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Applying Fuzzy Logic and Node Differentiation to Heterogeneous Wireless Sensor Networks

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Abstract: Developments in wireless technologies and MEMS have led to much ease of use of wireless sensor networks. The energy issue is still an open challenge. Clustering is a good solution if it ensures even load distribution. Recently fuzzy logic is being used to combine different characteristics of nodes to decide the cluster structure of the network. This paper proposes how node differentiation can be done in heterogeneous networks based on position of the node, and then fuzzy logic is used for the cluster formation. The fuzzy system has two outputs – node selection probability and cluster size bound. Thus our proposal not only elects CH but also determines that cluster stricture should be such that potential hot spots are not given much load. Potential hot spot nodes are identified using the proposed node differentiation technique. Connectivity of the network for longer time is our main QoS parameter.

Keywords: WSN, clustering, connectivity, heterogeneous, fuzzy logic, hotspot problem

I. INTRODUCTION

Wireless sensor Network (WSN) brings a new paradigm of real time embedded systems with limited computation, communication, memory, and energy resources that are being used for huge range of applications where traditional infrastructure based network is mostly infeasible. As Wireless Sensor Network has unrechargeable and very limited and less energy resources, it gives birth to the research in enhancing or increasing the lifetime of Wireless Sensor Networks, The sensor nodes are densely deployed in a hostile environment to monitor, detect, and analyze the physical phenomenon and consume considerable amount of energy while transmitting the information. It is impractical and sometimes impossible to replace the battery and to maintain longer network life time. So, there is a limitation on the lifetime of the battery power and energy conservation is a challenging issue.

A wireless sensor node carries out its function in the following steps [1]:

1. Geographically dispersed sensor nodes sense the surrounding environment. A node may have more than one type of sensor like temperature sensor, pressure sensor, etc depending on the application need. This part of a node which is involved in sensing activities is generally referred as sensing subsystem.
2. The sensed analog raw data will be converted into digital data using analog to digital converter (ADC).
3. The digital data will be processed according to the specifications in the node's microcontroller unit. It is generally called as processing subsystem.
4. Then the processed data will be given to the radio transceiver IC in order to be sent to other nodes or to the BS directly. This unit is generally referred as communication subsystem.

Thus, a sensor node in a WSN consumes energy for sensing, processing and communication of data. On the basis of technology and function a sensor node can be broadly categorized as thermal, pressure, visual, seismic, infrared, radar, magnetic and acoustic [2]. These sensor nodes perform function of measuring environmental factors that they are designed for; namely conditions are temperature, pressure, humidity, soil makeup, vehicular movement, noise levels, lighting conditions, the presence or absence of certain kinds of objects and mechanical stress levels on attached objects [3]. A single sensor node is not sufficient to monitor an entire region. Usually more than required numbers of nodes are deployed for redundancy in order to have a fault tolerant topology in WSN. The number of nodes could be thousands. All nodes in the region of application work collaboratively to form a network.

WSNs have an upper hand as compared to the wired sensing infrastructure due to several reasons. The cost of deployment is much lower and gets cheaper as the area increases or the terrain becomes inaccessible for humans. Thus they are easier and faster than the wired sensor networks to deploy [4]. Next, the WSNs are self-configuring, that is the topology is dynamic and can be changed whenever required even without a centralized control. WSNs have variety of applications such as military reconnaissance, disaster management, security surveillance, habitat monitoring, medical and health, industrial automation [5,6,7].

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Since WSNs have several applications, it is essential that energy saving methods for WSNs be researched. It is essential to develop an energy aware clustering protocol in WSN to reduce energy consumption for increasing network lifetime. Network topology and energy consumption are important issues in WSN for improving network performance in critical applications. Power control and Energy efficiency are the basic guarantee of any network performance for example, throughput and delay, hence is their importance.

Cluster based design is one of the ways to deal with to save the energy of the sensor devices. The energy consumption can be reduced by allowing only some nodes to communicate with the base station. These nodes called cluster-heads collect the data sent by each node in that cluster compressing it and then transmitting the aggregated data to the base station. Authors in [8] have presented a survey on clustering protocols in WSNs and identified following advantages of clustering algorithms when they are combined with other management techniques of WSNs like routing. Electing a CH node based on fuzzy approach is suitable for WSN where the degree of uncertainty is higher. Moreover it can be used for context by blending different parameters - rules combined together to produce the suitable result. Generally, fuzzy clustering algorithms use fuzzy logic for blending different clustering parameters to select cluster heads. This paper proposes two techniques: i) a node differentiation method that identifies the nodes that are likely to be hot spots; and ii) a fuzzy inference system that outputs two quantities, node selection probability and cluster size bound. The proposed clustering protocol describes how to elect CH and how to form the clysters so that potential hot-spots are not overloaded. The purpose is to prevent premature death of any node.

II. RELATED WORKS

There are diverse applications of intelligent techniques in wireless networks. Fuzzy logic (FL) control is capable of making real time decisions, even with incomplete information [9, 10]. Conventional control systems rely on an accurate representation of the environment, which generally does not exist in reality. Fuzzy logic systems, which can manipulate the linguistic rules in a natural way, are hence suitable in this respect.

Gupta et al [11] presented the first work that suggested how fuzzy logic can be used for clustering purpose in WSNs in 2005. Their technique is called Cluster -head election using fuzzy logic (CEFL). The authors propose a fuzzy logic approach to cluster head election based on three descriptors i.e. energy, concentration and centrality. But this technique uses a centralized control that incurs high communication overhead. Cluster Head election mechanism using fuzzy logic (CHEF) in wireless sensor network is proposed by Kim et al [12]. The inputs to the FIS in CHEF are energy and local distance, with priority to energy in deciding the output chance of the node to become CH. If the chance of a tentative cluster-head is greater than the other tentative cluster heads' chances in radius *r*, then that tentative cluster-head becomes an actual cluster-head.

Anno et al [13] have proposed two fuzzy based systems for election of cluster heads within sensor networks named as FCHS system 1 and FCHS system 2. FCHS stands for fuzzy-based cluster head selection. Both have FRB of 27 rules, but inputs are different. In FCHS-1, the inputs are Distance of Cluster Centroid, Remaining Battery Power of Sensor, and Network Traffic. The fuzzy output parameter is possibility of Cluster head selection. The authors found that the number of neighbour nodes is very important for the selection of the cluster head. So, FCHS-2 has inputs Remaining Battery Power of Sensor, Degree of Number of Neighbour Nodes and Distance from Cluster Centroid.
Energy Aware Unequal Clustering with Fuzzy logic (EAUCF) [14] is a very popular technique. EAUCF algorithm focuses on decreasing the intra cluster work of the cluster heads that are either near to the base station or whose remaining battery power is low. The only output for the fuzzy logic is the 'Competition Radius' of the cluster head.
Mhemed et al [15] present a Fuzzy Logic approach, named Fuzzy Logic Cluster Formation Protocol (FLCFP). It uses the energy level of the CH, distance between the BS and the CH, and distance between the CH and the node as input parameters for its Fuzzy inference system. Though the parameters are same as previous protocols, the difference lies in the use of these parameters and the fuzzy logic. The CHs are elected same as in LEACH. No fuzzy logic is used for the election purpose. Rather, fuzzy system is used for cluster formation. The nodes pick the CH to join using this logic. Each non-CH node applies the three descriptors for each CH using the Mamdani Fuzzy Inference System, and joins the CH that has the maximum chance value to form the cluster.

Lee and Cheng [16] proposed a very different approach towards incorporating fuzzy logic in a LEACH style clustering technique. Instead of using the parameters that most of the algorithms use, they proposed to use parameters that are estimates based on predictions of load a node might have in future. It is the first work to use expected residual energy (ERE) as a criterion for CH election. The ERE is estimated using the number of neighbour nodes a node has, the length of frame and hence the number of frames a node may receive during the steady state operation. ERE indirectly involves the number of neighbours as a criteria for CH election. It is a unique feature of this algorithm. A major drawback is this

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technique can be applied only when operations in all nodes are synchronized; otherwise the estimates of energy consumption would fail.

Natarajan and Selvaraj in their scheme Fuzzy-based Predictive Cluster-head Selection (FPCS) [17] have considered the energy drainage factor of node. Energy drainage refers to the frequency with which a node communicates. The drainage factor is quantized through a parameter Rate of recurrent Communication of Sensor Node (RCSN). It is defined as the number of times a node communicates with its CH. The fuzzy system uses five inputs, the four are similar to many previous works and a new input RCSN is used that is derived from the previous round of protocol.
Distributed Load Balancing Unequal Clustering in wireless sensor networks using fuzzy approach (DUCF)[18] is a recent work that produces clusters of unequal size to balance load in the network using single-hop communication for intra-cluster operations and multi-hop for inter-CH communication. The nodes are homogenous in nature. The three fuzzy inputs that are chosen for electing the CH are residual energy, node degree i.e. number of neighbours and distance to BS. DUCF differs from previous works as it has two output variables, ‘chance’ and ‘size’. ‘Chance’ is the probability of node to get elected as CH and ‘size’ is the maximum number of nodes it can have as cluster member if chosen as CH.
Logambigai and Kannan proposed an algorithm called fuzzy based unequal clustering (FBUC) [19].
This is an improved version of fuzzy energy aware unequal clustering algorithm (EAUCF) in three ways. Firstly, by using probabilistic threshold value; secondly, for electing cluster head they use three fuzzy variables instead of two variables; thirdly, in the non cluster head, nodes joining with the cluster head nodes are also considered and they use fuzzy logic with two variables. It is a distributive unequal clustering algorithm which works in rounds as Leach.
Julie and Selvi [20] proposed a Neuro fuzzy energy aware clustering scheme (NFEACS) for the formation of optimum and energy aware clusters. For achieving energy efficiency in forming clusters and cluster heads, NFEACS consists of fuzzy subsystem and neural network system. A dynamic situation is considered where the sensor nodes are also mobile.
Sert et al [21] have proposed a multi-objective fuzzy clustering algorithm (MOFCA) in 2015 that addresses both hotspots and energy hole problems in stationary and evolving networks. It suggests electing tentative CHs first using a probabilistic model. Thereafter, the tentative CHs compete to become CH using the fuzzy system. The main focus is on energy. Three fuzzy input variables are defined in MOFCA: residual energy, distance from the sink, and node density. These are used to determine the node’s competition radius.

Almost every fuzzy logic based protocol has used Mamdani inference system. Shoukohifar and Jalali [22] suggest to use Sugeno fuzzy system instead. Their proposed LEACH-SF algorithm is different from the existing classical and fuzzy cluster-based routing protocols. The cluster formation is inverse, that is first balanced clusters are formed and then an appropriate CH is selected for it. Thus, it can precisely control the number of CHs in the network.
Other clustering methods that do not use fuzzy logic, but consider heterogenous settings are now discussed. In 2006, Qing, Zhu and Wang [23] proposed a distributed clustering algorithm for heterogeneous networks. They called it Distributed Energy-efficient clustering (DEEC) algorithm. All nodes have different initial energy levels, such that m% of total nodes are advanced nodes having a times higher initial energy than normal nodes. The nodes that have high initial energy get a chance to become CH in earlier rounds. Later, CHs are selected based on the ratio of the residual energy to the average energy of the network.

Heterogeneous settings in WSNs have been considered recently by Han et al [24]. Their algorithm named Double-phase Cluster-head Election (DCE) scheme is a procedure of cluster head election itself divided into two phases. The first phase takes place at individual level. Every node computed its own election probability to decide whether its state will be tentative CH or not. The probability is calculated based on the initial energy and current residual energy. the average energy of entire network is considered and to make the protocol purely distributed, the quantity is estimated instead of collecting global information for it. The second phase replaces low energy tentative CHs so that they do not become a CH and energy hole is avoided. In this phase, each non-elected node determines its tentative cluster with the nearest tentative CH. The distances are estimated according to the RSS of the announcement message of the tentative CHs. Then, the non-elected nodes compare their own residual energy with that of their tentative CH. If a non-elected node has more energy, it will broadcast a short announcement message to the whole network, to state its replacement of the original CH node and its request to be the final CH node of this round. To avoid multiple substitutions for the same tentative CH, all the nodes, which are eligible to conduct the substitution, broadcast the announcement message randomly within a bounded period of time. The first node that broadcasts its message wins the election.

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III. PROPOSAL

A. Node Differentiation

We propose to observe load on a node by counting its neighbours that are nearer to BS than itself and the neighbours that are farther from BS than itself. The 1-hop neighbour nodes towards BS are now referred to as TBS-neighbours and the nodes away from BS as ABS-neighbours. A node with many ABS-neighbours is a ***crucial*** node (potential hot spot) in multi-hop communication models. A node with no or very few ABS-neighbours is ***crucial*** in single-hop communication. In any case, two steps are suggested:

i) Avoid crucial nodes to be selected as a CH

ii)If a crucial node is selected as CH, then limit the number of members joining it to decrease the load

Now, we proceed to propose a clustering protocol that deals with crucial nodes in different manner so that their energy can be saved. The objective is to prove that identifying a crucial node and handling it differently from other nodes helps in avoiding hot spot problem. Though it cannot be proved in absolute manner, but if a network remains connected for long that it implies that hot-spot nodes have not died prematurely.

B. Proposed Fuzzy Interference System

We propose to use fuzzy logic to compute the chance of nodes to become a CH and also bounds on size of the clusters. In case when a crucial node is selected as a CH, the size of its cluster is reduced to a set minimum i.e.5% of total nodes. The inputs to the proposed fuzzy inference system are:

- Residual energy – The energy remaining in a node is an important factor as we need to distribute the load among all nodes. The nodes with higher energy should get higher chance of being elected as CH. Three linguistic levels are decided here: High, Medium and Low.
- Distance to BS – The distance to BS is critical when selecting a node for CH role. Nodes nearer to BS stand a higher chance. But should have less members. The linguistic variables for this are : Nearby, Reachable and Distant.
- Degree – The number of 1-hop neighbors of a node within its communication radius are called its degree. The corresponding linguistic variables are: Huge, Average and Less.

The FIS of our proposal is also different from many existing works as it has two outputs:

- Node Selection Probability (NSP) - A value that indicates strength of a node's candidature for being elected as CH. a node having a higher value of NSP is more likely to be elected as a CH than a node with lower value of NSP in its neighboring region. The nine linguistic values aassociated to this variable are: Very High, High, Rather High, High Medium, Medium, Low Medium, Rather Low, Low, Very Low.
- Cluster Size Bound (CSB) – the maximum number of members allowed in a cluster must vary according to the load that should be given to the CH. This is decided by CSB. The associated 7 linguistic variables are : Very Large, Large, Rather Large, Medium, Rather Small, Small, Very Small.

We use Mamdani method for fuzzy inference. Three crisp input are required – residual energy, distance from BS and total number of neighbours. After fuzzification, each of them is translated into three linguistic levels each. This gives a fuzzy rule base of 27 rules which when applied produces two outputs that can be defuzzified to compute crisp values of NSP and CSB per node.

The idea behind framing of the rules can be explained through two extreme cases for NSP as:

- When a node has *high* residual energy and is *near* to the BS, then it has *very high* probability of becoming a CH.
- When a node has *low* residual energy and is *distant* from the BS, then it has *very low* probability of becoming a CH.

The effect of degree on NSP is not much but is included in the FRB so that single inference system can be used for two outputs. The two extreme cases for CSB are as following:

- When a node has *huge* degree and is *distant* from the BS, then it can have *very large* size of cluster.
- When a node has *less* degree and is *nearby* to the BS, then it can have *very small* size of cluster.

The FRB is designed such that the nodes that have higher values of NSP have moderate size of cluster, while those having medium values of NSP have large size of cluster. This maintains a balance of energy. The nodes that do not have much energy, have low values of NSP. Yet, if they are in any case elected as CH, then the size of cluster depends on their degree and distance from BS. A node with low energy can also be a CH of large cluster if it is near to CH. To avoid such treatment of a crucial node, the CSB of a crucial node is adjusted and hence will have a small cluster only

The 27 fuzzy rules of the proposed FRB are shown in Table I. The rules of FRB that may seem opposed to the purpose of the protocol in first glance are actually required to handle situations that occur later in a network. Such rules might never get triggered during first half life of the network. Later, when energy levels of most of the nodes are low and due to many dead neighbors, effective degree of the nodes changes dramatically and such rules need to be applied. In these situations CSB needs to be large because very few nodes are alive and fewer CHs should be elected. The triangular plots membership functions are shown in Fig 1, 2, 3, 4 and 5 respectively for the three inputs and two outputs of the fuzzy system.

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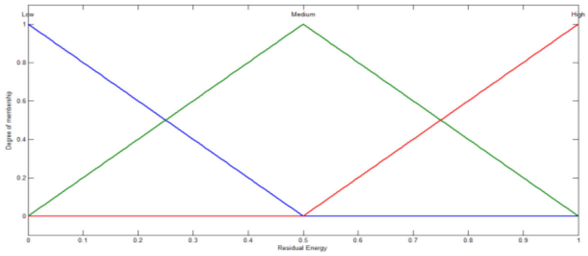

Fig 1. Membership function for Residual Energy – FLND fuzzy Inference Method

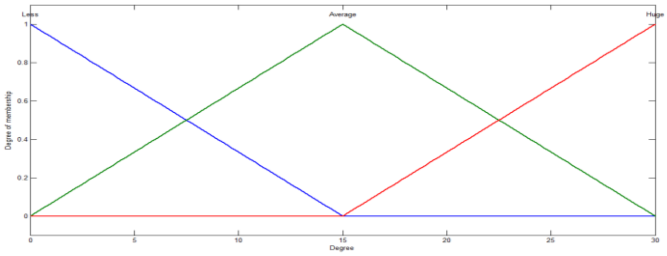

Fig 2. Membership function for Node Degree – FLND fuzzy Inference Method

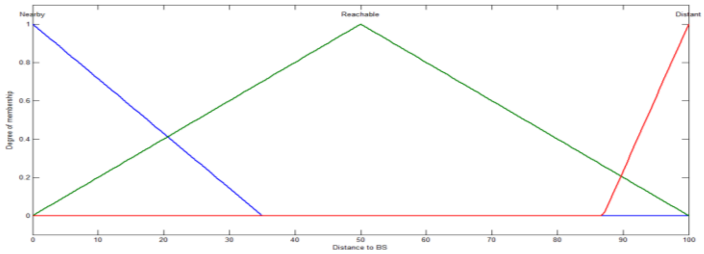

Fig 3.Membership function for Distance to BS – FLND fuzzy Inference Method

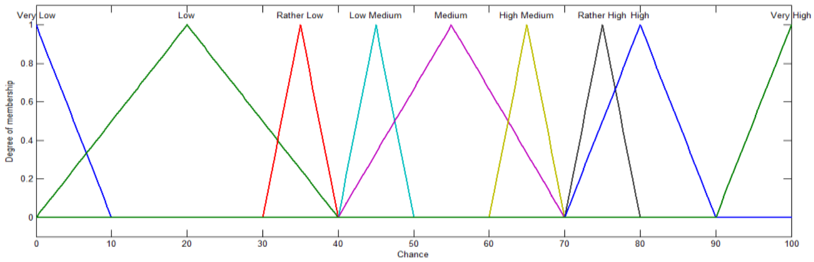

Fig 4. Membership function for Node Selection Probability – FLND fuzzy Inference Method

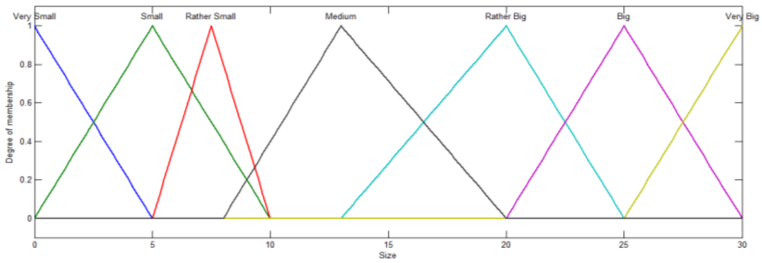

Fig 5. Membership function for Cluster Size Bound – FLND fuzzy Inference Method

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	Input Variables			Output Variables	
	Residual energy	Node degree	Distance to BS	NSP	CSB
1	High	Huge	Nearby	Very high	Rather large
2	High	Huge	Reachable	High	Large
3	High	Huge	Distant	Rather high	Very large
4	High	Average	Nearby	Very high	Medium
5	High	Average	Reachable	High	Medium
6	High	Average	Distant	Rather high	Medium
7	High	Less	Nearby	Very high	Very small
8	High	Less	Reachable	High	Small
9	High	Less	Distant	Rather high	Rather small
10	Medium	Huge	Nearby	High medium	Rather large
11	Medium	Huge	Reachable	Medium	Large
12	Medium	Huge	Distant	Low medium	Very large
13	Medium	Average	Nearby	High medium	Medium
14	Medium	Average	Reachable	Medium	Medium
15	Medium	Average	Distant	Low medium	Medium
16	Medium	Less	Nearby	High medium	Very small
17	Medium	Less	Reachable	Medium	Small
18	Medium	Less	Distant	Low medium	Rather small
19	Low	Huge	Nearby	Rather Low	Rather large
20	Low	Huge	Reachable	Low	Large
21	Low	Huge	Distant	Very low	Very large
22	Low	Average	Nearby	Rather Low	Medium
23	Low	Average	Reachable	Low	Medium
24	Low	Average	Distant	Very low	Medium
25	Low	Less	Nearby	Rather Low	Very small
26	Low	Less	Reachable	Low	Small
27	Low	Less	Distant	Very low	Rather small

Since we have used only triangular membership functions, each membership function has a general form of

$$\mu_A(x) = \begin{cases} 0 & , x \le a \\ \frac{x-a}{b-a} & , a \le x \le b \\ \frac{c-x}{c-b} & , b \le x \le c \\ 0, & x \ge c \end{cases} \qquad (1)$$

Here, x is value of the variable and A is one of its set corresponding to linguistic variables. For every membership function, we have to decide the values of constants a, b and c. Through experiments and literature study, we have decided these values.

Defuzzification of the output is performed through centre of area (COA) method, computed as

$$COA = \frac{\int \mu_A(x) x d(x)}{\mu_A(x) d(x)} \qquad (2)$$

C. Proposed Clustering with Node Dufferentiation

The proposed clustering protocol progresses in rounds, each round having two phases:

i) Cluster formation phase
   a. Fuzzy computations
   b. Adjusting cluster size bound
   c. Local CH election
   d. Joining of members

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ii) Sensing phase
   a. Sensing data
   b. Transmit to CHs
   c. Aggregation of data
   d. Transmit to BS

Fig 6 shows the progression of the protocol in phases, and sequence of phases.

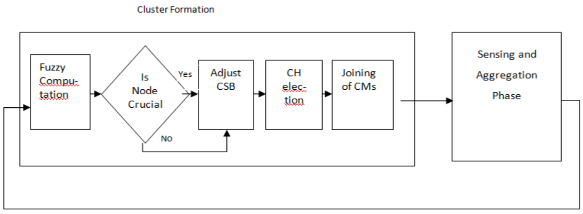

Fig 6. Phases of one round of the proposed algorithm FLND

Setup

The setup of the network is performed only once at the time of deployment. Each node has a unique ID associated to it. Instead of a location-aware mechanism like GPS, the distances between nodes and BS and pair wise distances of nodes are estimated through received signal strength index (RSSI). The base station will trigger the network initialization by broadcasting a beacon message, and other nodes will relay that message, so that global settings, like transmission range, can be spread throughout the whole network. Moreover, neighbour discovery can be done simultaneously. The optimum value for cluster size of crucial nodes is also transmitted to all nodes.

```
FLND Algorithm:
For very node do
  this.State = probabitionary CH
  this  = pointer to current node
  this.ND = number of nodes within communication radius 'r'
  this.DBS = distance of the node with BS
  this.RE =residual energy of the node
  this.ABS=number of nodes within communication radius 'r' and away from BS
  this.TBS= number of nodes within communication radius 'r' and towards BS
  NSP,CSB = calculateFuzzy(this.ND, this.DBS, this.RE)
  If this.ABS>this.TBS
          Limitsize(this.CSB)
  end
  for m=1:N
          Send CH_CANDIDATE to all neighbor nodes
          x=list of all CH_CANDIDATE from neighbor nodes
          if (this.chance > chance(x) )
                  advertise CH_WON
                  this.State =  Final_CH
          end
  end
 if  this.state ==Final_CH
          Receive requests from other nodes
          for every request do
                  if  this.CSB>count(current members)
                          Send CM_ACCEPTANCE
                  else
                          Send CM_REJECTION
                  end
          end
else
          for every received CH_WON
                   send CM_JOIN to nearest CH in sequence
                  if received CM_ACCEPTANCE
                          Join CH which issued CH_WON
                          this.State=Member_Node
                          break
                  end
          end
          if not joined any CH
                  this.state=Final_CH
          end
end
```

Fig 7. Proposed FLND algorithm

Cluster formation phase

During the cluster formation phase, local decisions of selecting cluster heads are taken. Each node executes a fuzzy function call that computes two values: first a probability of the node to become a CH and second its cluster bound. The fuzzy logic takes input the residual energy of the node, its distance from BS and the number of its neighbours. The outputs are two – first chance of a node to be CH and maximum allowed size of its cluster. The value of cluster bound for the crucial nodes, if larger, is decreased to 5% of total nodes. Each node broadcasts its probability to its neighbours. The node with highest value of probability within its neighbouring region is elected as CH. The non-CH nodes send join request to the nearest CH. Each CH node accepts a join request only if it can be adjusted within its cluster bound. The non-CH node, if rejected sends the join request to next nearest CH. This process continues till it joins a CH. If a node is rejected by all CHs, then it declares itself as CH.

Protocol

The clustering method to dynamically manage the topology of the network and how to perform data collection and forwarding can now be outlined. After the deployment of the network and setup phase, the protocol executes in rounds. Each node computes its NSP using the fuzzy system. The value of NSP is broadcasted among the first-hop neighbours. The node with highest value is selected as CH.

Now, the non-CH nodes join the cluster by sending a request message to the nearest CH. If that CH has members lesser than allowed by its CSB, the request is accepted else declined. In case the request is declined, the node sends request to the next CH according to distance from itself. In case, the node is not able to join any of the CHs, it declares itself as CH. The algorithm listing is provided in Fig 7.

It can be noticed that unlike many other unequal clustering methods, there is no regular pattern of cluster size according to distance from BS. Rather any size of cluster is forming anywhere. In fact, this is so because the size of cluster is being guided by the CSB values that are computed using the fuzzy inference. And the size depends on distance from BS and degree.

Sensing Phase

The CHs send a TDMA schedule to their members. The non-CH nodes sense data and send it to the CHs according to the schedule. The member nodes have to transmit its sensed data to its CH by following the TDMA schedule given to it. Members will be awake only during its allotted time slot for transmission and will be in a sleep state in the remaining time. The length of the frame depends on number of cluster members and time allotted for each member for data transmission. Since it is a homogenous network, all the members are given the same amount of time slot. A member has to send one data per frame. Data gathered by the CHs may contain redundant information since the member node's data will be highly correlated. The CHs aggregates the received data packets from members into a single packet. At the end of the frame, the aggregated data are sent to BS using multi-hop communication according to the TDMA schedule sent by the BS.

In some cases, when the members transmit the data to its CH, the data may be reaching the other nearby CHs too since the radio is broadcast in nature. In order to avoid this inter cluster interference spread codes are used. When the cluster members, send the data to their respective CH nodes, the spread code of the concerned cluster is attached to avoid inter cluster interference.

TABLE II
VARIOUS CONTROL MESSAGES WITH THEIR PURPOSE IN CLUSTER FORMATION

Message	Purpose
CH_CANDIDATE	This is the first broadcast message from each node to its neighboring (those falling under communication range 'R') nodes after chance is computed.
CH_WON	On finding no competition, the nodes elected as CHs broadcast this message to the neighboring nodes.
CM_JOIN	This message is sent by all the non-CH nodes to the elected CHs lying within the communication range 'R' to join their cluster.
CM_ACCEPTANCE	This message is broadcasted by the CHs to those nodes that are accepted by the CHs to be their member nodes. This is done by first checking if there exists a scope of adding members based on the CSB value.
CM_REJECTION	In case the cluster is full as per the CSB value, this broadcast message is sent by the elected CHs to the nodes that broadcasted the CM_JOIN messages

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IV. SIMULATION RESULTS

A. Simulation Setup

To measure the performance and study the effect of various parameters on the performance of the proposed algorithm, we perform simulation in MATLAB. The assumptions about the network considered are as follows.

- A number of sensor nodes are randomly dispersed in a square field and all nodes are stationary once deployed.
- Intra-cluster communication is single-hop, each cluster member sending packets directly to its CH.
- The CHs communicate using multi-hop communication through a backbone network setup among the CHs.
- Node death is either due to energy depletion or due to disconnectivity.
- Nodes are heterogeneous. The initial energy of the nodes is different from each other. There are two kinds of nodes: normal and advanced. The normal nodes have initial energy, and the advanced nodes have as initial energy.

Adopting the radio model the transmission and reception energy is computed as

$$E_{tx} = l * E_{elec} + \varepsilon_{fs} * d^2, \text{ if } d < d_o \quad (11)$$

$$E_{tx} = l * E_{elec} + \varepsilon_{mp} * d^4, \text{ if } d > d_0 \quad (12)$$

$$E_{rx} = l * E_{elec} \quad (13)$$

The parameters of simulation are as shown in Table III.

TABLE III
SIMULATION PARAMETERS

Parameter	Description	Values
l	Packet size	4000
E_{elec}	Energy consumed in transmission and reception	50 nJ/bit
ε_{fs}	Energy dissipated in free space propagation	10 pJ/bit/m^2
ε_{mp}	Energy dissipated in multipath propagation	0.0013pJ/bit/m^4
Data Packet Size	Size of a data packet	500 bytes
Control Packet Size	Size of a control packet	25 bytes
Aggregation ratio		10%
Range		20 m
d_0		87m

The algorithms against which we compare the performance of the proposed protocol are:

- LEACH – The standard LEACH algorithm [25] with P=0.05 is implemented.
- CEFL – The method suggested by Gupta et al [11] is implemented as centralized fuzzy system
- DUCF – The fuzzy approach by [18] is implemented as distributed system

The metrics used for comparison are Life till connected, First node die, Average energy consumption per round, Standard deviation of number of CHs elected and number of dead nodes when network got disconnected.

We analyze the proposed protocol's performance variation when certain parameters of simulation are changed. We take area of simulation $50 \times 50\ m^2$, $75 \times 75\ m^2$,$100 \times 100\ m^2$, $125 \times 125\ m^2$and $150 \times 150\ m^2$; while nodes are 100. We then increase the number of nodes as 75, 100, 125 and 150 within the area of $100 \times 100\ m^2$.

In each simulation the BS is stationary at any one of the following positions, producing three different scenarios:
i) Scenario I – the BS is situated at the middle of the RoI.
ii)Scenario II – the BS is situated at any one corner of the RoI.
iii) Scenario III – the BS is situated outside of the RoI.

B. Experimental Evaluation for Heterogeneous Networks

The three scenarios as previous set of experiments were generated again, but with heterogeneous nodes. All simulation parameters are kept same as before. The value of a is taken as 2, that is the advanced nodes have double the energy of normal nodes initially. The area of simulation is varied as $25 \times 25\ m^2$, $50 \times 50\ m^2$, $75 \times 75\ m^2$, and $100 \times 100\ m^2$. Comparison of Life till connected is shown in Fig 8, 9 and 10 respectively for BS placed at a corner of sensing field, BS in middle and BS outside the RoI. The average number of rounds executed when the area is increased but number of nodes is kept fixed at 100 are shown. While LEACH and CEFL perform poorly in the sense that the network becomes disconnected much earlier as compared to DUCF and the proposed algorithm FLND. Out of these, FLND runs for more rounds before network gets disconnected.

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The comparison of energy consumption per round for the four algorithms is shown in Figre 11, 12 and 13, respectively for BS at corner, in middle and outside of the RoI. The energy consumption of the proposed FLND algorithm is lowest among all.

The average number of CHs appointed at each round by the four algorithms is obtained in three different scenarios. The comparison is shown in Fig 14, 15 and 16 respectively. It is higher for the proposed algorithm. The average increases as the area of simulation increases. To gain more insight, we next record the standard deviation of number of CHs elected in the four algorithms. The comparative values are shown in Fig 17, 18 and 19 respectively. Though, the average was high for the proposal, we can see the standard deviation is low, indicating that the proposal has more predictable behaviour than others.

Next we record the number of nodes that were alive when the network got disconnected. This gives idea that if more nodes were alive then the protocol leads to premature death of certain nodes and is prone to hot spot problems. If it is low, then the protocol is able to handle hot spot problem. As is clear from Fig 20, 21 and 22 that the proposed algorithm has lowest value of alive nodes at disconnectivity.

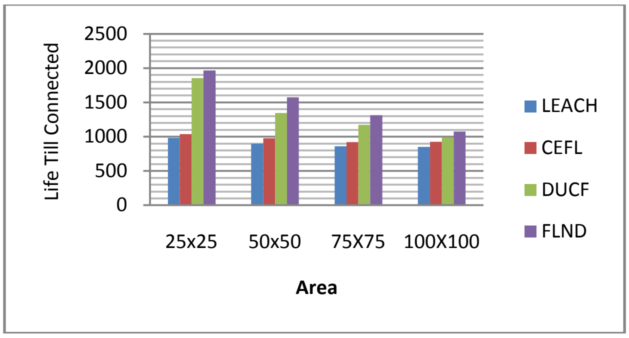

Fig 8 Comparison of Life till connected of different algorithms when BS is in corner of RoI

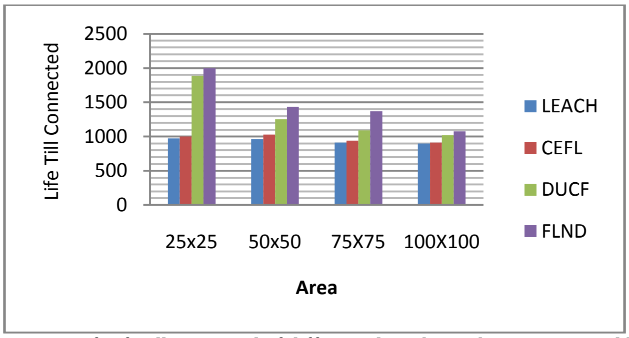

Fig 9 Comparison of Life till connected of different algorithms when BS is in middle of RoI

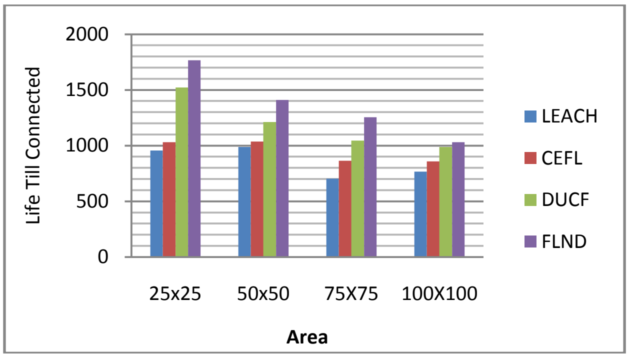

Fig 10 Comparison of Life till connected of different algorithms when BS is out of RoI

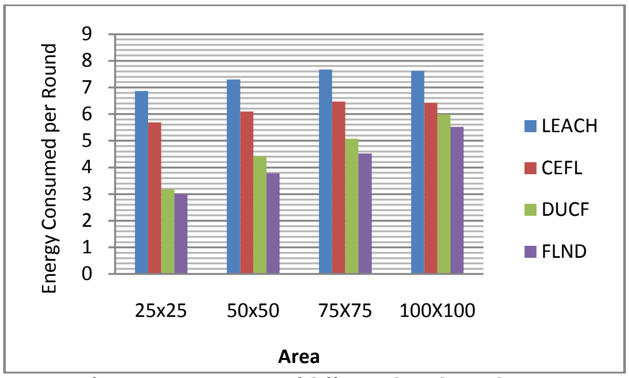

Fig 11 Comparison of Energy consumption of different algorithms when BS is in corner of RoI

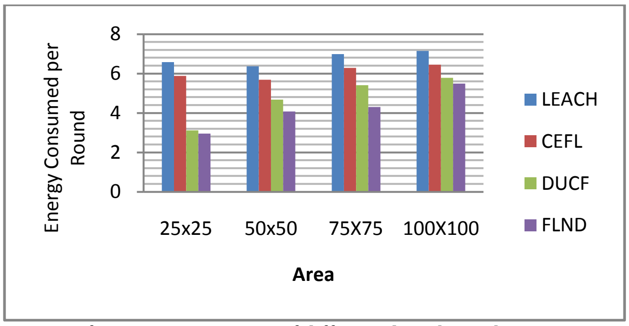

Fig 12 Comparison of Energy consumption of different algorithms when BS is in middle of RoI

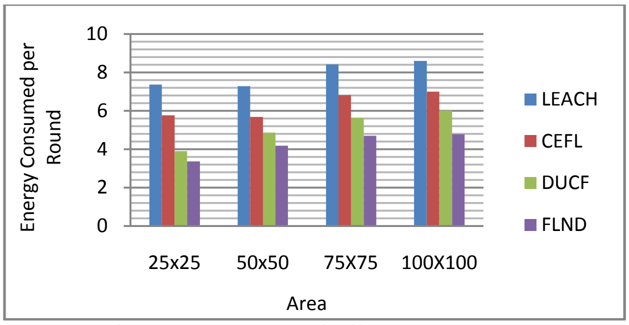

Fig 13 Comparison of Energy consumption of different algorithms when BS is out of RoI

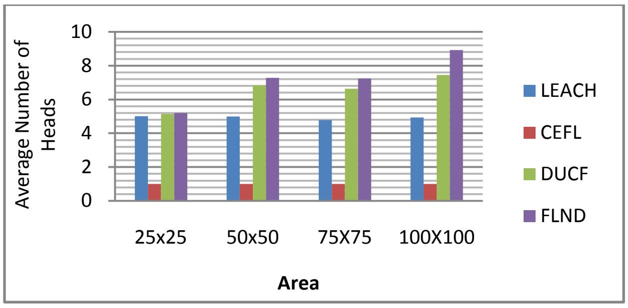

Fig 14 Comparison of Average number of CHs elected by different algorithms when BS is in corner of RoI

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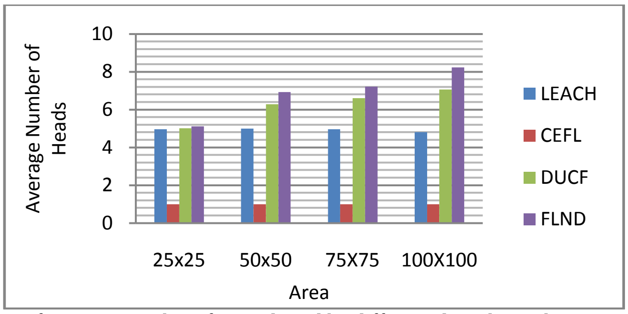

Fig 15 Comparison of Average number of CHs elected by different algorithms when BS is in middle of RoI

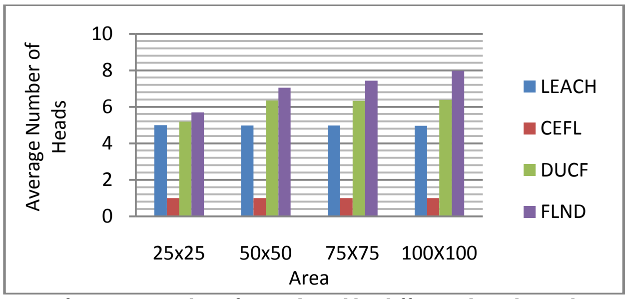

Fig 16 Comparison of Average number of CHs elected by different algorithms when BS is out of RoI

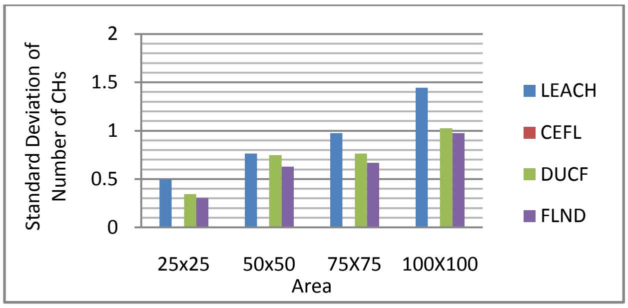

Fig 17 Comparison of Standard deviation in number of CHs elected by different algorithms when BS is in corner of RoI

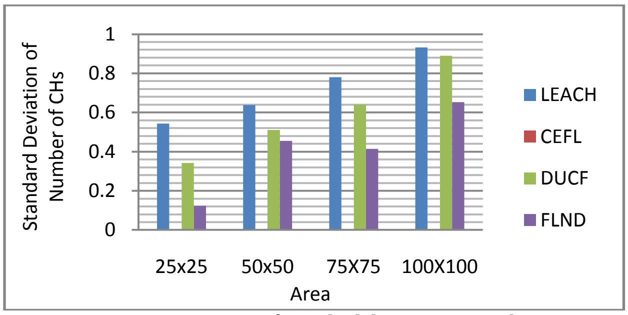

Fig 18 Comparison of Standard deviation in number

of CHs elected by different algorithms when BS is middle of RoI

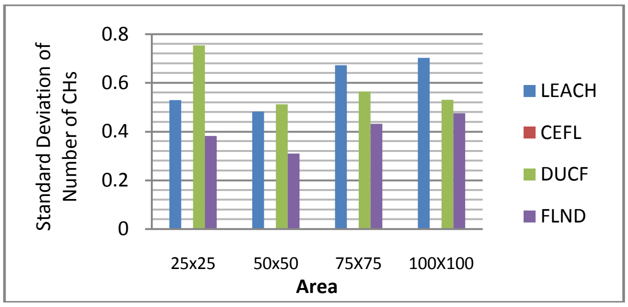

Fig 19 Comparison of Standard deviation in number of CHs elected by different algorithms when BS is out of RoI

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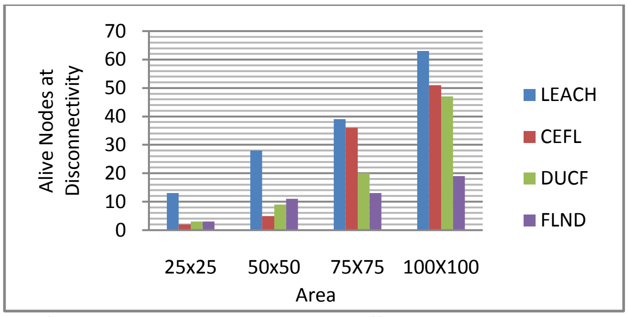

Fig 20 Comparison of Alive Nodes at Disconnectivity in different algorithms when BS is in corner of RoI

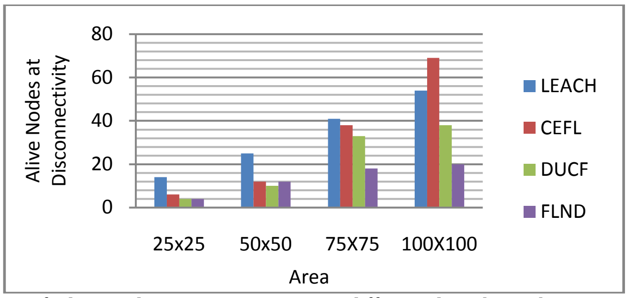

Fig 21 Comparison of Alive Nodes at Disconnectivity in different algorithms when BS is in middle of RoI

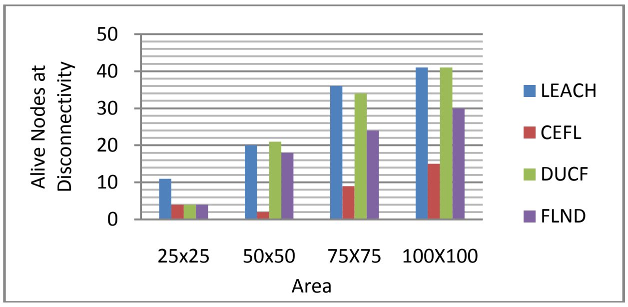

Fig 22 Comparison of Alive Nodes at Disconnectivity in different algorithms when BS is outside RoI

V. CONCLUSION

The popularity of WSNs is increasing for many reasons, but it is essential requirement to develop a clustering method that evenly distributes load among the nodes of the network. Connectivity is essential for long life of the network. Hot spot problem refers to the problem of premature death of a node causing the network to become disconnected. We proposed a technique to identify the crucial nodes that may possibly become hot spots. And try to minimize load on such nodes. Also, the size of each cluster is bounded by an upper limit according to properties of its CH through fuzzy logic. CH is also elected according to output of the fuzzy system.

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