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FUZZY LOGIC BASED CLUSTER HEAD SELECTION IN WIRELESS SENSOR NETWORKS

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Abstract: Wireless Sensor Networks (WSN) become more popular due to the wide range of applications in various fields. WSN consists of a group of sensor nodes deployed in the region of interest. Energy efficiency is the major challenge while deigning WSN. Clustering is one of the important energy efficient techniques. Clustering is the process of grouping the nodes into clusters. A cluster consists of a Cluster Head (CH) and number of cluster members. CH is responsible for collecting data from cluster members, aggregating it and forwarding the aggregated data to Base Station (BS). So, CH selection plays a vital role to preserve energy in WSN. Many researchers are carried out to select the proper CHs. CH selection influences the overall performance of the WSN. In this paper, a dynamic CH selection using Fuzzy logic is proposed. The fuzzy input parameters are residual energy and the distance to BS. The output parameter is the probability of becoming CH. The proposed method is compared to the well known clustering protocol LEACH. Simulation results shows that the proposed method produces better results than LEACH interms of energy consumption and network lifetime.

Keywords: Clustering, Cluster Head selection, Energy efficiency, Network lifetime, Wireless Sensor Networks

1. Introduction

Rapid development in the field of telecommunication and MEMS technology leads to the development of low cost, compact size sensor nodes [1]. Wireless Sensor Networks comprises of huge number of sensor nodes deployed in the region to be sensed [14-18]. The sensors are deployed randomly or the position of the sensor nodes is predefined based on the application requirement [19-23]. WSN is popular due to the applications in various fields such as environmental monitoring, border surveillance, health care monitoring, habitat monitoring, smart homes, smart cities, weather monitoring, etc [2][3]. The sensor node consists of four units: sensor unit, power unit, processing unit and communication unit [24-27]. The sensor unit is used to measure the physical parameters needs to be measured. The physical parameters can be temperature, pressure, humidity, vibration, acoustic signal, etc [4]. The sensed value is processed by the processing unit and the communication unit is used to forward the data to BS.Powerunit is the crucial unit in WSN [28-32]. The sensor nodes are battery powered and needs to operate for longer time. It is very difficult or impossible to recharge or replace batteries in the sensor node [5]. So, effective usage of available energy is the primary way to maximize the network lifetime.

The architecture of a WSN is shown in Fig 1. The sensor nodes are randomly deployed in the sensing region. BS or sink is located far away from the deployed region [33-36]. The sensor node senses the physical parameter and forwards the data to BS directly or through intermediate sensor nodes [6]. When the distance between the sensor node and BS is less, the node transmits the data directly to BS. In large scale WSN, the distance between the BS and sensor node is large. In those situations, data is forwarded in multi-hop fashion, i.e. data is transmitted through the intermediate nodes. The remote user can access the data from BS via internet [36-40].

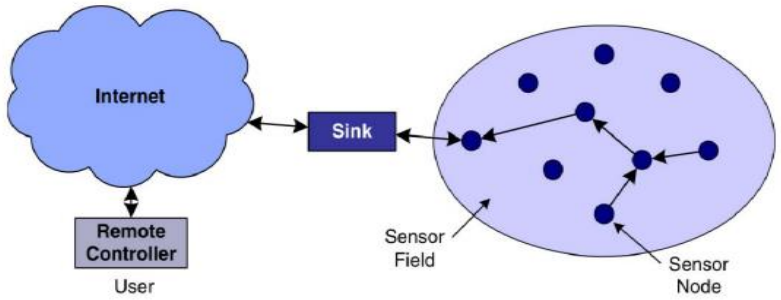


Fig. 1. Architecture of a WSN

Various approaches have been developed to achieve energy efficiency in WSN [7]. Clustering is the most popular energy efficient technique to reduce the overall energy consumption in the network [8]. The architecture of clustering in WSN is shown in Fig 2. The network is partitioned into various clusters and a leader is selected among the nodes. The leader is called as Cluster Head (CH) and remaining nodes are termed as cluster members or cluster nodes. The cluster members sense the region and transmit the data to CH [40-44]. The CH performs three operations: receives data from cluster members, aggregate the data and forward the data to sink. There are two types of communication in clustered WSN. They are intra- cluster communication and inter-cluster communication. The intra-cluster communication refers to the data transmission within a cluster, i.e. cluster members sends data to CH. The inter-cluster communication refers to the data transmission between several CHs. For transmitting data to sink, CH uses several CHs as intermediate nodes in multi-hop communication [44-50].

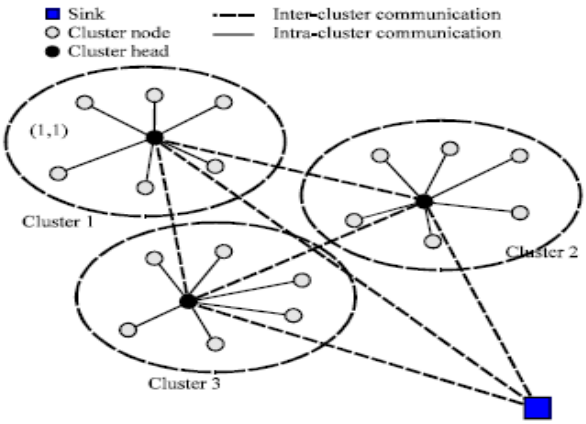


Fig. 2 Architecture of Clustering in WSN

CH plays an important role in clustered WSN. Random selection of CHs reduces the energy efficiency. Various methods are proposed to select the CHs effectively [51]. Proper selection of CHs makes the network energy-efficient and it makes equal distribution of load among the network. After certain time period, rotation of CHs takes place [52]. When the energy level of the current CH becomes very low, it will become the cluster member [54]. Next possible node will become the CH. This results to the uniform energy dissipation in the entire network.

In this paper, fuzzy logic is used to select the CHs dynamically. The fuzzy input parameters are residual energy and the distance to BS. The output parameter is the probability of becoming CH. The proposed method is compared to the well known clustering protocol LEACH. Simulation results shows that the proposed method produces better results than LEACH interms of energy consumption and network lifetime. The rest of the paper is organized as follows. Related works are described in Section 2. Preliminaries are given in Section 3. Section 4 explains the proposed method in detail. The proposed method is simulated and the results are given in Section 5. The paper is concluded in Section 6.

2. Related works

In the last decade, several clustering techniques have been proposed which can be differentiated by the process of CH selection. Hierarchical based clustering protocols attain maximum energy efficiency in WSN. LEACH [8] is the first and most popular hierarchical based clustering protocol in WSN. It has been proposed to reduce the energy consumption and lengthen the network lifetime [55-57]. It is a distributed; probability based clustering protocol without any central control. It does not need any global information of the sensor nodes (energy, distance, etc.) Additionally, each node independently takes decisions of becoming CH. LEACH works in two phases: setup phase and steady state phase. In setup phase, each node determines the probability of becoming CH by choosing a random value between 0 and 1. The node becomes a CH in the present round, when the random number is less than the predefined threshold value:

$$T(n) = \begin{cases} p/\left(1 - p\left(r \bmod \frac{1}{p}\right)\right), n \in G \\ 0 \qquad\qquad\qquad\qquad , n \in G \end{cases} \tag{1}$$

where p is the desired percentage of CHs, r is the number of rounds and G is the set of all nodes which is not elected as CH in the past 1/p rounds. The number of CHs is determined by the following equation (2):

$$K_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \times \frac{\sqrt{\varepsilon_{fs}}}{\sqrt{\varepsilon_{mp}}} \times \frac{Len}{d_s^2} \tag{2}$$

where, N is the number of alive sensor nodes in the present round, Len is the length of the deployed region, d_s is the distance between the nodes and sink.Once the CHs have been selected, the CHs broadcast an advertisement message to other nodes within its communication range that they are the present CHs. When a non-CH node receives the message, it joins the cluster with minimum distance. When the clusters are formed, CH creates a TDMA schedule with time slots for each cluster member. In the steady state phase, each cluster member senses the data and

sends the data in its respective time slot. Then CH receives the data, aggregates it and forwardsto BS. After certain time period, setup phase will initiate again followed by steady state phase.

LEACH protocol has some limitations. It does not consider the present state of the sensor nodes (e.g. residual energy, distance to sink, etc.). When the node with less residual energy becomes CH, it will die soon. And the distance to BS is also not considered [58-60]. The nodes located far from BS become CH; the energy consumption is increased enormously. It is not suitable for large scale WSN where the distance between the sensor node and BS is high. LEACH does not employ use multi-hop communication even for longer distances. This makes the CH spends more energy and exhausts its battery soon.

LEACH-C [9] is a centralized protocol where each node sends its location, energy level information to the sink. With this information, BS determines the clusters and selects some nodes as candidate nodes based on the higher residual energy. Final CHs are selected from candidate CHs based on simulated annealing algorithm. The BS sends the CH's ID to the network. When the node ID is matched with the received ID from BS, it broadcasts itself as CH. The nodes nearer to CH join the cluster as cluster member. The results of LEACH-C are better than LEACH.

LEACH-EP [10] is also a centralized energy-efficient protocol where the nodes with maximum residual energy have higher probability of becoming CH. The process of LEACH-EP is same as LEACH. One major difference is the process of CH selection. LEACH-EP uses Equation (3), an energy aware threshold to select CH.

$$T_{ep} = \begin{cases} p \times \frac{E(n)}{E_{ch_{av}}} & if \;\; E(n) \geq 0.5 \times E_{ch\_av} \\ 0 & if \;\; E(n) < 0.5 \times E_{ch\_av} \end{cases} \qquad (3)$$

where E(n) is the residual energy of the node, p is the percentage of CHs and E_{ch_av} is the average residual energy of the CHs.

LEACH-DT [11] is a distance aware clustering protocol. It is proposed to minimize the energy consumption and maximize the network lifetime. It selects the CH based on the probability of the distance from the BS. It uses same equation as LEACH with an additional formula to calculate p.

$$p_n = k \times \frac{\xi_n}{\sum_{j=1}^{N} \xi_j} \qquad (4)$$

$$\xi_n = (\bar{E}_{CH} \times d_n - \bar{E}_{non-CH})^{-1}$$

where $p_n$is the probability of n node to be chosen as CH, k is the number of CHs, d_n is the distance between node and sink,$\bar{E}_{CH}$is the average residual energy of CHs, and $\bar{E}_{non\text{-}CH}$ is the average residual energy of non-CH nodes. In this paper, fuzzy logic is used to select the CHs dynamically. The fuzzy input parameters are residual energy and the distance to BS. The output parameter is the probability of becoming CH. The proposed method is compared to the well known clustering protocol LEACH. Simulation results shows that the proposed method produces better results than LEACH interms of energy consumption and network lifetime.

3. Preliminaries

3.1 Network model

Before explaining the proposed algorithm in detail, the characteristics of the system model used in implementation are given. Some assumptions made are:

- Nodes are randomly deployed in the sensing field
- Nodes and BS are stationary after deployment
- All nodes are homogeneous
- Links are symmetric
- Nodes are location unaware
- BS has sufficient knowledge about the network

3.2 Energy model

To minimize the energy consumption, first order radio model is used to very transmission power with respect to the distance [12]. The reduction in transmission energy reduces the interference. The energy dissipation at the transmitter (E_{TX}) and receiver (E_{RX}) with distance d for transmitting an l-bit data packet is computed in equation (5) and (6):

$$E_{TX}(l,d) = \begin{cases} l \times E_{elec} + l \times \varepsilon_{fs} \times d^2 & if\ d \leq d_0 \\ l \times E_{elec} + l \times \varepsilon_{mp} \times d^4 & if\ d > d_0 \end{cases} \quad (5)$$

$$E_{RX}(l) = l \times E_{elec} \quad (6)$$

where $E_{elec}$is the dissipated energy in transmitter or receiver and it is based on various factors like digital coding, modulation, filtering, and spreading of the signal. The distance threshold is defined as $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. Based on the transmission distance d, the free space ($_{fs}$) or multipath fading channel ($_{mp}$) is used for the transmitter amplifier.

4. Proposed System

Many researchers are involved in fuzzy based clustering technique. Because of the uncertainties occurring in the WSN environments, increasing number of clustering-based protocols make use of fuzzy logic for clustering in WSNs. Using the fuzzy input and output variables, uncertainties inherent in the WSN nature are handled effectively. And, it has low computational complexity and more flexibility than crisp logic. The fuzzy inference system can be employed to get a better combination of the applicable input parameters to obtain optimal output, which is the CH selection procedure in this context. The fuzzy logic controller consists of four parts which is shown in Fig 3.

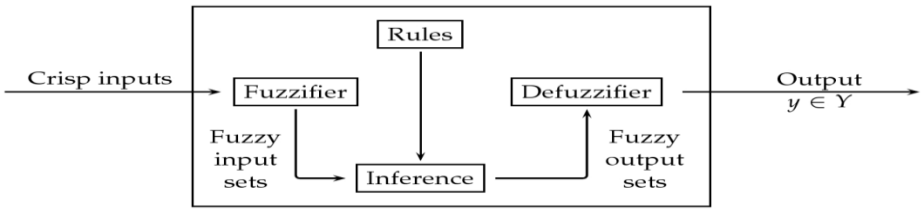


Fig. 3. Fuzzy Logic Controller

- Fuzzy rule base: It stores a set of IF-THEN rules.
- Fuzzy Inference Engine: The inference engine maps the input values with rule base table to produce fuzzified output rules
- Fuzzification module: translates crisp inputs into fuzzy values.
- Deffuzification: translates fuzzy outputs into crisp values

In this paper, a dynamic CH selection is done with the help of fuzzy logic. The fuzzy input parameters are residual energy and the distance to BS. The output parameter is the probability of becoming CH. Initially, the crisp inputs and mapped into appropriate fuzzy sets. The linguistic variables for the input variables and the respective values are shown in table1.

Table 1 Parameters and the linguistic variables

Parameters	*Linguistic variables*
Residual energy	Low, Medium, High
Distance to BS	Close, Medium, Far
Probability of becoming CH	Very large, Large, Rather large, Medium large, Medium, Medium small, Rather small, Medium Small, Very small

The proposed method uses triangular and trapezoidal membership functions. Trapezoidal membership functions are used for border values and triangular membership functions are used for intermediate values. The rule base table of the proposed system is shown in Table 2. For example, IF (Energy ==Low) AND (Distance ==Close) THEN (Probability== Very High). Likewise, rule base table have 27 rules.

Table 2 Fuzzy rule base table

Rule no	*Residual energy*	*Distance to BS*	*Prob. of becoming CH*
1	Low	Close	Very high
2	Medium	Close	High
3	High	Close	Rather high
4	Low	Medium	Medium high
5	Medium	Medium	Medium
6	High	Medium	Medium low
7	Low	Far	Rather low
8	Medium	Far	Low
9	High	Far	Very low

Crisp inputs are transformed into fuzzy sets by applying the fuzzification functions then combined with if-then rules to get the fuzzy output. Defuzzification process transforms the fuzzy output probability to a crisp value representing the probability of a node to become a cluster-head. Once the probability of becoming CH is determined by fuzzy logic, BS broadcasts its

probability to all nodes. The nodes receive the message and identify its probability. The nodes advertise the probability value to its neighbors within the communication range. When no higher probability message is received by a node, it elects itself as CH. The CH broadcasts its status to its neighbors. The nodes receiving the CH message, joins the cluster as cluster member. After the formation of clusters, cluster member sense the value and forwards to CH. CH receives the data and aggregates into a single packet. CH forwards the aggregated packet to BS via intermediate CHs.

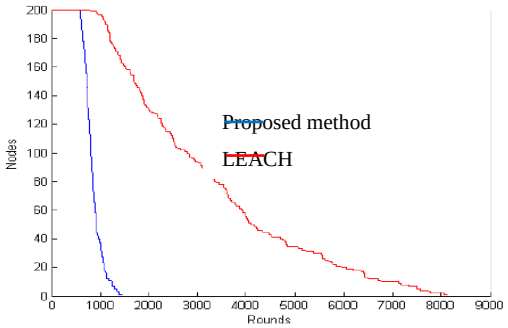
5. Simulation results and discussion

The proposed method is simulated and results are evaluated using MATLAB. The proposed method is compared with the well known existing clustering protocol LEACH. The extensive experimental results show that the performance of the proposed method is better than LEACH in terms of energy consumption and network lifetime. The simulation parameters are listed in Table 3. We have randomly deployed 100 sensor nodes in a region of 200x200m^2.

Table 3 Simulation Parameters

Parameter	*Value*
Area	200x200m^2
Number of sensor nodes	100
Initial energy	0.5 J
E_{elec}	50nJ/bit
$_{fs}$	10 pJ/bit/m^2
$_{mp}$	0.0013 pJ/bit/m^4
Packet size	4000 bits

The number of alive nodes for several rounds is shown in Fig 4. From Fig 4, it is clear that the number of alive nodes is high for the proposed method than LEACH. LEACH selects the CHs randomly and does not include any node parameter for CH selection. Fuzzy logic uses residual energy and distance to BS to compute CH selection. This result to effective selection of CH and the nodes operates for longer time than normal. This leads to the increase in number of alive sensor nodes in the network. The energy consumption of the proposed method is compared with the LEACH is shown in Fig 5. It shows the energy consumption of the proposed system is lower than LEACH. The increase rate of energy consumption of the proposed system is much lower than the rate of LEACH. The sensor node in the proposed method consumes lesser energy compared to LEACH. This proves that the dynamic CH selection using fuzzy logic performs well and produces better results than LEACH.



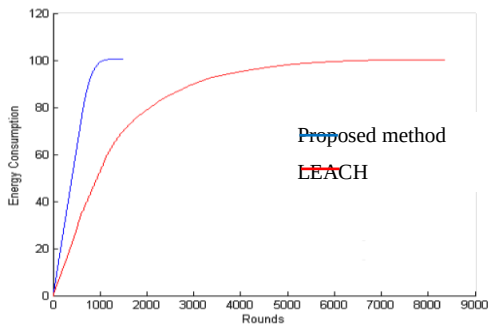


Fig 4. Number of alive sensor nodes Fig 5. Energy consumption of sensor nodes

6. Conclusion

In this paper, fuzzy logic based dynamic CH selection is done in WSN. The residual energy of the sensor node and the distance between sensor node and BS is used as fuzzy input parameters and the probability of becoming CHs is the output parameter. The proposed method is simulated and the proposed method is compared to LEACH. The experimental results show that the proposed method produces better results than LEACH. The proposed method is compared to LEACH interms of energy consumption and network lifetime. The fuzzy based CH selection minimizes the energy consumption and maximizes the network lifetime significantly.

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