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Fuzzy Logic Based Quadrant LEACH Protocol for WSN

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Abstract: Energy is predominant factor to be considered in designing WSN clustering algorithm in vogue achieve energy efficiency and LEACH is significant one. LEACH uses probability mode and energy efficiency is not maximized. Partition of network into quadrants yield efficient energy utilization reduction of transmission of load of sensor nodes and of optimum position of cluster head.

Fuzzy logic technique have inherent ability to integrate numeric and logic aspects of reasoning necessary to deal with multiple parameters for cluster head selection in wireless sensor networks.

The proposed work partition sensing area into four quadrants for better area coverage. The centralized clustering protocols utilize fuzzy logic to select cluster head based on the parameters energy expenditure and distance of node from base station. The developed FQL protocol is compared with AODV and QL protocol for metrics, average energy consumed and packet delivery ratio. The results depict the validity of protocol.

Keywords: *fuzzy logic, QL, FQL.*

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I. INTRODUCTION

Wireless Sensor Network is structured by nodes to sense events and to transit sensed information to central location base station (BS) for further processing and dissemination of data. Nodes of network imbibe computing sensing and communicating skills [1]. WSN network is tailored to spend bottom line energy that is scarcest battery powered energy resource to execute its potential applications [2].

Routing algorithm necessary to successfully implement the application need to minimized energy expenditure and balance load of the network. Present clustering algorithm leach [3] minimizes energy by forming non uniform clusters. The cluster head selected based on probability in a distributed manner for load balancing leads to message over head.

The proposed protocol fuzzy logic quadrant leach is novel and based on three factors foremost the energy expenditure is proportional to square of distance of the location to which it transmits the information, because if transmittance distance is greater than parameter d_0 than energy expenditure increases by an amount of fourth power of distance (d^4) as of trans-receiver model of wsn. The latter factor is that the proposed approach generates optimum energy clusters considering energy of the node and distance from the base station. The last factor massage over head due to exchange of neighbor node information receiving joining request messages is reduced in the proposed protocol. In this protocol the approach of the cluster head (CH) selection is based on fuzzy logic algorithm, which is run at the base station centrally assume to have abundant energy.

The system module of FLQL is depicted in section II, the proposed protocol implementation is described in section III, in section IV simulation parameters results and analysis are discussed. The conclusion is presented in section V.

II. SYSTEM MODEL

2.1 Main assumptions

1) Sensor nodes are deployed randomly for continuous monitoring.
2) Network considered homogenous that is all sensor nodes have same initial energy.
3) Nodes have ability to control power based on distance of receiving nodes.
4) Distance between nodes computed based on signal strength.
5) Base station is assumed to have abundant resource power.
6) Base station is located centrally in network area.
7) Radio link is symmetric such that energy consumption of transmission in forward and reverse direction is same.
8) Every sensor node can function either in sensing mode to collect surrounding information and send it to allocated cluster head or in CH mode to collect data manipulate and send it to base station.

2.2 Network Model

We consider a set of sensor nodes F_N and a sink node. Each sensor node F_{Ni} (i = 1, 2, ………n) has location information (xi, yi). The sleep mode is used to conserve energy. The communication is accomplished between the sensor node using TMAC protocol [4]. Base station possessed unlimited energy and memory space and has ability acquire information and data from the sensor node. The threshold energy is the minimum residual energy of a node below which it cannot perform additional function other than sensing and relaying.

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The key concept of proposed network model is to partition a network into four quadrants for better coverage and efficient energy utilization [5]. The nodes are deployed in a given 500 x 500 area based on location information base station divides network into four parts.

A = a1 + a2 + a3 + a4 --------------------->2. 1

$a_n = A(x_m, y_m)$ where n = 4 m = 500

$$\lim an_{xm=0,\ 250}^{ym=0,\ 250} + \lim an_{xm=251,\ 500}^{ym=0,\ 250} + \lim an_{xm=0,\ 250}^{ym=251,\ 500} + \lim an_{xm=251,\ 500}^{ym=251,\ 500}$$

Such portioning reduces transmission load and cluster are more deterministic optimum position of cluster head (CH).

2.3 Radio Energy dissipation model

In the proposed work the base station is located at center of the simulation area so that the distance between transmitter node and receiver base station and vice versa is less than threshold value d_0 based on this assumption free space model (f_s) is utilized. The energy expenditure is proportional to square of the transmission distance d^2. If L is number of bits of data to be transmitted for a distance d then energy expenditure for transmission is given by

$$E_{Tx}(l,d) = \begin{cases} l\ x\ E_{elec}^{Tx} +\ l\ x\ \in f_s\ d^2\ d < d_0 \\ l\ x\ E_{elec}^{Rx} +\ l\ x\ \in amp\ d^4\ d > d_0 \end{cases} \text{---->2.3}$$

Where,

$d_0 = \sqrt{\frac{\epsilon f_s}{\epsilon amp}}$ ϵf_s and ϵamp are energy usage factor of amplification for free space and multipath radio model which depends on distance of the receiver and acceptable bit error rate.

E_{elec}^{Tx} *and* E_{elec}^{Rx} are electronic energy consumption per bit for transmitter and receiver circuits respectively.

This parameter depends on characteristics like coding, filtering and modulation [6].

2.4 Fuzzy Model for Selection of CH Cluster Head and Cluster Members

Fuzzy logic is defined as super set of Boolean logic extending two values to multiple values between true or false using concept of membership degree.

The fuzzy logic can be describe by fuzzy sets membership function, linguistic variables fuzzy operations. If then rules FIS and de-fuzzification.

A. Fuzzy sets

it is extension of classical set (Boolean) that allows to define distinct function with values between 0 and 1[7,8,9,10].

A= { x, μA (x) } x ϵ U --------------- 2.4.1

A = Classical set, μA(x) = characteristic function, U = Universal set.

Extending this to Fuzzy set

Ā = {x, μĀ (x)} x ϵ U ---------------2.4.2

Ā= Fuzzy set, μĀ (x) = Membership function of x in Ā

B. Membership Function

The characteristic $\mu A(x) = \begin{cases} 1 \text{ if and only if } x \in A \\ 0 \text{ if and only if } x \notin A \end{cases}$ ---- 2.4.3

C. Linguistic variables

The variables used to control the system behavior called linguistic variables. They can be divided to values for flexibility to variables for example true false are variables, very true, true and very false are values.

D. Fuzzy Operations

The operations of fuzzy sets are same as classical sets: Union (OR) Intersection (AND) complement (NOT)

Union

it is the process of collecting elements of two or more sets in one set which is an OR operator of fuzzy logic [11].

$\bar{C} = \bar{A} \cup \bar{B}$ --------------------2.4.4

$\bar{\mu}_C(x)$ = Max { $\bar{\mu}_A(x), \bar{\mu}_B(x)$} = {$\mu_A(x), \cup\ \bar{\mu}_B(x)$} ----2.4.5

Intersection

It Contains shared elements of two sets $\bar{\mu}_A(x)\ \bar{\mu}_B(x)$ with minimum membership value for both sets.

$\bar{C} = \bar{A} \cap \bar{B}$ -------------------- 2.4.6

$\bar{\mu}_C(x)$ = Min ($\bar{\mu}_A(x)\ \mu_B(x)$} = {$\mu_A(x), \cap\ \bar{\mu}_B(x)$} --------2.4.7

Intersection is a AND operation of fuzzy logic.

Complement, equality containment is other operations used in fuzzy logic.

F. Fuzzy if then rules: - Fuzzy or if then rules are statements consisting of parts: antecedent, proposition and consequences, more than one antecedent contain (AND) OR operator. Fuzzy IF-THEN rules in statement form can be written as

IF x_1 is A AND/OR x_2 is B than y I C

A, B and C are called linguistic values x_1, x_2 and y are called variables

G. Fuzzy inference system

FIS is a collection of an assertiveness of IF THEN fuzzy rules, a data base comprising membership function of linguistic variables and fuzzy reasoning [12].

FIS is divided into four steps fuzzification, rule evaluation aggregation and difuzzification. Mamdani FIS is popular intuitive [13] compare to Sugeno Tsu Kamato FIS [14] . Due to better aggregation ad difuzzification process.

H. Fuzzification

The input is assumed as crisp values of variables based on which the value of membership function which is intersection point of value of parameter with the degree of membership.

I. Rule Evaluation

Feed these values to IF_THEN rules to determine new fuzzy output set. Fuzzy operator AND selects minimum value of membership function to get single number.

J. Aggregation

It is process of union of all outputs obtained by applying rules to FIS model. Hence we use OR operator which selects maximum of rule evaluation values generating new aggregate fuzzy set.

K. Defuzzification

It is the process of obtaining chance value or calculation of implication value by COA method also called Mamdani Technique.

2.5 Performance Matrices

The quality of service parameters to check the efficacy of the protocol are energy consumption, time delay, packet delay duration and throughput [15].

A. Energy consumption

It is the total energy consume by each sensor node during transmission of messages and data processing, receiving and sleeping. The protocol compute the energy expended based on free space energy module i.e., less the energy consume higher the efficiency of protocol.

B. Time Delay

It is the time taken by the generated data packets to transmit over a network from source to sinks within the allocated time of the protocol which is inclusive of queuing delay and route discovery and computing delay.

C. Packet Delivery

It is the ratio of data packet received at the sink to the data packet sent by the sensor nodes. This metric depicts successful delivery of the packets signifying consistence and reliability of the protocol.

D. Throughput

This is the measure of bandwidth consumed to maintain the channel and used for data communication.

III. PROPOSED PROTOCOL

The proposed FLQL – Fuzzy Logic Quadrant Leach is a cluster based protocol in which coverage area is divided into quadrant. This approach is suitable for uniform load distribution, the cluster head selection and cluster formation is based on the technique of fuzzy logic which produces energy optimum cluster head and cluster.

The base station is responsible for computing the cluster head and also forming the cluster. The base station uses the methodology by dividing area into quadrants leading to efficient energy utilization. The protocol is implemented in four phases i.e., uniform area division, cluster head and cluster formation, data transmission and re-clustering. In the proposed protocol the base station is positioned at the center of coverage area.

3.1 Uniform area bifurcation phase

The base station flags area bifurcation phase y requesting information from sensing area Chapter 4 figure 4.4 through request packet containing its id and location information lb. the sensor node send information through INFO packet containing there (id, location, energy). The base station from received information creates area division into quadrants. The base station intimates the nodes by INT packet their respective areas as A1, A2, A3 and A4 in area (500 x 500) A x A.

$$A = A1 + A2 + A3 + A4$$

$$A = \lim_{xm=0\ to\ 250} (A1)^{ym=0\ to\ 250} + \lim_{xm=251\ to\ 500} (A2)^{ym=0\ to\ 250} + \lim_{xm=0-250} (A3)^{ym=251\ to\ 500} + \lim_{xm=251-500} (A4)^{ym=251\ to\ 500}$$

The clusters so formed by the base station are more deterministic leading to optimum energy utilization.

3.2 Cluster head selection and cluster formation

The cluster head selection and cluster formation is based on the principle of Mamdani Fuzzy inference system [16]. To evaluate the chance of the node to become cluster head. It is based on two variables as inputs to inference system that is energy expenditure of the node and distance of the node from the base station. The output variable is the chance value of the cluster head. The process is depicted in figure 1.

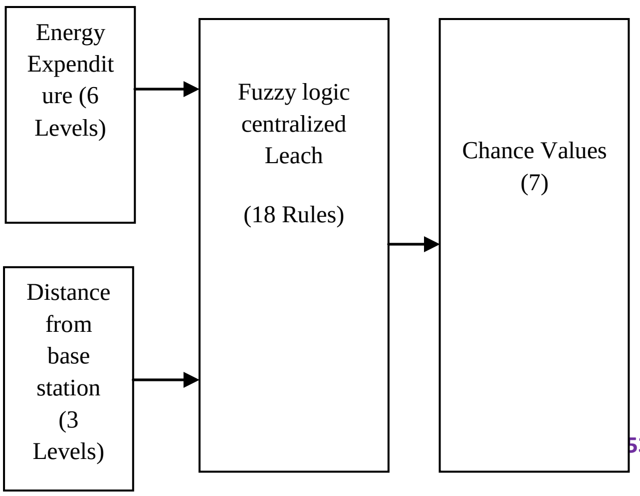

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Fig 1: Fuzzy with two variable inputs

The fuzzy sets (membership) formed for energy available input variable is depicted in Table 1. The linguistic variables used are high (H), rather high (RH), medium (M), rather low (RL), low (L) and very low (VL) variables.

The trapezoidal membership functions are used for high variable and very low variable. The triangular membership function is used for remaining four linguistic variables. The second input distance from the node to the base station is shown in figure. The linguistic variable for distance is close, medium and far. The trapezoidal membership functions are used for close and far variables. The triangular membership function are used for medium variables. The fuzzy output or chance value has 7 linguistic values very high (VH), high (H), rather high (RH), medium (M), rather low (RL), low (L) and very low (VL). The evaluation of chance is done using fuzzy IF_THEN rules to take care of uncertainties. For the selected two fuzzy input variables 18 fuzzy mapping rules are declared in table 1. From the defined fuzzy rules output or chance variable is extracted. The fuzzy output variable is converted to crisp value for practical use which is called defuzzification. The COA method is best defuzzification method which is utilized.

The membership function are available in NS2 simulator [19] inclusive of triangular trapezoidal Gaussian S-shape and Z-shape. However a triangle and trapezoidal functions are use full due to ease of degree determination. The formula for triangle and trapezoidal membership function are depicted in [20]. Hence forth we chose to use them to represent our parameters energy and distance as in figure.2.

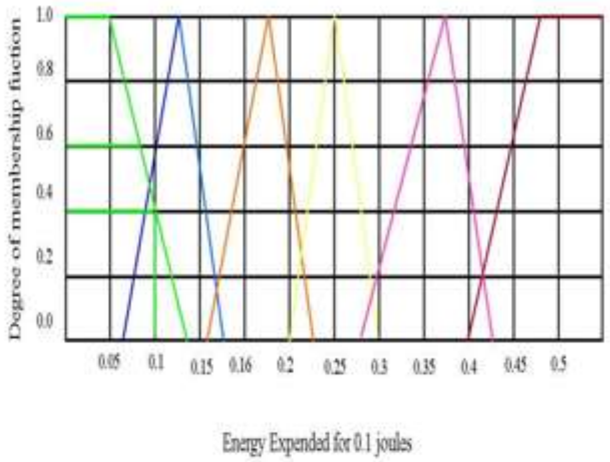

Fig 2: Energy Expended for 0.1 joules.

We have two parameters divided into 18 levels as shown in table which indicates our fuzzy if_then rules. The extremities of rules are

1. If energy expended is high it leads to low remaining energy in node and if distance of the node to base station is far then chance is very low.
2. If energy expended by the node is low its leads to high remaining energy and if distance is close chance is very strong.
3. All the other rules work within these extremities as depicted in the table.

<u>Fuzzy if then Rule using AND operator</u>

Sl. No	Energy	Distance to BS	Chance		Sl. No	Energy	Distance to BS	Chance
1	H	C	VH		1	H(0)	0 C	VH (min 0)
2	H	M	H		2	H(0)	0.2 M	H(0)
3	H	F	M		3	H(0)	1F	M(0)
4	RH	C	H		4	RH(0)	0 C	H(0)
5	RH	M	RH		5	RH(0)	0.2 M	RH(0)
6	RH	F	M		6	RH(0)	1F	M(0)
7	M	C	M		7	M(0)	0 C	M(0)
8	M	M	M		8	M(0)	0.2M	M(0)
9	M	F	RL		9	M(0)	1F	RL(0)
10	RL	C	VL		10	RL(0.4)	0 C	VL(0)
11	RL	M	M		11	RL(0.4)	0.2 M	M(0.2)
12	RL	F	RL		12	RL(0.4)	1 F	RL(0.4)
13	L	C	L		13	L(0)	0 C	L(0)
14	L	M	L		14	L(0)	0.2 M	L(0)
15	L	F	L		15	L(0)	1 F	L(0)
16	VL	C	VL		16	VL(0.6)	0 C	VL(0)
17	VL	M	VL		17	VL(0.6)	0.2 M	VL(0.2)
18	VL	F	VL		18	VL(0.6)	1 F	VL(0.6)

Table 1: FUZZY if then rules

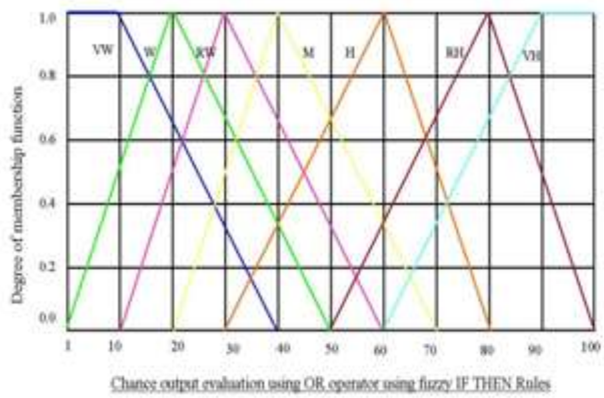

Fig 3: CHANCE OUTPUT

Aggregation of rule outputs

After fuzzyfication and rule evaluation the aggragation is done which is the union of the outputs the OR operator selects maximum of our rule evaluation for aggregation.

Deffuzification

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The chance value obtained is by Mamdani technique which is centroid defuzzyfication computed by the equation

$$\text{COA} = \frac{\sum \mu_A(x) * \ x\,dx}{\sum \mu_A(x)\,dx}$$

Where, μ_A (x) is degree of membership function $\sum$ algebraic summation.
The chance value evaluated for 0.1 and 140 is 23%.

The NS2 simulator having fuzzy tool box evaluated the chance values for various energy remaining after the expenditure and distance to base station as in table 2 below.

Sl. No	Energy after Expenditure	Distance to BS	Chance %
1	0.25	70	45
2	0.05	30	40
3	**0.45**	**30**	**77**
4	**0.5**	**10**	**77**
5	0.15	100	32
6	0.2	17	66
7	0.25	22	66

Table 2:

If the chance value is same the node chooses cluster head with higher energy level i.e., the case of 4 in the table 2.

The cluster head selection in the respective quadrant is broadcast by the base station. The nodes compares their ID by info (ID) packet sent by the base station if it matches with the node then that node is called as cluster head CH.

The normal nodes after CH selection sends joining request to the cluster head. In study state phase the cluster head creates TDMS slot for member nodes in respective quadrants then it receives data from the member nodes aggregate compresses and transmit data to the base station.

3.3 Algorithm 1 for cluster head formation

A. Input

N: - Wireless sensor network Nodes = 52.

nn: - Total number of nodes in networ

k: - Number of cluster heads = 4

a: - Node in the network.

T: - Random number selected for CH

Chance (a): - Chance of node to be CH based on available energy at present and distance from the base station.

Probability (a): - True for node with chance (a) above threshold

Candidate (a): - CH of the nodes among nn nodes.

B. Output

Cluster (a): - CH of nodes a node among nn nodes.

C. Function

Broadcast (data, range of distance).

Send (data, Receiver)

Fuzzy logic (energy, distance)

Find MIN distance (Nodes x_1, nodes y_1)

D. Set up phase

1. Send (location node ID energy distance to base station)

E. At Base station

2. Begin base station bifurcate N x N area into A1, A2, A3, A4 based on location information
3. For each node nn belong to area A.
4. Chance (a) < = Fuzzy logic (energy, distance)
5. Probability (a) = False.
6. If Chance (a) > T than
7. Probability (a) is true.
8. Node = CHA
9. Broadcast CH message
10. On receiving join request
11. Else
12. On receiving CH message send join request message to near CH
13. End if.
14. Cost = find minimum distance (node x1, node y1, k node x2, node y2, nn, node Index and CI)
15. Else probability (a) = false
16. End.
17. Else if (node belongs to area B)
18. Repeat 3 to 14
19. Else if (node belongs to area C) then
20. Repeat 3 to 14
21. Else if (node belong to area D) than
22. Repeat 3 to 14
23. End if
24. End if

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25. End if
26. End.

3.4 Nodes Association in setup phase Algorithm 2

1. N ϵ group of nodes
2. G ϵ group of CHs (selected based on FL)
3. If N ϵ (A, a1) than
4. Where
5. A = a1, a2, a3, a4
6. Check all possible ACHs
7. Find (minimum distance node x1, y1, nn and CH)
8. Associate with A CH
9. Than
10. Transfer data occurs
11. End if
12. If N ϵ (A, a2) than
13. Repeat steps 5 to 8 for B CH
14. End if
15. N ϵ (A, a3) than
16. Repeat 5 to 8 C CH
17. End if
18. If N ϵ (A, a4) than
19. Repeat step 5 to 8 for D CH
20. End if.

IV. SIMULATION AND RESULTS

Quality of service is set of requirements to be met by network while transporting packet stream from source to destination. From network perspective these are to address optimal sensor resource utilization in resource constrained WSN. The parameters from resource perspective are energy, throughput average delay and packet delivery ratio.

4.1 Simulation setup

In this section we present simulation setup for protocols AODV, quadrant leach and fuzzy quadrant logic FQL protocols followed by performance matrices to analyze the efficiency of developed protocol . Simulation performed with software simulator NS2[17] on Linux. The values are calculated using C++ codes. Simulation scenario is set as per table no.3.

Parameters	Values	Parameters	Values
Simulation area	500 m X 500 m	Base station	250 X 250
Number of nodes	51	Data pay load	500 bytes/per packet
Queue size	51	Routing	AODV, QL, FQL
Traffic type	CBR (UDP)		51
Initial energy	0.5 joules	Channel	Wireless
Simulator	NS-2	Duration	2, 4, 6, 8 and 10 sec
Transmission range	180	MAC layer	
Packet rate	8 packets/sec		
Radio model	Start up energy E_{elec}^{Tx} , E_{elec}^{Rx} ε_{fs} ε_{am}	2 joules 50 nJ/bit 10 PJ/bit/m^2 0.0013 PJ/bit/m^4	

Table 3:

4.2 Simulation parameters and result analyses

A. Average energy consumption

The energy consumed by AODV protocol[18] for simulation time for 10 sec is 90% compare to 75% quadrant leach protocol QL and 40% by proposed protocol fuzzy quadrant leach FQL. The AODV consumes energy due to route construction from source to destination requiring request/reply messages. The QL and FQL protocol are cluster based whose cluster head formation construction happens at the base station which is energy rich. Further the cluster head selection is based on fuzzy logic in proposed FQL protocol leading to further energy reduction. The results are depicted in respective tables no.4 and fig.4 with graphs generated by X-graphs in NS2.

TIME	ENERGY		
	A0DV	**QL**	**FQL**
0	0	0	0
2	16.77	12.7	4.0
4	17.37	13.1	12.84
6	17.9688	13.78	13.0
8	18.5385	14.2	13.1
10	19.1357	14.9	13.2

Table 4:

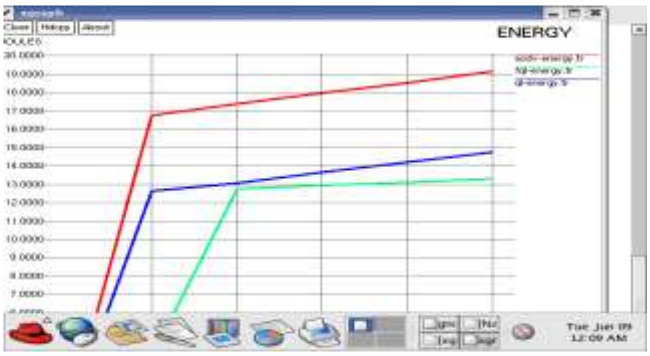

Fig 4 :

B. Packet delivery ratio

It is the ratio of number of packet sent from the source to packet received at the distention within the simulation time. The PDR packet delivery ratio is high for AODV protocol during initial part of simulation time, but with the formation of cluster and cluster head in QL and FQL the PDR increase sharply from 36% to 42% in quadrant leach and 36% to 67% in FQL compare to 20% to 23% in AODV.

TIME	PACKET DELIVERY RATIO		
	A0DV	QL	FQL
0	0	0	0
2	0.2500	0.0165	0.036
4	0.2022	0.3695	0.36
6	0.1808	0.4844	0.534
8	0.1817	0.4566	0.658
10	0.2322	0.4288	0.670

Table 5:

Fig 5:

V. CONCLUSION

This chapter proposed uniform area bifurcation clustering scheme with fuzzy logic technique called as fuzzy logic quadrant leach.

The work load on the sensor node is decreased by giving more responsibility to centrally located base station which is energy resource rich. The fuzzy logic for selection of CH and formation of cluster head is based on the parameters energy expenditure and distance of the node from the base station. Such a logic helps in optimum selection of cluster head and cluster formation which increases packet delivery ratio decreases latency. The cluster based data collection reduces traffic and aggregation of the data at the cluster head improves energy consumption. The simulation results source at the proposed protocols outperforms existing AODV and quadrant leach protocol.

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