Fuzzy Logic Based Cluster Head Election for Wireless Sensor Network

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Abstract — **In practice, hundreds or thousands of wireless sensor nodes are used to form a complex but useful wireless sensor network for monitoring and analysis of the environmental purpose. In general, environmental monitoring cluster based hierarchical routing protocol is among the most common protocol being opted due to the load balancing among each other sensor. Normally, sensors are randomly deployed in a specific area to collect useful information periodically for a few months or even a few years. Therefore, the lifetime of battery power becomes a limitation and challenging issue. It is impractical to maintain the network lifetime by changing the battery frequently. LEACH is one of the famous clustering protocols that elect the cluster head based on the probability model which will possibly lead to a reduce in network lifetime due to selection of cluster head with a least desired location in the network. For wireless sensor networks, the distribution of cluster head selection directly influences the network's lifetime. This paper presents a fuzzy logic based cluster head election conducted in base station. The base station is placed in the middle of the network and it considers two selection criteria from sensor nodes which are energy level and distance to the base station to select the suitable cluster head that will prolong the first node die (FND) time and data stream guaranteed in every single round. The proposed method also eliminates the need of location information, Global Positioning System (GPS) of the sensor nodes, as GPS may be ineffective in some cases.**

Keywords – Wireless Sensor Network; Cluster Head; Cluster; Fuzzy Logic

I. INTRODUCTION

Wireless sensor networks contain hundreds or thousands of sensor nodes equipped with sensing, computing and communication abilities. The sensor nodes can be equipped with different type of sensors such as temperature sensor, humidity sensor, gas sensor, and etc. When the sensor nodes sense the surrounding elements of the environment, the processing units inside the sensor nodes will convert the analog signal to digital data by using analog to digital converter module and further sends the data to the base station for processing. Wireless sensor nodes not only communicate directly to base station, it also communicates among its peers. In the near future, it is possible to implement smart adaptive sensor nodes by loading artificial intelligence algorithm into it.

It is challenging to design the wireless sensor nodes that can achieve a cost saving and compact size of the design. The trade-offs for being compact are limited computation capability, limited power source and small memory storage. The nodes' energy is the most important issue because the nodes are small in size and it may be deployed in hazardous areas, thus making battery replacement unpractical and impossible. It is more practical to save energy and prolong the network lifetime by improving the routing algorithm. Cluster based hierarchical routing protocol is an energy-efficient routing protocol. In the cluster routing, the sensor nodes are divided into a few groups with one cluster head elected for each group. The cluster head collects data from member nodes in the same cluster and aggregates the collected data so that it can be transmitted to the base station. Implementing this protocol will significantly reduce the overall energy used and reduce the network congestion by only allowing the cluster head to communicate with the base station [1, 2, 3].

LEACH protocol is one of the famous cluster routing protocols which aims to achieve the load balancing in sensor nodes so it can prolong the network lifetime. In cluster routing protocol, energy consumption is concentrated on cluster heads which collects and aggregates the sensed data from member nodes and forwards the aggregated information to the base station [4, 5]. In LEACH protocol each sensor nodes elects itself as a cluster head based on the probability model. Each sensor node will become cluster head in every cycle to evenly distribute the work load. The main problem of LEACH protocol is it only depends on the probability model to elect the cluster head and therefore it is possible that no cluster heads or too many are selected in a single round [6]. Furthermore, the selected cluster heads may be located near to each other or even near to the edge of the networks which leads to inefficient energy distribution [7].

LEACH-C uses a centralized algorithm to elect the cluster heads where each node sends information about its current location and energy level to the base station and elects the cluster head using the simulated annealing algorithm [8]. Gupta proposed a cluster head election method using fuzzy logic based centralized algorithm [9]. By considering three parameters which are energy, concentration and centrality of sensor nodes, the base station will elect the suitable cluster head among all the nodes which show the improvement of network lifetime compared to LEACH. These cluster head election mechanism needs the location information of the sensor nodes (possible determined using a GPS receiver) [10]. To use the algorithm, the sensor nodes need to know the location information. At the first round, location information will be transmitted to the base station and the algorithm assumes all sensor nodes under minimal mobility constraint.

This paper aims to maximize the First Node Dies (FND) period, data collection is guaranteed for each round and this method does not require the location information of the nodes. In this study, a cluster head election mechanism in base station using fuzzy logic is proposed. Fuzzy logic system can manipulate the linguistic rules into mathematical form, it can make real time decision due to the algorithm's simplicity [11]. Moreover extra parameters such as battery charging rate, data queue length are among the parameters that can be added into fuzzy logic system to produce an optimized solution.

This paper is organized as follows. In the next section, overview of cluster based hierarchical routing protocol LEACH and fuzzy logic cluster based are demonstrated. Section III explains the system model and simulation results are analyzed. Lastly, section IV concludes the findings.

II. RELATED WORK

A. Cluster based Hierarchical Routing Protocol

In cluster routing, nodes with more energy will become the cluster head in the networks. By forming few clusters, the surrounding node only need to communicate to cluster head in the same cluster to reduce the energy consumption used to communicate among other nodes at different clusters.

LEACH [3] is one of the clustering mechanisms aims to distribute the energy concentration in the cluster head. This protocol operates in rounds; each round consists of two phases which are set-up phase and steady phase. Set-up phase include advertisement phase and cluster set-up phase while steady phase include schedule creation and data transmission. In each round, each node independently generates the random number between 0 and 1. If the generated number is less than the threshold value $T(n)$ which defines by equation (1), the node wills self-elect to become the cluster head for the current round.

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & , if\ n \in G \\ 0 & , otherwise \end{cases} \tag{1}$$

r is the round which already ended.

p is the proportion of the nodes to cluster heads.

G is a set of those nodes which have never be cluster head in the last $1/p$ rounds.

Fig. 1 shows the LEACH protocol flow chart used in [8] and uses it after each node self-generated a random number.

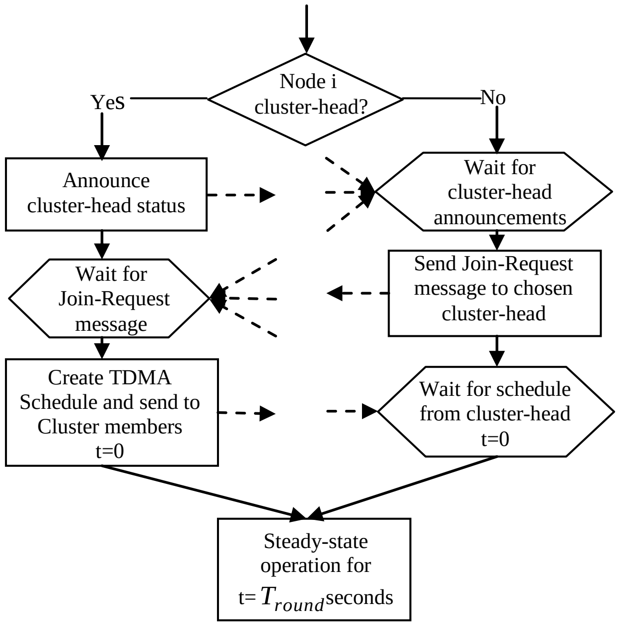

Figure 1. Flow chart of the distributed cluster formation fo LEACH.

Although LEACH protocol distributes the energy concentration in the cluster head but it has some disadvantages.

- LEACH depends on only the probability model to elect the cluster head, elected cluster head may be very close to each other.
- In each round the number of the cluster head is dynamic and it cannot guarantee the data stream receive by base station.
- In every cycle $1/p$, each node will become cluster head, which mean the cluster head will appear in the edge of the network or in the place where the node density is very low.

It can be observed that the disadvantages of LEACH protocol are mainly due to only using the local information [4, 5]. By using centralized algorithm in the base station with global information, it will possibly elect the suitable cluster head in the network.

B. Cluster-Head Election using Fuzzy-Logic

In the centralized algorithm, base station has the global view of the overall networks. Fuzzy logic is chosen to elect the suitable cluster head. The base station is more powerful than the sensor nodes in term of computation power, sufficient memory, unlimited power and storage. Gupta proved that, by considering three fuzzy parameters which are energy, concentration and centrality, the network lifetime can be improved. Energy level is available in each node, concentration is the number of neighbor nodes and centrality is a value based on how central the node to the cluster. In reality, the main problem is not all the nodes are equipped with GPS receivers and in some circumstances they might not be able to provide location information.

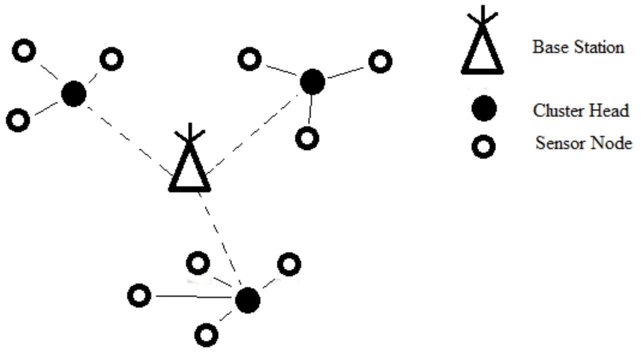

Figure 2. Basic system model.

III. SYSTEM MODEL

In this study, the base station which located at the centre of the sensing field as shows in Fig. 2, use fuzzy logic to calculate the chance of a node to become a cluster head, and then it will select $p \times$ total number of nodes with the highest chances from the list of the cluster heads. Here are some assumptions made for the system model.

- It assumes that all nodes can transmit with enough power to reach the base station and base station have a wide transmission range, hence can use a single broadcast to reach all the sensor nodes.
- The distance between nodes and base station can be measured based on the wireless radio signal strength.
- Cluster head election is performed centrally at the base station.
- All nodes are homogenous, with the same nodes model and same energy resources.

A. Radio Model

Fig. 3 shows the block diagram of radio model used in this research. The model consists of the transmitter model and receiver model for energy calculation.

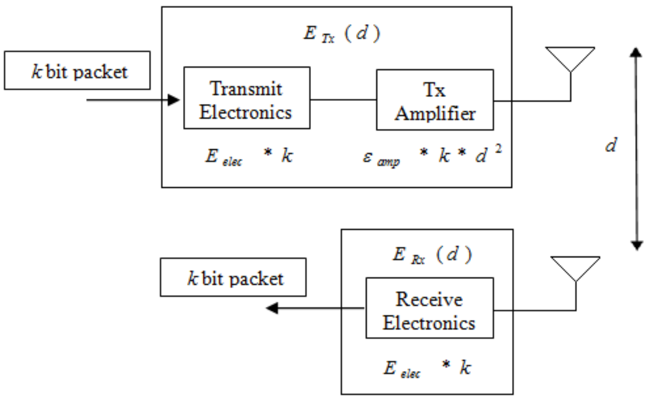

Figure 3. Radio energy model.

The radio model used in this study refers from [3]. The expended energy during transmission and reception for k bits message to a distance d between transmitter and receiver node is given by:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \tag{2}$$

$$= \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2 & if\ d < d_0; \\ kE_{elec} + k\varepsilon_{mp}d^4 & if\ d \geq d_0, \end{cases}$$

Distance d_0 is the threshold for swapping amplification models, it can be calculated as $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. To receive k -bit message, the radio model expend as:

$$E_{RTx}(k) = E_{elec}k \tag{3}$$

B. Fuzzy Logic Control

Fuzzy inference technique via Mamdani method is used due to its simple structure [7]. There are four steps in the Mamdani method:

- Fuzzification of the input variables, transforms the system inputs, which are crisp values, into fuzzy sets.
- Rule evaluation, taking the fuzzified inputs and evaluate them to the antecedents of the fuzzy rules.
- Aggregate conclusions, the process of unification of the outputs of all rules.
- Defuzzication, transforms the fuzzy set obtained by the inference engine into a single crisp value.

For the defuzzification module, the fuzzy set obtained from the inference engine needs to be transformed to the single crisp value. Thus, COA (centre of area) is use to calculate the crisp value from the aggregate output membership function by using the Eqn. 4, $\mu_A(x)$ is the membership function of the fuzzy sets:

$$chance = \left(\int x.u_A(x)dx \Big/ \int xdx\right) \tag{4}$$

C. Expert Knowledge Representation

Expert knowledge is represented based on the following two descriptors:

- Node Energy – energy level remain in the node.
- Distance – the distance between the node and the base station.

Energy is the most important factor to be considered in prolonging the FND time and it can be achieved through the balance remains of energy at each node. The battery level is from each node via ADC (analog to digital converter) which can sense the remaining energy of the node. Distance is also factor to be considered, since the proposed method did not know the exact location of each node. Therefore, the distance between the base station and other nodes are the key information that can be used to elect the suitable cluster head. The distance information can be acquired when the base station broadcasts the elected cluster head information to the whole network. Then, each node calculates the distance to the base station based on the receive signal strength indicators (RSSI). Eqn. 5 is the formula use to normalize the energy level into fuzzy set node energy. The universe of discourse (UOD) for distance can be calculated by dividing the measured distance with the distance between the base station and the edge of the sensing field.

$$\text{Node energy} = \frac{E_{remaining}}{E_{initial}} \quad (5)$$

The linguistic variables used to represent the node energy and the distance are divided into three levels; high, medium, and low for energy as in Fig. 5; and then, far, medium and near for distance as in Fig. 4. The outputs to represent the node cluster head election chance was divided into nine levels: very weak, weak, little weak, lower medium, medium, higher medium, little strong, strong and very strong as in Fig. 6. For the fuzzy rule base, it has $3^2 = 9$ rules. The membership functions developed and their corresponding linguistic states are represented in figures below.

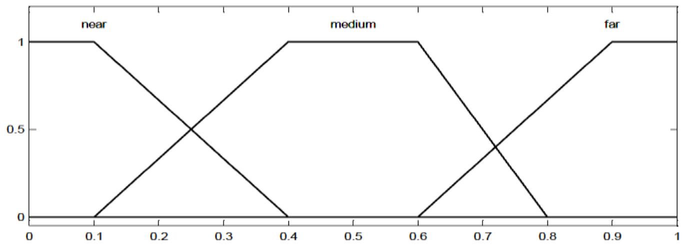

Figure 4. Membership functions of distance.

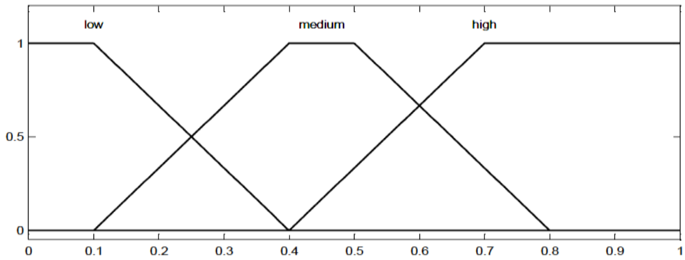

Figure 5. Membership functions of energy.

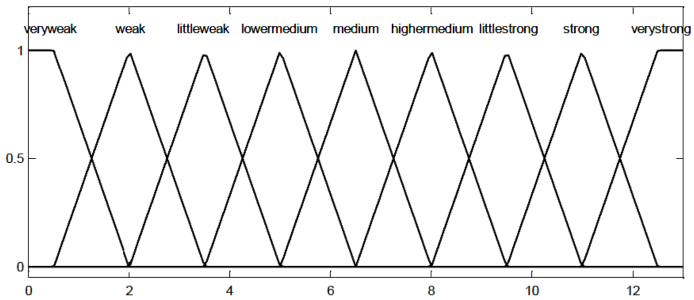

Figure 6. Membership functions of chance.

TABLE I. FUZZY RULE BASE

No	Energy	Distance	Chance
1	Low	Far	Very Weak
2	Low	Near	Weak
3	Low	Medium	Little Weak
4	Medium	Far	Lower Medium
5	Medium	Near	Medium
6	Medium	Medium	Higher Medium
7	High	Far	Little Strong
8	High	Near	Strong
9	High	Medium	Very Strong

Table I shows the rule base set in the fuzzy inference system (FIS), the rule set as if the energy is low and the distance is far, then the chances to be cluster head is very weak. On the other hand, if the energy is high and the distance is medium, the chances become very strong. For distance rule base, medium is set to higher priority than near because the cluster head in the medium zone will perform better than near zone. This is due to the numbers of member nodes from the far zone need to spend higher energy to transmit to the cluster head in near zone compare to cluster head which locate in medium zone.

In fuzzy based centralized algorithm, base station will calculate the chances for every node to become cluster head via FIS, where the base station will elect the cluster heads according to $p \times$ total number of nodes. The data transmission phase is similar to the LEACH steady state phase.

D. *Results and Discussions*

The simulation was carried out in MATLAB with the parameters show in Table II. The base station was placed in the middle of the network.

Since the proposed method need extra information to elect the cluster heads. Therefore, the data sent in the proposed method was added 24 bits from member node to cluster head transmission as extra energy and distance information. 480 bits was added for cluster head to base station transmission as extra energy and distance information for each cluster members and the cluster head.

TABLE II. SIMULATIONS PARAMETERS

Parameter	Value
Topology size	100 x 100 m^2
Base Station Position	50 m ,50 m
Simulation Round	200
Number of Node, *n*	100
Cluster Head Probability, *p*	0.05
Initial Energy, E_0	0.05 J
Packet Size, *k*	4000 bit
Energy of transceiver, E_{elec}	50 nJ/bit
Energy of data aggregate, E_{DA}	5 nJ/bit/message
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4

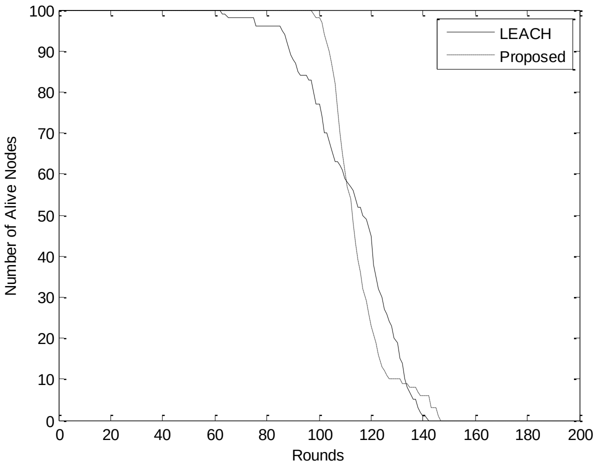

Figure 7. Network lifetime.

Referring to Fig. 7, the simulation results show that the proposed method performs better than LEACH during the first node fails and the last node fails, however the proposed method defeated by LEACH during 60 % of total nodes to 10 % of total nodes. On the other hand, the proposed method performs better than LEACH after 10 % of the total nodes. In LEACH, cluster head is elected based on probability model. This makes the cluster head exhausts the energy rapidly compare to the proposed method which considers critical factors in electing the cluster head. Although the proposed method may elect the cluster heads near to each other because the base station only knows how far the node from it but not where the exact location is. But overall, the elected cluster head is more efficient than LEACH. The following discussions explain the simulation result when the first node fails for the proposed method is longer than LEACH which is round 62 for LEACH and round 97 for the proposed method.

After the FND, the proposed method start to drastically decrease in number of nodes until LEACH has more nodes than the proposed method at around 60 % of total nodes. This is because the proposed method uses energy level as one of the factor to consider in electing the cluster head, so it made all sensor nodes distribute the energy consumption evenly. Therefore, after the FND, the remaining nodes die faster due to the less and almost same amount of energy.

The proposed method performs better than LEACH when the remaining node becomes less. This is because when the remaining node becomes less, the cluster heads elected is located far away from the node. Therefore the nodes need to spend more energy to communicate with the cluster head and the nodes will die faster. In the proposed method, the number of cluster head will be maintain which nodes can select which is the nearest to communicate with to save energy.

Moreover, the proposed method will maintain the numbers of cluster heads based on $p \times$ total number of nodes so that it can always guarantee the data collection from sensor networks and also to ease the base station's burden as it will not have a dynamic number cluster heads elected every round.

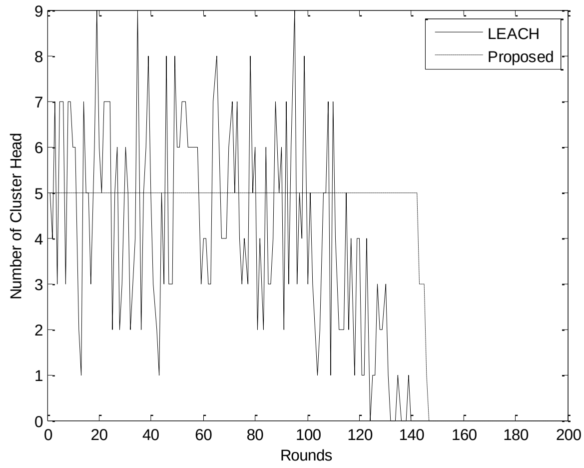

Figure 8. Number of cluster heads.

Fig. 8 shows the number of cluster head over rounds. The proposed method maintains the constant number of cluster head until it reach the case that the numbers of cluster heads same as the remaining nodes, while LEACH will elect cluster heads based on the probability model. By doing so, LEACH is possible to obtain no cluster heads or no data stream in some round as shown in Fig. 8. The cluster heads elected may more or less unpredictable and become worst when the remaining nodes are not much, which it will lead to no cluster heads elected. As shown in Fig. 9, in round 134 there is no cluster head elected in LEACH compare to 5 cluster heads elected in the proposed method.

In Fig. 9 and Fig. 10, the base station is labeled as BS in the middle of sensing field, whereas cluster head is labeled as CH and the last is sensor nodes which label as SN. It is shown in round 134, CH appears in the proposed method but LEACH does not have any CH elected. Although energy is saved when there is no cluster heads chosen, the shortfall of LEACH is no cluster heads to aggregate and forward the data to the base station.

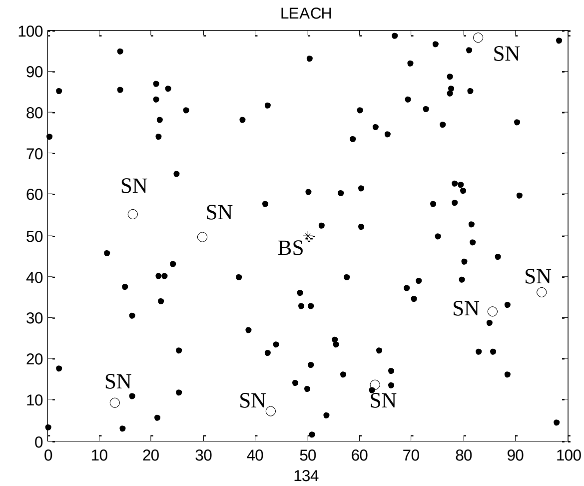

Figure 9. Elected cluster heads in LEACH.

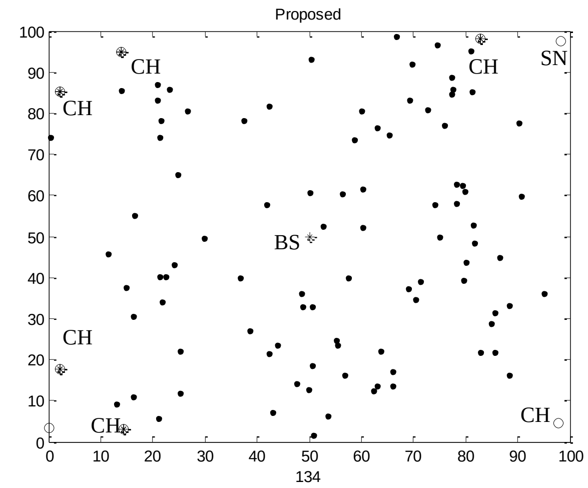

Figure 10. Elected cluster heads in proposed method.

The quality of the networks is depending on the most effective data received after the networks completed with all the nodes. Fig. 11 shows the data receive by the base station or throughput in term of bits. The data received by base station in the proposed method before FND is 54 % more than LEACH.

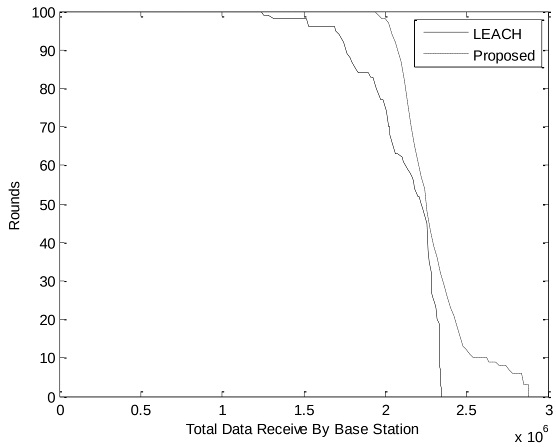

Figure 11. Data sent to base station.

IV. CONCLUSION

As a conclusion, the proposed method achieved its objective to prolong the FND time, data collection guarantee for every round and also works independent without the requirement of location information. It shows improvement compared to LEACH protocol because the base station have partial global knowledge of the networks and the use of fuzzy logic to elect the suitable cluster head based on two factors which are energy level and distance.

More simulations can be run to prove the proposed method works and also to optimize the fuzzification function and rules. The proposed method can be further improved by adopting some intelligent algorithm to modify the shape of each fuzzy set to achieve optimum result in specific cases. With the global knowledge of the network, multi-hop routing can be implemented to reduce the energy consumption in the cluster head.

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