A Fuzzy Based Predictive Cluster Head Selection Scheme for Wireless Sensor Networks

Hemavathi Natarajan[1], Sudha Selvaraj[2]
[1]Research Scholar, [2]Associate Professor
Electrical and Electronics Engineering Department
National Institute of Technology, Tiruchirappalli, India
[1]nuhemasen@gmail.com, [2]sudha@nitt.edu

Abstract-**Clustering, an energy efficient approach is used in Wireless Sensor Network. Clustering involves cluster formation and Cluster Head Selection. As the Cluster Head is involved in carrying out the entire communication, a high energy node has to be selected as Cluster Head. In this paper, a novel predictive Fuzzy based Cluster Head selection algorithm is proposed. The proposal suggests a new input parameter, Rate of recurrent Communication apart from the standard parameters namely the Residual Power of Sensor Nodes, Degree of Neighboring Nodes, Distance between the Node and Base Station, Sensor Node Movement. In this approach, the fuzzy logic evaluates the Cluster Head Selection Probability which is based on the node's previous communication history to decide the Cluster Head. The proposed algorithm is implemented using Matlab. The simulation results show that the proposed Cluster Head Selection technique is superior to other proposals.**

Keywords- wireless sensor networks; cluster head selection; fuzzy logic; rate of recurrent communication; prediction.

I. INTRODUCTION

Wireless Sensor Networks (WSN) is deployed in remote and human unattended environments for critical applications. The sensor nodes of the WSN senses the information, processes it and then transmits the processed data to the sink or destination node. All the nodes are monitored and controlled by a Base Station (BS) [1][2]. Since, sensor nodes have limited energy; clustering, an energy efficient approach is preferred in Wireless Sensor Network. Clustering is the process of organizing nodes into groups termed as clusters. Clustering saves energy as the communication is restricted to few nodes, thereby increasing the network lifetime [3]. Clusters may further be divided into sub clusters. The cluster size is defined as the number of sensor nodes in the cluster**.** Cluster formation in a dynamic environment is a major issue in hierarchical routing as it affects the energy dissipation of the network.

Since, all the communications between the sensor nodes (source nodes) and sink nodes (Base Station) occur only through Cluster Head (CH), it is mandate that the CHs have sufficiently more energy. Therefore, many researchers have proposed Cluster Head selection schemes based on various factors such as the residual energy of the nodes, Distance of the node from the Base Station, Distance between Head and Member (M), number of adjacent nodes, proximity of the neighbor nodes etc. [4]-[8]. Since, the characteristic of CH decides the performance of the cluster and the entire network in turn; the CH selection plays a vital role in WSN. LEACH is a classic cluster based routing protocol with balanced energy consumption for WSN [9]. However, CH selection is not based on the energy factor. PEGASIS forms a linked structure by connecting the node which is at the farthest end from the Base Station towards the node which is closer to BS [10]. Nevertheless, this algorithm is greedy consuming more energy as the farthest node is selected as CH.

In order to minimize the number of data transmission between source and sink nodes; aggregation is used in clustering [11]. In weight based Unequal Clustering, the sensor field is divided into energy levels [12]. For each level, there is one node chosen as CH leader. Then the CH leader collects the data from other CH's and sends them to the CH leader in the next level. Hence, at a particular level the node with highest residual energy is the CH leader. However, the algorithm is complex and further the higher level CH's consume more energy than the lower level CH's. The Cluster Head Selection Probability (CHSP) is estimated using Fuzzy logic, based on the distance between the node and BS, remaining battery energy and network traffic [13]. Subsequent to this, the number of neighboring nodes was also considered as input. The inclusion of the degree of the neighboring nodes showed improved performance compared to their earlier work [14]. However, all these schemes assume the sensor nodes to be stationary. Subsequently, the CHSP is evaluated by including the sensor node movement in addition to the above inputs [15-16]. However, in this the node with high residual energy has the highest probability and therefore be selected as CH.

However, the earlier works did not consider the energy drainage factor i.e. the number of times a node communicates. Let us take two nodes of the same cluster; one-the highest energy node say 'A' that communicates frequently and the other node 'B' with relatively lesser energy that communicates less frequently. According to the previous algorithms, Node 'A' will be chosen as CH because of its higher energy level, while Node 'B' is the member. In such a scenario, the energy of node 'A' depletes faster because of its frequent communication, while the energy depletion of Node 'B' is negligible compared to that of Node 'A' because of its infrequent communication.

In this situation if Node 'A' continues as CH for subsequent communication sessions, its energy depletes and specifically when its energy is below the threshold, reselection of CH occurs. A similar situation can occur to any node in the cluster which is selected as CH in the current session or in the subsequent sessions. This leads to frequent reselection of CH, which is a time and energy consuming process. To mitigate this drawback the new parameter, Rate of recurrent Communication of Sensor Node (RCSN) is taken into consideration. RCSN is defined as the number of times a node communicates with its CH. In order to emphasize the impact of RCSN on CHSP a fuzzy logic based CH selection algorithm is proposed. With RCSN, the algorithm is able to predict energy consumption of the nodes which paves a better way for CHSP compared to the earlier works.

The structure of WSN with a BS and two clusters along with their CHs and members is shown in Fig.1.

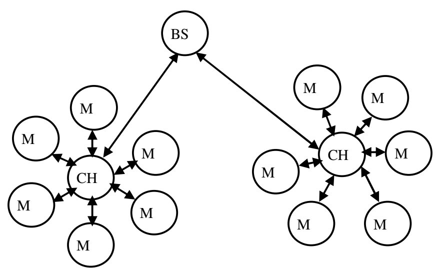

Figure 1. Structure of a WSN

II. ENERGY PREDICTION MODEL

The first order radio model of Jin Shyan Lee et. al.[8] which ignores the energy consumption of the nodes during idle/ sleep mode is considered. In the model, each node is assumed to send 'l' bit of data to a node at distance 'd' with electronics energy E_{elect} consuming an energy E_{Tx} for transmission which is given by :

$$E_{Tx} = \begin{cases} l * E_{elect} + l * \varepsilon_{fs} * \mathrm{d}^{2} \ (\mathrm{d} < \mathrm{d}_0) \\ l * E_{elect} + l * \varepsilon_{mp} * \mathrm{d}^{4} \ (\mathrm{d} \geq \mathrm{d}_0) \end{cases} \tag{1}$$

where ε_{fs}, ε_{mp} are the energy consumption factor of amplification for the free space and multipath radio models respectively and d_0 is the threshold value given by

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{2}$$

Depending on the distance (d), either the free space or multipath fading channel model is employed.

The energy required by each node to receive data (E_{RX}) given by [8] is

$$E_{Rx} = l * E_{elect} \tag{3}$$

This model calculates the transmission (E_{Tx}) and reception (E_{Rx}) energy of a node, discarding the role of the node; either a member or CH.

The role played by a node as CH or member varies depending on their tasks. The number of times a member communicates is different from that of a CH and therefore, the energy consumption varies depending on whether the node is a member or CH. Hence, the energy consumption by CH (E_{CH}) and its member (E_{M_ID}) can be computed independently by modifying (1) and (3) taking RCSN into consideration. E_{CH} and $E_{M\text{-}ID}$ are computed as follows:

$$E_{CH} = E_{Rx\_BS} + \left(E_{Tx\_M} + E_{Rx\_M}\right) * m + E_{DA} + E_{Tx\_BS} \tag{4}$$

$$E_{M\_ID} = E_{Rx\_CH} + E_{Tx\_CH} \tag{5}$$

where

E_{Rx_BS}	Energy consumed by CH due to reception of message from BS
E_{Tx_M}	Energy consumed by CH due to transmission of message to its Cluster Members
E_{Rx_M}	Energy consumed by CH due to reception of data from a Cluster Member and is given by *RCSN* x E_{Rx}
m	Number of members in a Cluster
E_{DA}	Energy consumed by CH due to aggregation of data
E_{Tx_BS}	Energy consumed by CH for transmission of aggregated data to BS
E_{Rx_CH}	Energy consumed by a node for receiving messages from CH
E_{Tx_CH}	Energy spent by a node for transmission of data from a node to CH and is given by *RCSN* x E_{Tx}

III. PROPOSED SYSTEM

In general, the energy of the CH and members drain during sensing, processing and communication. So, when the energy of CH is less than the threshold it is unlikely to communicate further, leading to CH reselection. In such a scenario there may be a chance for a node which frequently communicates to become a CH because of its high residual energy at that point of time. But, this is not desirable since the energy of the node which is involved in frequent communication with its neighbors drains out quickly when compared to the node which communicates less frequently thereby resulting in frequent reselection of CH.

On the other-hand, if the energy consumption of CH and the members of a cluster can be predicted based on its previous communication history, then the reselection interval of CH could probably increase.

In order to circumvent the shortcomings of the earlier works, prediction based fuzzy CH selection scheme is proposed. The prediction is based on the Rate of recurrent Communication of Sensor Node.

Fig.2 shows the structure of the proposed Fuzzy Clustering Scheme (FCS). The Fuzzy Logic Controller (FLC) uses five input parameters to evaluate the output parameter namely the Cluster Head Selection Probability. The RCSN is used for prediction in addition to the existing four input parameters namely the Residual Power of Sensor Nodes (RPSN), Degree of Neighboring Nodes (DNN), Distance between Node and Base Station (DNBS) and Sensor Node Movement (SNM).

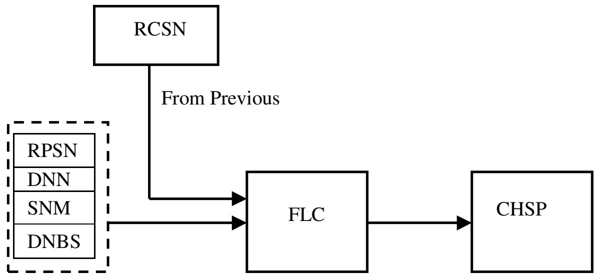

Figure 2. Fuzzy clustering scheme

Fig.3 shows the general FLC structure with Fuzzifier, Inference Engine, Fuzzy Rule Base (FRB) and Defuzzifier. The crisp input is fuzzified through the predefined membership functions. The Fuzzy Rule Base is a set of rules which is applied to the fuzzified input. The output of the inference engine is converted to crisp output by the process of defuzzification. The method of defuzzification used is the Largest of Maximum (LoM).

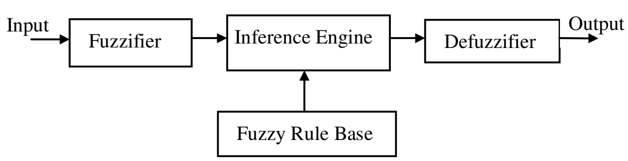

Figure 3. FLC structure

Fig.4 depicts the flowchart for evaluating the Cluster Head Selection Probability using the Fuzzy logic.

IV. IMPLEMENTATION OF THE PROPOSED FCS

FCS is implemented using Matlab 7. The input and output parameters along with their term set, membership functions and their limits are shown in Tables I & II respectively.

TABLE I. INPUT PARAMETERS TERM SETS WITH MEMBERSHIP FUNCTIONS

Input Parameters	Term Sets	Membership functions	Limits
RPSN	Low(Lo),Middle(Mi), High(Hg)	Trapezoidal	0 to0.001
DNN	Few(Fw),Medium(Me), Many(Mn)	Trapezoidal & Triangular	0 to 15
DNBS	Near(Nr),Moderate(Mo),Far(Fr)	Trapezoidal & Triangular	0 to 20
SNM	Slow(Sl),Medium(Md), Fast(Fa)	Triangular	0 to 50
RCSN	Small(Sm),Medium(Mu), Large (Lg)	Trapezoidal	0 to 20

TABLE II. OUTPUT PARAMETER TERM SET WITH MEMBERSHIP FUNCTIONS

Output Parameter	Term Sets	Membership functions	Limits
CHSP	Very Weak (VW), Weak(W), Little Weak(LW), Medium(MD), Little Strong (LS),Strong (S), Very Strong(VS)	Trapezoidal & Triangular	0 to 1

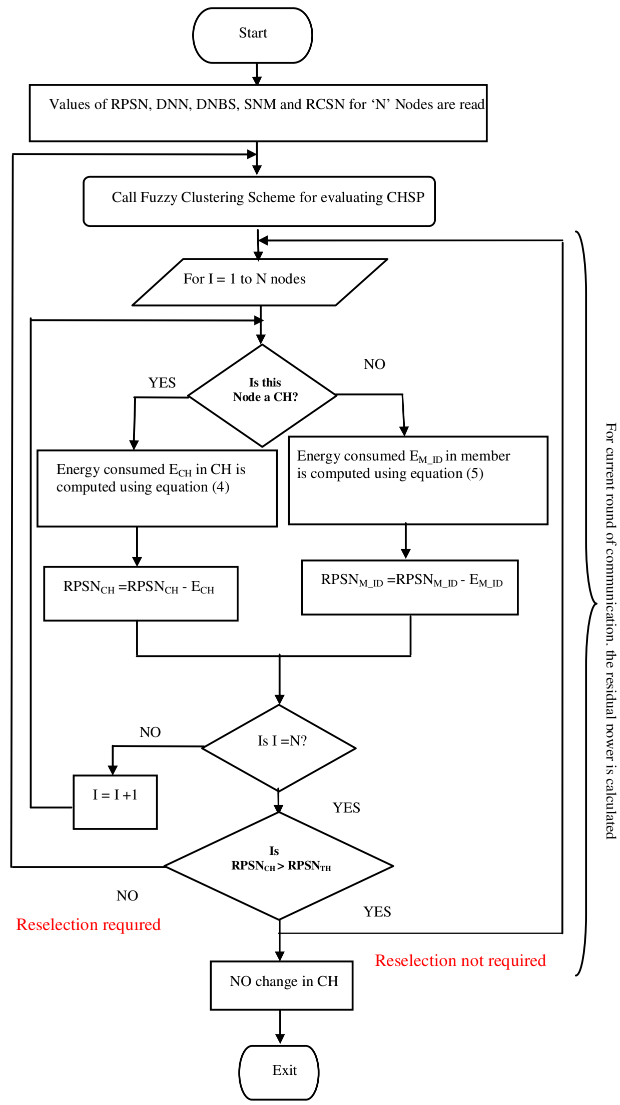

Figure 4. Flowchart of Fuzzy based CH Selection

Fig.5 depicts the snapshot of the simulated FCS. Both triangular and trapezoidal membership functions have been used for input and output.

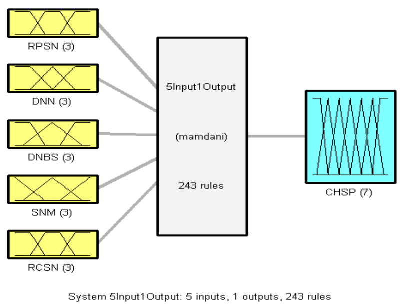

Figure 5. Snapshot of the simulated fuzzy clustering scheme

TABLE III. FUZZY RULE BASE

Rule	RPSN	DNN	DNBS	SNM	RCSN	CHSP
1	Lo	Fw	Fr	Sl	Sm	W
2	Lo	Fw	Fr	Sl	Mu	VW
3	Lo	Fw	Fr	Sl	Lg	VW
.						
20	Lo	Fw	Nr	Sl	Mu	W
.						
28	Lo	Me	Fr	Sl	Sm	LW
57	Lo	Mn	Fr	Sl	Lg	W
61	Lo	Mn	Fr	Fa	Sm	LW
.						
63	Lo	Mn	Fr	Fa	Lg	VW
.						
82	Mi	Fw	Fr	Sl	Sm	MD
.						
109	Mi	Me	Fr	Sl	Sm	LS
.						
127	Mi	Me	Nr	Sl	Sm	LW
.						
136	Mi	Mn	Fr	Sl	Sm	LS
.						
190	Hg	Me	Fr	Sl	Sm	S
.						
217	Hg	Mn	Fr	Sl	Sm	VS
218	Hg	Mn	Fr	Sl	Mu	LS
219	Hg	Mn	Fr	Sl	Lg	MD
223	Hg	Mn	Fr	Fa	Sm	LS
224	Hg	Mn	Fr	Fa	Mu	MD
225	Hg	Mn	Fr	Fa	Lg	LW
226	Hg	Mn	Mo	Sl	Sm	VS
227	Hg	Mn	Mo	Sl	Mu	S
228	Hg	Mn	Mo	Sl	Lg	LS
232	Hg	Mn	Mo	Fa	Sm	MD
233	Hg	Mn	Mo	Fa	Mu	MD
234	Hg	Mn	Mo	Fa	Lg	MD
.						
238	Hg	Mn	Nr	Md	Sm	S
239	Hg	Mn	Nr	Md	Mu	LS
240	Hg	Mn	Nr	Md	Lg	MD
241	Hg	Mn	Nr	Fa	Sm	LS
242	Hg	Mn	Nr	Fa	Mu	MD
243	Hg	Mn	Nr	Fa	Lg	MD

The FRB of the proposed system is depicted in Table III. The proposed system considers five inputs namely RPSN, DNN, DNBS, SNM and RCSN to decide CHSP. The 243 (3x3x3x3x3) rules are derived based on |T(RPSN)| X |T(DNN)| X |T(DNBS)| X |T(SNM)| X |T(RCSN)| by considering three different membership functions for all the input parameters. From rule 217 of Table III, it is clear that CHSP will be Very Strong (VS) if (RPSN is High) and (DNN is Many) and (DNBS is Far) and (SNM is Slow) and (RCSN is Small). Similarly in rule 218, the CHSP is Little Strong (LS) when the RCSN is medium by maintaining all other four inputs same. The output parameter CHSP is obtained by LoM defuzzification method.

V. SIMULATION SETUP

The location of the nodes, RPSN, RCSN and SNM are initialized with some random values. Given the location of the nodes, DNBS is calculated by using (6).

$$DNBS = \sqrt{(x - x_0)^2 + (y - y_0)^2} \quad (6)$$

where x, y - the location of the node
x_0, y_0 – the location of the Base Station

The DNN of all the nodes is taken as N-1 where N is the number of nodes in the cluster. Since all the nodes are assumed to be at one hop distance, DNN is same for all nodes of a given cluster. Then, the fuzzy based cluster head selection algorithm is invoked to select the Cluster Head. Subsequent to one round of communication, the energy consumed by all nodes ($RPSN_{CH}$ and $RPSN_{M\_ID}$) is calculated based on (4) and (5) respectively. The RPSN of the current CH is compared with that of threshold ($RPSN_{TH}$=0.3mJ). If the RPSN is less than the threshold, then select the next CH by invoking the CHSP algorithm again.

Now, simulations are carried out to study the influence of RCSN on different cluster sizes with and without sensor node mobility. Their corresponding results are presented.

A. Scenario1: A cluster size of seven

Simulation is carried out for a cluster of seven nodes. The location of the seven nodes and their corresponding RPSN, RCSN and DNBS is presented in Table IV. Fig.6 portrays the position of the nodes in the cluster.

TABLE IV. LOCATION OF THE NODES AND THEIR DATA

Nodes	Co-ordinates (x,y)	RPSN (mJ)	DNBS (m)	RCSN
1	(6.5,2.0)	1.0	10.06	1
2	(5.5,1.0)	0.8	11.41	3
3	(8.0,1.0)	0.6	10.44	8
4	(7.0,0.5)	0.3	11.24	10
5	(7.5,3.5)	0.1	8.28	15
6	(5.0,2.5)	0.4	0.40	13
7	(8.5,2.5)	0.5	8.86	20

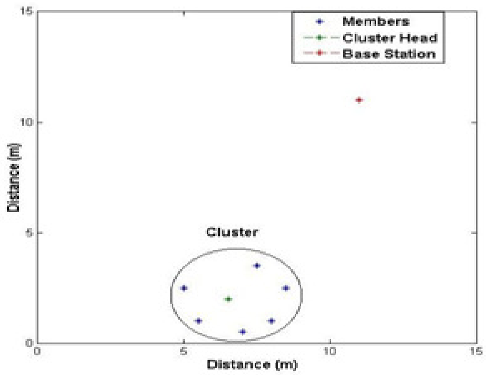

Figure 6. Snapshot of the cluster with seven nodes

TABLE V. ENERGY PARAMETER VALUES

Energy Parameter	Value
E_{elect}	50nJ/bit
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
E_{DA}	5nJ/bit/message

The energy parameter values used for simulation are presented in Table V. The CHSP for the nodes with and without RCSN for both static (SNM=0) and mobile (SNM=25) scenarios is obtained and plotted in Figs.7 & 8 respectively.

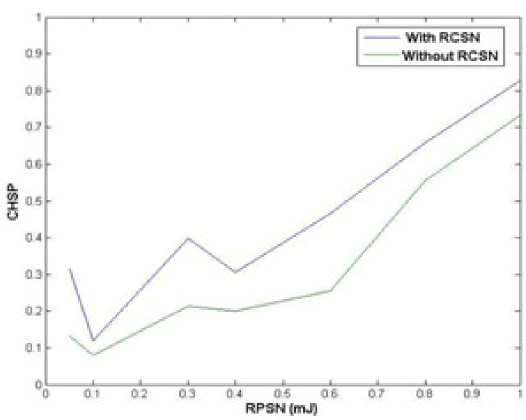

Figure 7. Plot of CHSP for 7 nodes (SNM=0)

From Fig.7, it is clear that the CHSP with RCSN is higher than without RCSN. This proves that RCSN has an impact on Cluster Head Selection. Further, this can be emphasized from the fact that CHSP of node 6 with RCSN is observed to be less than that of node 4 inspite of its high RPSN. This helps to conclude the impact of RCSN rather than RPSN.

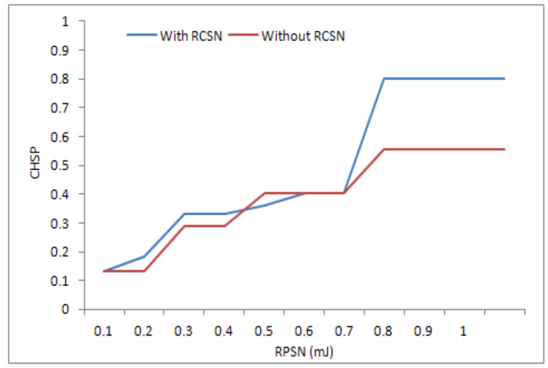

Figure 8. Plot of CHSP for 7 nodes (SNM =25)

From Fig.8, the CHSP with RCSN corresponding to node 6 is observed to be less than the plot of CHSP without RCSN. This is because of the fact that RCSN has an impact on CHSP inspite of its relatively high RPSN. This emphasizes the fact that RPSN is not the only deciding factor but also RCSN. Similarly, comparing Figs.7 & 8 the CHSP of a mobile node is found to decrease in contrast to that of the static node. This is because of the energy consumption due to node movement. Hence, RPSN of mobile nodes will be less resulting in comparatively lesser CHSP.

B. Scenario : Cluster size of Fourteen Nodes

Similarly, simulation for a cluster of fourteen nodes is carried out to study the impact of network density on CHSP. The location of the nodes and the values used in simulation are tabulated in Table VI.

TABLE VI. LOCATION OF THE NODES AND THEIR DATA

Nodes	Co-ordinates (x,y)	RPSN(mJ)	DNBS(m)	RCSN
1	(6.5,2.0)	1.0	10.06	1
2	(5.5,1.0)	0. 8	11.41	3
3	(8.0,1.0)	0. 6	10.44	8
4	(7.0,0.5)	0. 3	11.24	10
6	(5.0,2.5)	0. 4	10.40	13
7	(8.5,2.5)	0. 5	8.86	20
8	(6.0,0.5)	0. 35	11.63	3
9	(7.25,3.0)	0. 15	8.84	12
10	(7.75,2.75)	0. 7	8.87	6
11	(5.5,3.0)	0. 75	9.71	10
12	(6.75,3.5)	0. 65	8.62	4
13	(6.25,2.25)	0. 55	9.95	9
14	(5.75,3.5)	0. 25	9.15	7

Fig.9 shows the snapshot of the simulated cluster of 14 nodes. The CHSP corresponding to this when the nodes are both immobile and mobile are plotted in Figs. 10 & 11 respectively.

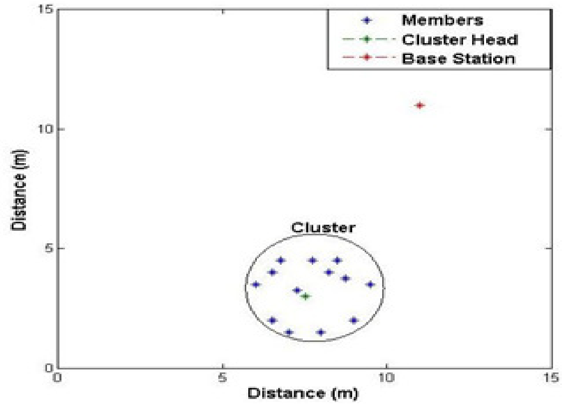

Figure 9. Snapshot of the cluster with fourteen nodes

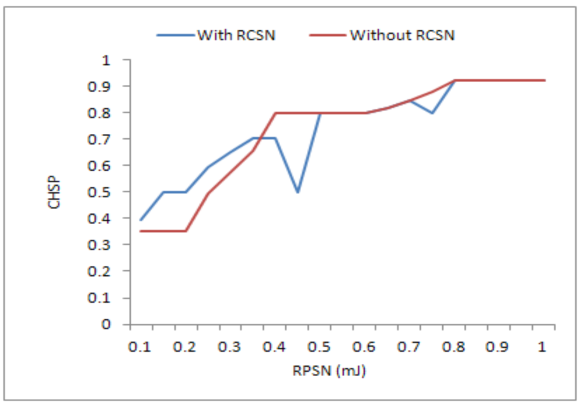

Figure 10. Plot of CHSP for 14 Nodes (SNM=0)

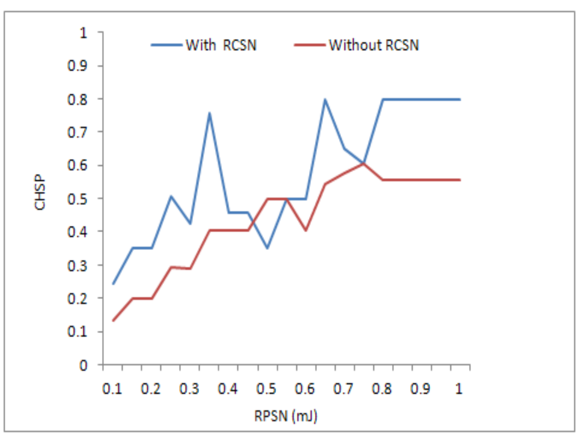

Figure 11. Plot of CHSP for 14 Nodes (SNM = 25)

From Figs.10 & 11 it is inferred that both RPSN and RCSN decide the Cluster Head similar to the earlier case. CHSP for a cluster size of 14 is found to be high when compared to that of 7 due to its relatively high DNN.

C.Scenario 3: Impact of RCSN on CHSP

To study the influence of RCSN on CHSP, simulation is carried out for the same setup of 7 and 14 nodes considering the mobility and immobility of the nodes but for different values of RCSN i.e. 0, 5, 10, 15 and 20. RPSN was varied from 0.1mJ to 1mJ, fixing DNBS at 10m. The results corresponding to seven stationary and mobile nodes are depicted in Figs. 12 & 13. Figs. 14 &15 correspond to fourteen nodes for both static and mobile conditions. In Fig.12, the CHSP for RCSN=0 and RCSN=5 coincide, while in Fig.13, they do not. This is because of the small difference in RCSN in addition to the impact of SNM. A similar situation is also observed in Figs.14 & 15. From the Figs.12-15, it is inferred that as RCSN increases CHSP decreases.

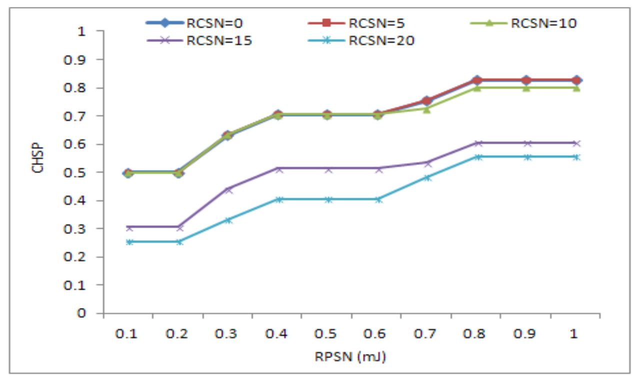

Figure 12. Impact of RCSN on CHSP for 7static nodes

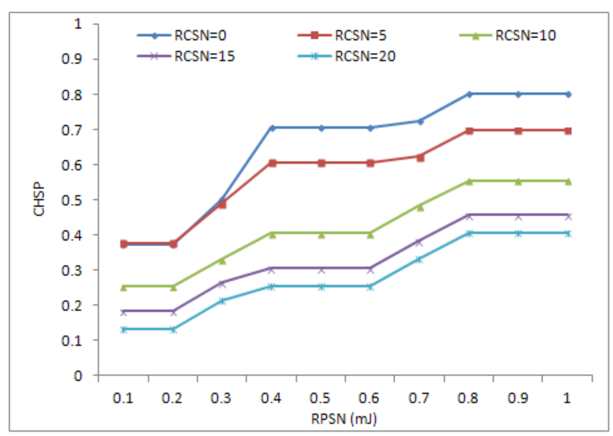

Figure 13. Impact of RCSN on CHSP for 7 mobile nodes

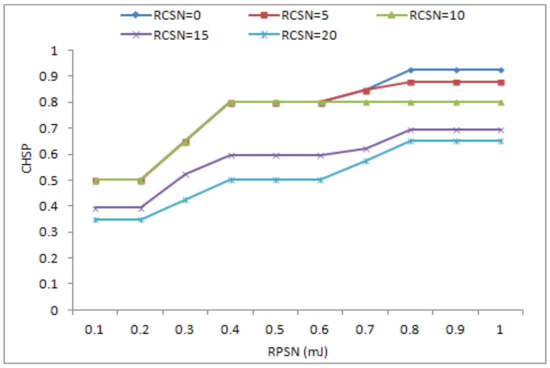

Figure 14. Impact of RCSN on CHSP for 14 static nodes

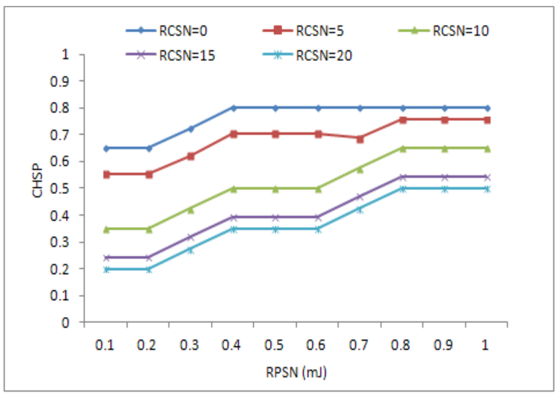

Figure 15. Impact of RCSN on CHSP for 14 mobile nodes

Hence, it is concluded that the cluster head selection probability relies also on RCSN apart from RPSN, DNN, DNBS and SNM. Further, CHSP is observed to be high when RPSN, DNN and DNBS are high; and SNM and RCSN are low. Since the energy of a fast moving node drains out sooner, the probability of it being selected as CH is less in comparison with that of a slow moving node. Thus, the speed of the sensor node is also found to influence the CH selection.

VI.CONCLUSION

In this paper, a novel predictive Fuzzy based Cluster Head selection algorithm is proposed. The proposed system uses a new parameter namely the Rate of recurrent Communication of the Sensor Node in addition to the Residual Power of Sensor Nodes, Degree of Neighboring Nodes, Distance between the Node and Base Station and Sensor Node Movement. The proposed algorithm is implemented using Matlab. The simulation results show that the inclusion of Rate of recurrent Communication of Sensor Node is found to yield better results compared to the earlier works. The proposal can be implemented by including a state variable in every sensor node to keep in track of RCSN whenever a node communicates.

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