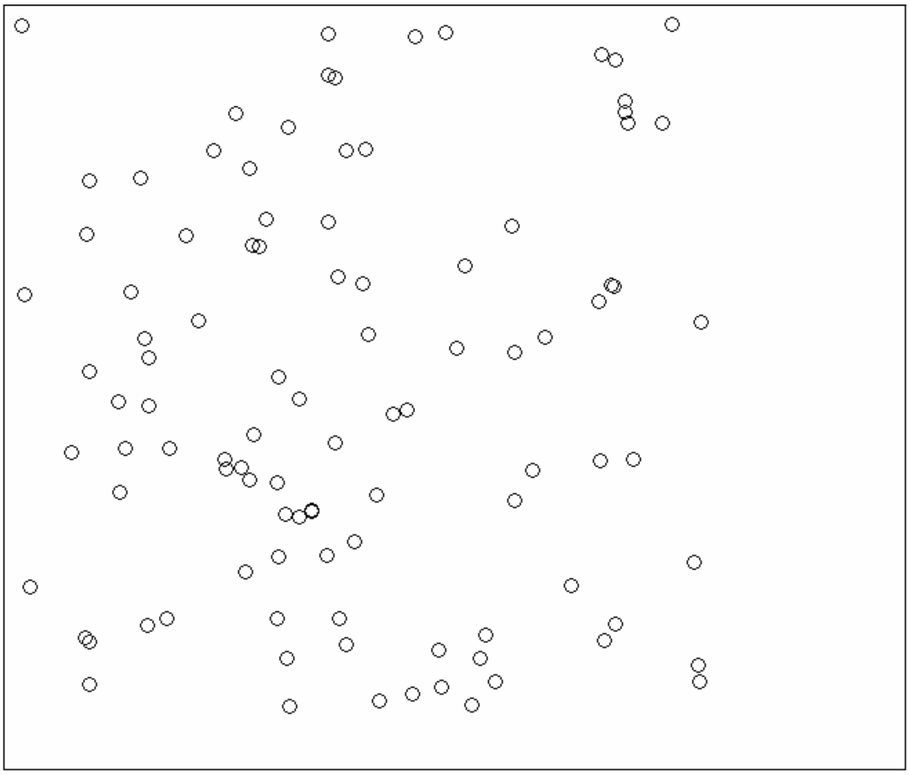

Fig 1. Random Deployment of the Network in an Area of 500 by 500 meter square

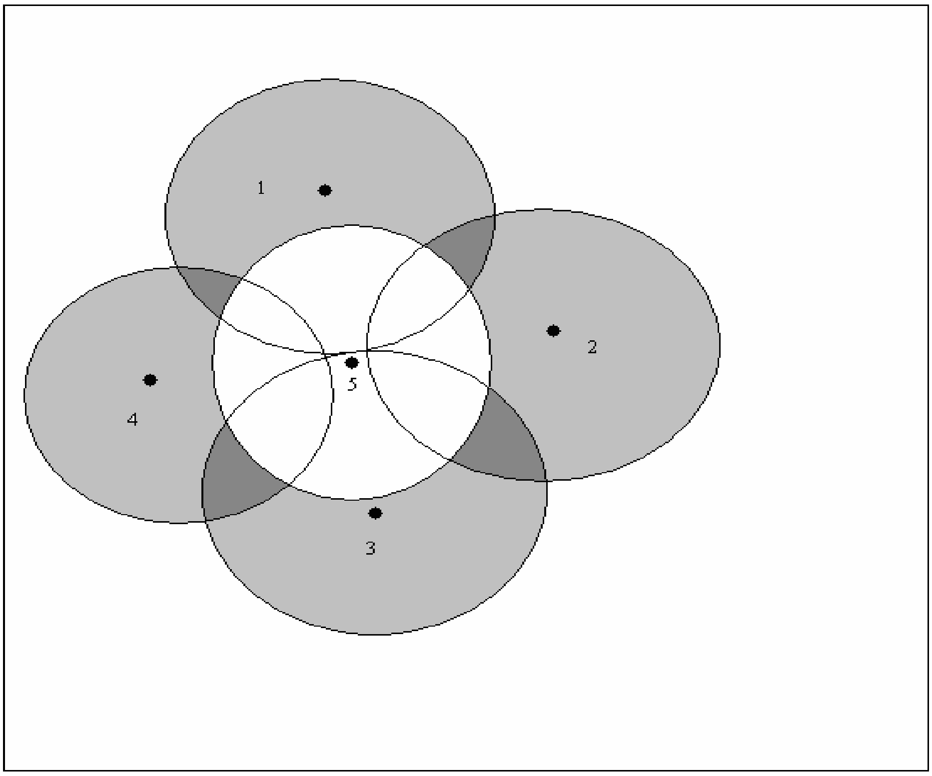

Fig 2.Formation of Temporary Cluster Head

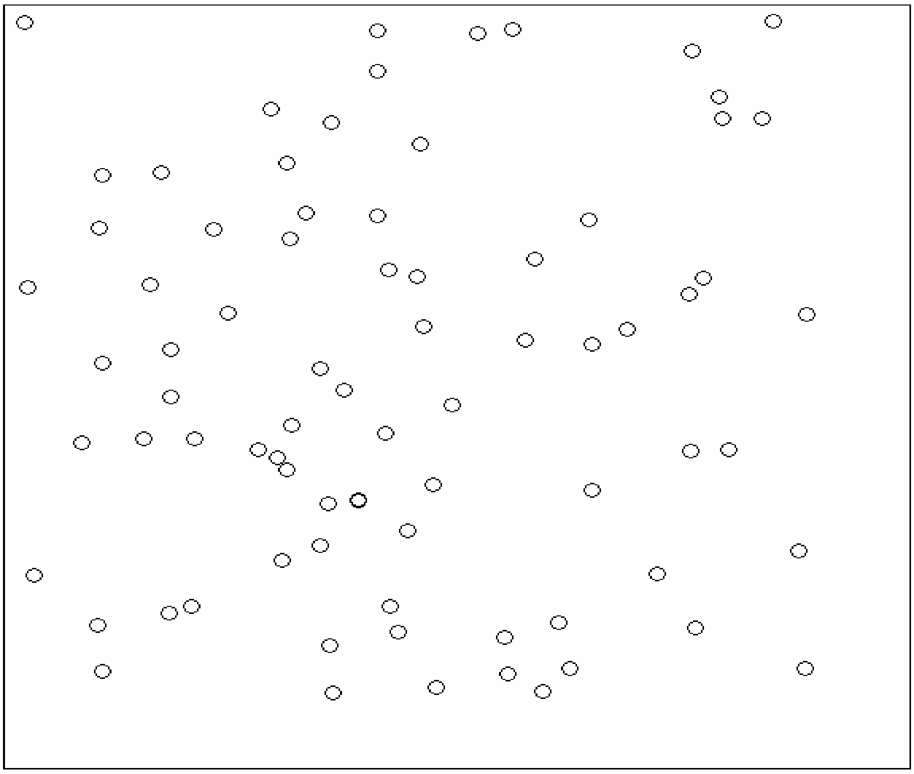

Fig 3. Bottom Layer of the Network

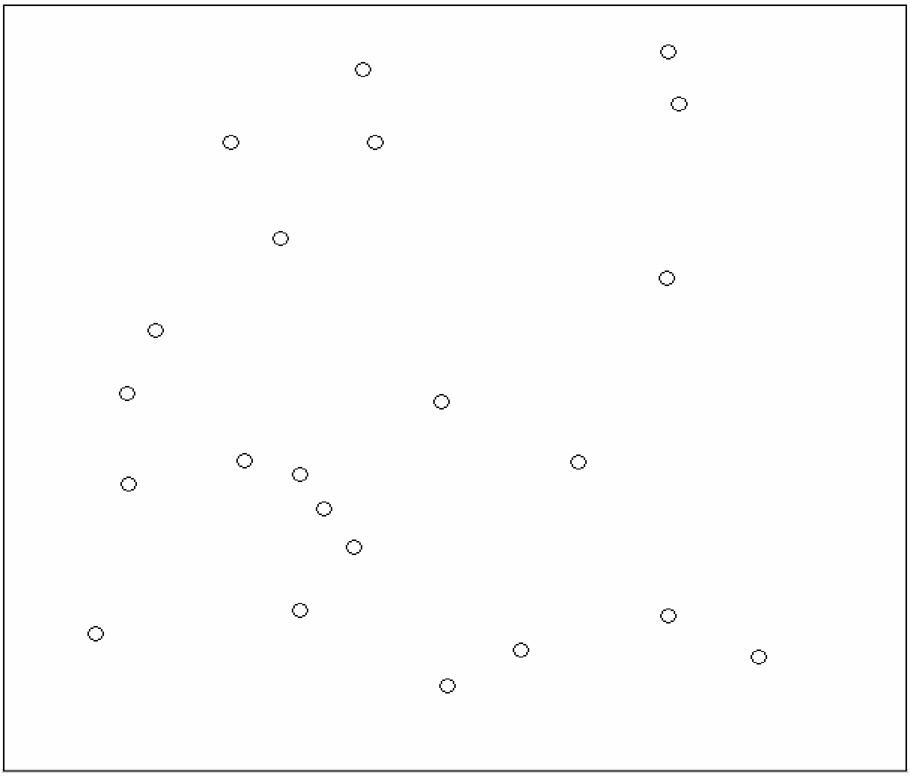

Fig 4. Top Layer of the Network

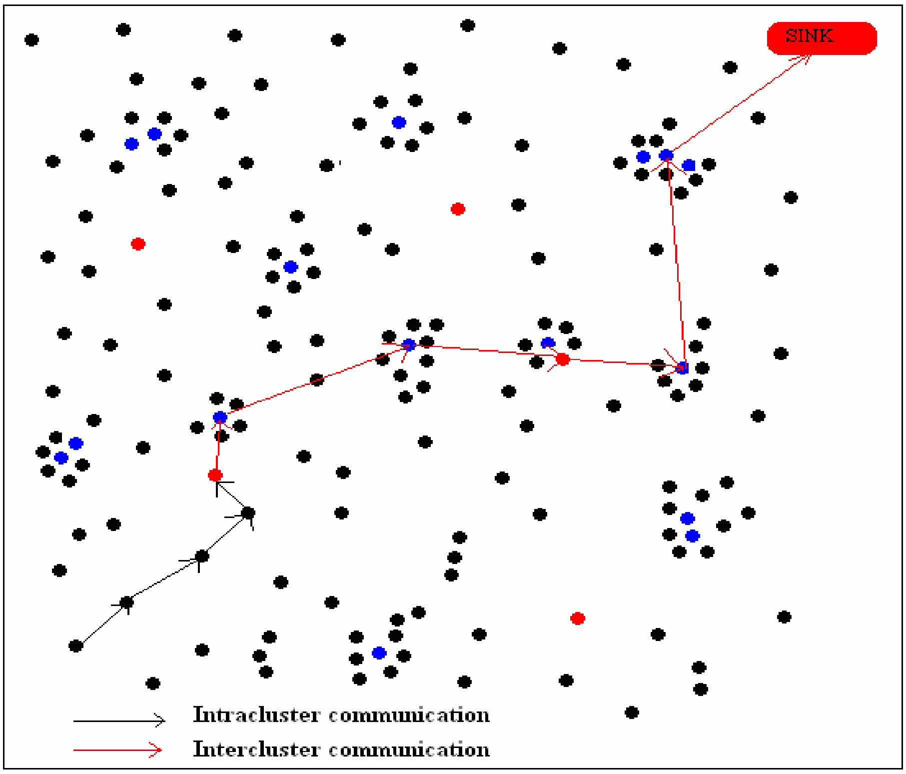

Fig 5. General Operation of the Algorithm

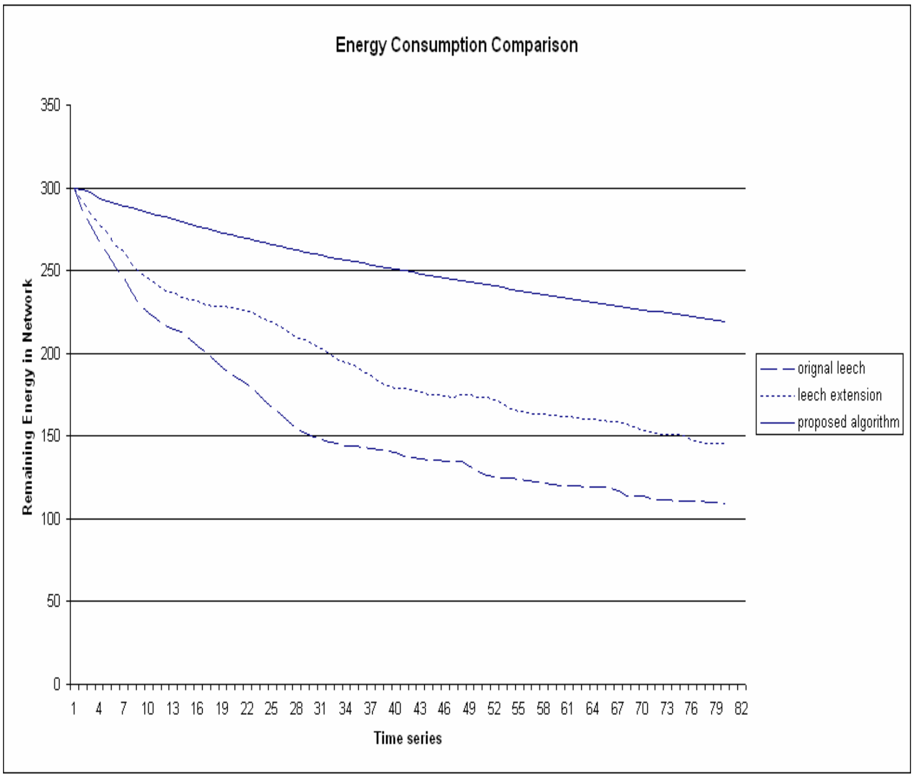

Fig 6. Energy consumption Comparison of leach, Extended Leach and Proposed Algorithm

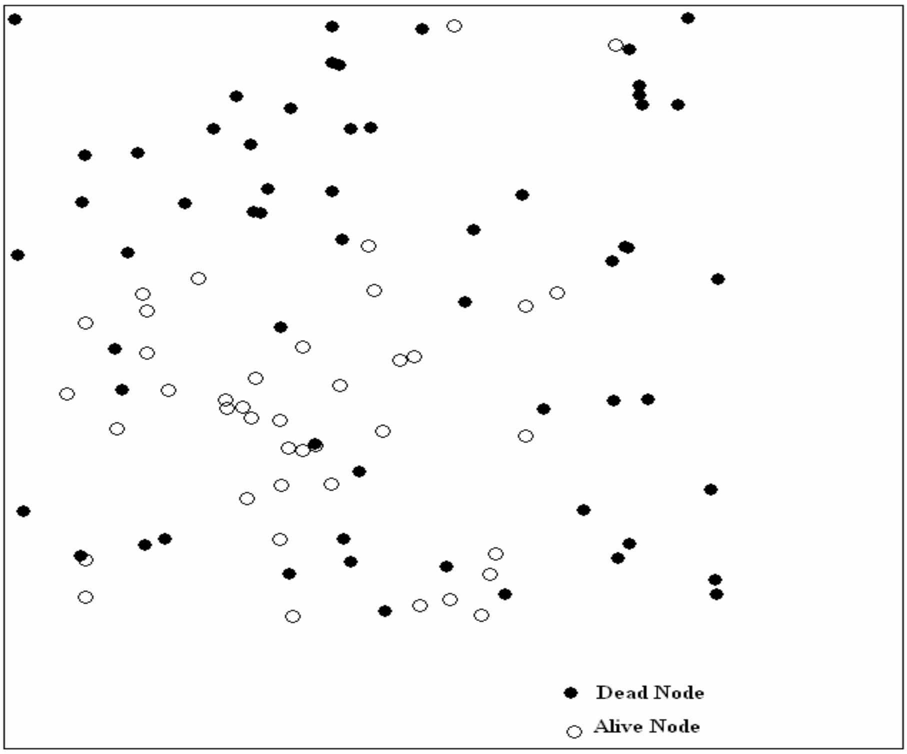

Fig 7. Dead Nodes Distribution in Leach after Simulation Ends

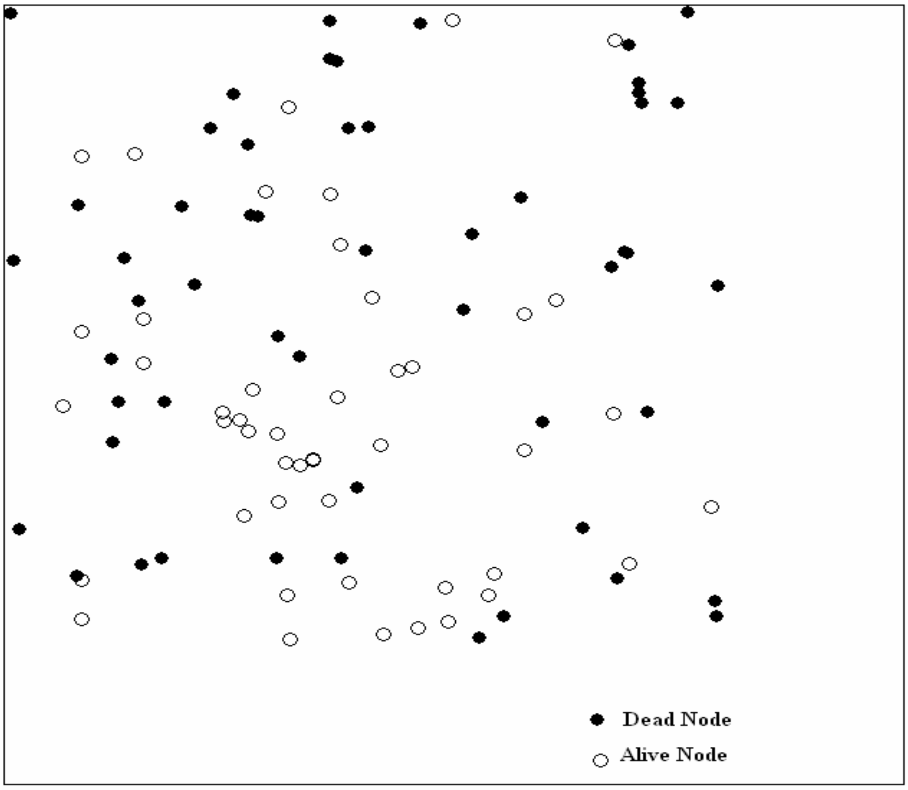

Fig 8. Dead Node Distribution in Extended Leach After Simulation Ends

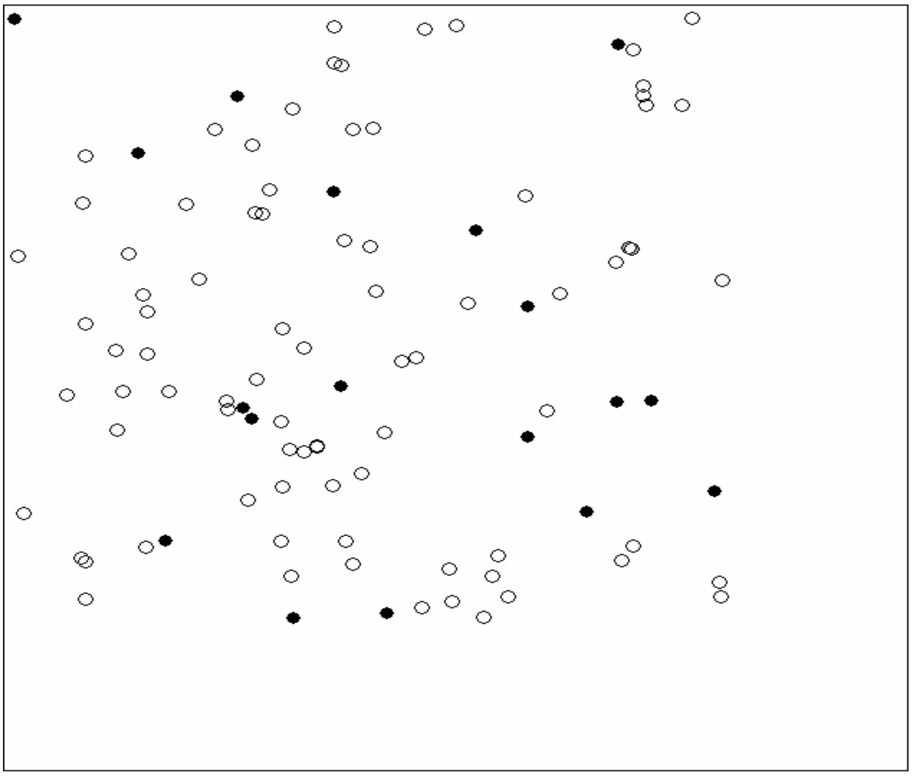

Fig 9. Dead Nodes in the Proposed Algorithm after Simulation Ends

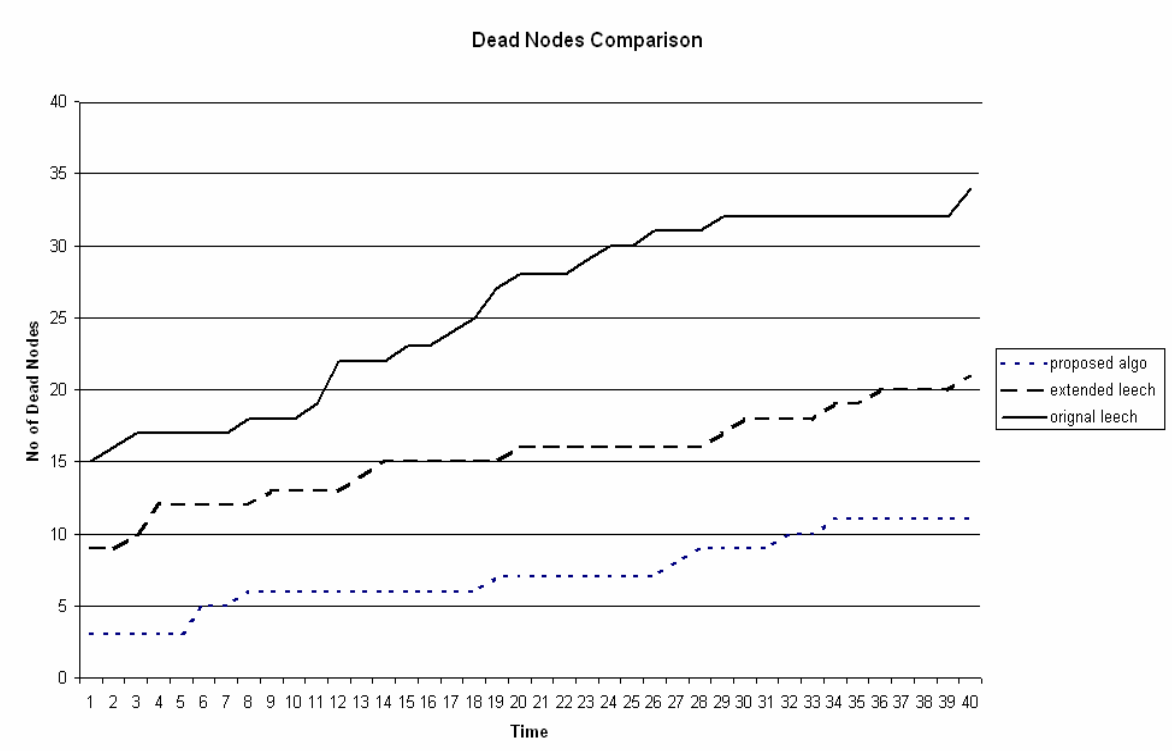

Fig 10. Dead Node Comparison of the three Algorithms as the simulation Progresses

7. CONCLUSION AND FUTURE WORK

It is obvious from the simulation result that by exploiting the density property of the WSNs it is possible to enhance the network life time and also efficiently balance the energy consumption load across the network. Also the energy consumption of across the network. Also the energy consumption of the network becomes uniform and it doesn't matter even if the cluster are balanced or unbalanced compared to leach. The future extension of the work includes heterogeneous network and possibly with some mobility in the network.

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