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Cluster head selection scheme using fuzzy based prediction for wireless sensor networks based on leach-ere algorithm

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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. Current clustering approaches often use two methods: selecting cluster heads with more residual energy, and rotating cluster heads periodically, to distribute the energy consumption among nodes in each cluster and extend the network lifetime. Most of the previous algorithms have not considered the expected residual energy, which is the predicated remaining energy for being selected as a cluster head and running around. A fuzzy-logic-based clustering approach with an extension to the energy predication has been proposed to prolong the lifetime of WSNs by evenly distributing the workload.

I. INTRODUCTION

A wireless sensor network (WSN) consists of a large number of distributed sensor devices those are used to collect data from the environment to monitor different types of environmental or physical conditions. Wireless Sensor Networks 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 these sensor devices are equipped with non-rechargeable batteries, energy efficiency is a major design issue in order to increase the life-time of sensor networks.

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. Cluster-based design conserves the energy of the sensor devices since only some nodes, called Cluster Heads (CHs), are allowed to communicate with the base station. The CHs collect the data sent by each node in that cluster, compress it, and then transmit the aggregated data to the base station, thereby increasing the network lifetime [3].

In order to overcome the problem of the limited power of the sensor battery and thus prolonging the lifetime of a Wireless Sensor Network (WSN), many routing algorithms were proposed to gather and forward the sensed data to the base station. Low - Energy Adaptive Clustering Hierarchy (LEACH) protocol [4] [5], which uses a pure probabilistic model to select CHs and rotates the CHs periodically in order to balance energy consumption is one of the well-known routing algorithms. It is a dynamic cluster-based routing protocol that divides the network lifetime to rounds where each round is composed of two phases: setup and steady state. The key factor of each round is the number of nodes that will act as cluster heads (CHs). Each CH is responsible for collecting the sensed data from the sensor nodes that are in the same cluster and then forwarding the aggregated data to the base station.

One of the most important weaknesses of LEACH is load unbalance, i.e. as the CHs are selected randomly, some nodes may be selected as CHs, which are in close proximity of each other. This specifies the fact that the CHs are not evenly distributed over the network, which constrains to maximize the energy efficiency.

To overcome the defects of LEACH, Gupta *et al.*[6] proposed to use three fuzzy descriptors (residual energy, concentration, and centrality) during the cluster-head selection. The concentration means the number of nodes present in the vicinity, while the centrality indicates a value which classifies the nodes based on how central the node is to the cluster.

Kim *et al.* [7] proposed a similar approach (namely CHEF: Cluster Head Election mechanism using Fuzzy logic), but in a distributed manner by using two fuzzy descriptors (residual energy and local distance). The local distance is the total distance between the tentative CH and the nodes within predefined constant competition radius.

Anno *et al.* [8] employed different fuzzy descriptors, including the remaining battery power, number of neighbour nodes, distance from cluster centroid, and network traffics, and evaluated their performance.

Taheri et al. [9] proposed an energy-aware distributed dynamic clustering protocol (ECPF), which uses multi-hop communication along with fuzzy technique. Here, the clustering process is divided into three phases. In first phase, neighbour information is updated and fuzzy output is computed. During second phase, each node waits until finish the delay time to hear the CH-message from any other sensor nodes. If it cannot, it declares itself as a tentative-CH and broadcast CH-message within its cluster range. Although ECPF shows better performance than existing protocols, it has more computation complexity.

Bagci and Yazici [10] proposed another fuzzy based protocol named as EAUCF (Energy-Aware Unequal Clustering with Fuzzy), where the selection of tentative CH is almost like LEACH. The competition radius of the tentative CH is calculated using fuzzy logic. EAUCF shows better performance than LEACH.

In addition to the residual energy, the expected residual energy (ERE) has been introduced to act as a fuzzy descriptor during the on-line CH selection process. In order to estimate the ERE, the expected energy consumption (EEC) is required. The proposed approach adopts the LEACH [4]-[5] architecture with an extension to the energy predication based on the ERE, and thus the approach is named LEACH-ERE.

II. PREDICATION OF THE ENERGY CONSUMPTION

A. *LEACH Clustering Algorithm*

LEACH (Low Energy Adaptive Clustering Hierarchy) is one of the popular cluster-based structures, which has been widely proposed in wireless sensor networks. The operation of LEACH is divided into periods and each period consists of a set-up phase and a steady-state phase. During the setup phase, nodes communicate with short messages and are organized into clusters with some nodes selected as cluster heads.

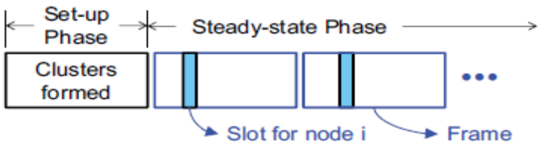


Fig. 1. Cluster formation and operation.

The set-up phase is followed by a steady-state phase when data are transferred from the nodes to the CH and on to the base station. LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. Each node *i* elects itself to be a CH at the beginning of round *r* +1 (which starts at time *t*) with probability *Pi(t)*. *Pi(t)* is chosen such that the expected number of CHs for this round is *k*. If there are *N* nodes in the network, each node would choose to become a CH at round *r* with the probability as (1).

$$P_i(t) = \begin{cases} \frac{k}{N-K*\left(r \bmod \frac{N}{K}\right)} & : C_i(t) = 1 \\ 0 & : C_i(t) = 0 \end{cases} \quad (1)$$

Where *Ci(t)* is the indicator function determining whether or not node *i* has been a CH within the most recent (*r* mod *N*/*K*) rounds (*Ci(t)* = 0 means node *i* has been a CH). Thus, only nodes that have not already been CHs recently (i.e. *Ci(t)* = 1) may become CHs at round *r* + 1.

B. *Radio Model for Energy Analysis*

In this paper, the first-order radio model has been adopted to model the energy dissipation for transmission and reception. The nodes are assumed to have power control features so as to adjust their transmit power to the minimum level required for successful transmission.

As the distance between the transmitter and receiver is less than a threshold value d_0, the free space model (d_2 power loss) is employed. Otherwise the multipath fading channel model (d_4 power loss) is used. Equation (2) shows the amount of energy consumed for transmitting *l* bits of data to *d* distance, while (3) represents the amount of energy consumed for receiving *l* bits of data.

$$E_{\mathrm{Tx}}(l,d) = \begin{cases} l * E_{\mathrm{elec}}^{\mathrm{Tx}} + l * \varepsilon_{\mathrm{fs}} * d^2, d < d_0 \\ l * E_{\mathrm{elec}}^{\mathrm{Tx}} + l * \varepsilon_{\mathrm{mp}} * d^4, d \geq d_0 \end{cases} \quad (2)$$

$$E_{\mathrm{Rx}}(l) = l * E_{\mathrm{elec}}^{\mathrm{Rx}} \quad (3)$$

$E^{Tx}{}_{elec}$ and $E^{Rx}{}_{elec}$ are the energy consumption per bit in the transmitter and receiver circuits. ε_{fs} and ε_{mp} are the energy consumption factor of amplification for the free space and multipath radio models, respectively. The threshold value d_0 could be obtained via (4).

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}. \qquad (4)$$

C. *Expected Residual Energy*

Before the cluster formation, the number of cluster members is unknown. However, since it is proportional to the number of neighbours near a potential CH (in a specific transmission range), the number of neighbours (defined as value *n)* could be used to obtain the expected energy consumption during the CH selection. After the cluster formation, the steady-state operation is broken into frames, where nodes send their data to the CH at most once per frame during their allocated transmission slot. In a frame, suppose a CH has *n* cluster members, it would receive *n* messages from all the members and then transmit one combined message to the base station with a distance d_{toBS}. The number of frames could be obtained by (5).

$$N_{frame} = \frac{t_{ssPhase}}{n * t_{slot} + t_{CHtoBS}} \qquad (5)$$

where, $t_{ssPhase}$ is the operation time of the steady-state phase (i.e. the time of a node to be a CH), t_{slot} is the slotted time required for the transmission from members to the CH, and t_{CHtoBS} is the time required for the transmission from CH to the base station. The expected consumed energy of a node to be a CH after a steady-state phase could be represented as (6).

$$E_{expConsumed}(l, d_{toBS}, n) = N_{frame} * \big(E_{Tx}(l, d_{toBS}) + n * E_{Rx}(l)\big). \qquad (6)$$

All the sensor nodes are assumed to transmit and receive the same size of messages, i.e. *l* bits of data. The distance to the base station, d_{toBS}, could be computed based on the received signal strength. Then, the expected residual energy of a node to be a CH after a steady-state phase could be obtained via (7).

$$E_{expResidual}(l, d_{toBS}, n) = E_{residual} - E_{expConsumed} \qquad (7)$$

Where, the $E_{residual}$ is the residual energy of a sensor node before the cluster head selection.

III. PROPOSED CLUSTERING APPROACH

A. System Assumptions

1) All sensor nodes and the base station are stationary after deployment.
2) The network is considered homogeneous and all sensor nodes have the same initial energy.
3) Nodes have the capability of controlling the transmission power according to the distance of receiving nodes.
4) The distance between nodes can be computed based on the received signal strength.
5) The radio link is symmetric such that energy consumption of data transmission from node A to node B is the same as that of transmission from node B to node A.

B. Fuzzy Inference Systems

The model of fuzzy logic control consists of a fuzzifier, fuzzy rules, fuzzy inference engine, and a defuzzifier. The process is performed in four steps:

1. Fuzzification of the input variables energy, concentration and centrality - taking the crisp inputs from each of these and determining the degree to which these inputs belong to each of the appropriate fuzzy sets.
2. Rule evaluation - taking the fuzzified inputs, and applying them to the antecedents of the fuzzy rules. It is then applied to the consequent membership function (Table 1).

. Aggregation of the rule outputs - the process of unification of the outputs of all rules.

4. Defuzzification - the input for the defuzzification process is the aggregate output fuzzy set *chance* and the output is a single crisp number. During defuzzification, it finds the point where a vertical line would slice the aggregate set *chance* into two equal masses.

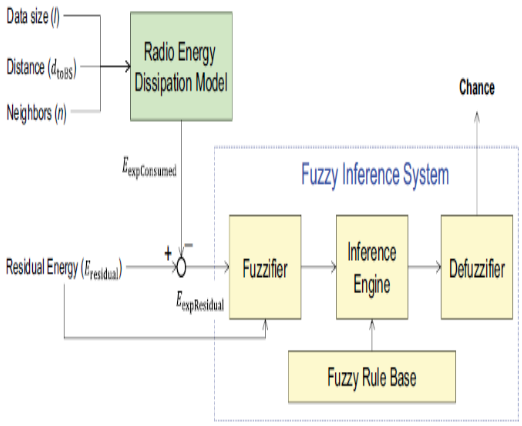


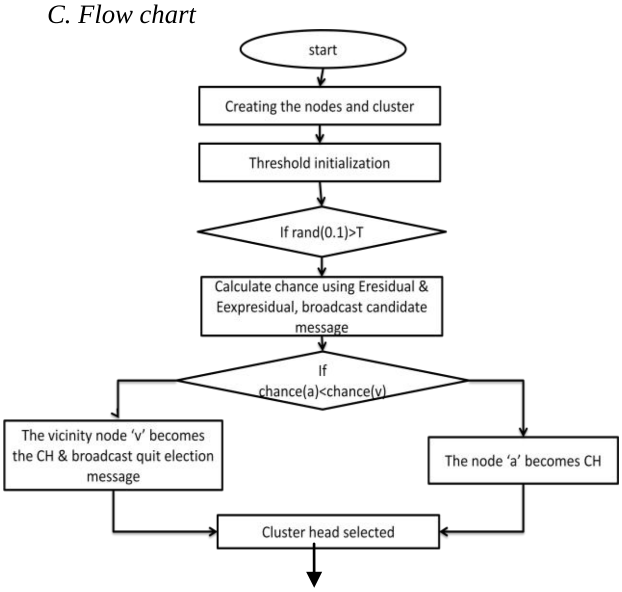
Fig. 2. Proposed scheme of the probability reasoning during cluster head selection.

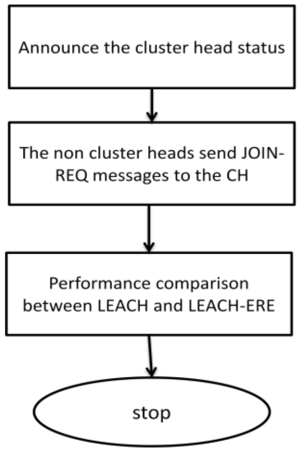
Table 1
Fuzzy mapping rules

	residual energy	ERE	chance
1	High	High	Very high
2	High	Medium	High
3	High	Low	Medium
4	Rather high	High	High
5	Rather high	Medium	Rather high
6	Rather high	Low	Medium
7	Medium	High	Medium
8	Medium	Medium	Medium
9	Medium	Low	Rather low
10	Rather low	High	Very low
11	Rather low	Medium	Medium
12	Rather low	Low	Rather low
13	Low	High	Very low
14	Low	Medium	Very low
15	Low	Low	Low
16	Very low	High	Very low
17	Very low	Medium	Very low
18	Very low	Low	Very low

The *chance* calculation is accomplished by using predefined fuzzy if-then mapping rules to handle the uncertainty. Based on the two fuzzy input variables, 18 fuzzy mapping rules are defined in Table I. From the fuzzy rules, the fuzzy variable *chance is obtained.* This fuzzy variable has to be transformed to a single crisp number that is a form we can use in practice. In my approach, the center of area (COA) method is used for defuzzification of the *chance*. Generally, fuzzy rules can be generated either from heuristics or from experimental data. In this paper, the heuristic fuzzy rule generation method is used with the principle: A node which holds more residual energy and more ERE has a higher probability to become a CH.

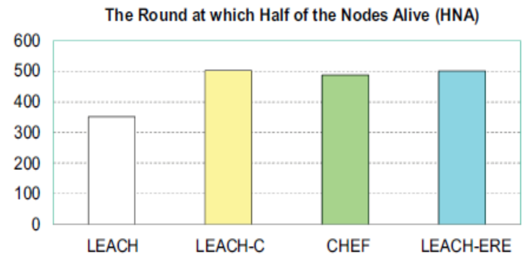
C. Flow chart





IV. Simulation results

The metric *Half of the Nodes Alive* (HNA) which denotes an estimated value for the round in which half of the senor nodes die. This metric is useful in densely deployed sensor networks. As shown in Fig. The proposed LEACH-ERE approach outperforms LEACH and CHEF. LEACH-ERE is more efficient than LEACH about 42.61% and CHEF about 2.87%. LEACH performance is the poorest one, since it does not consider the residual energy level of sensor nodes during clustering. Moreover, the distributed LEACH-ERE has the similar performance as compared with the centralized LEACH-C.



V. Conclusion

In this project, a fuzzy logic- based clustering approach based on LEACH architecture with an extension to the energy predication has been proposed for WSNs, namely LEACH-ERE. The main objective of algorithm is to prolong the lifetime of the WSN by evenly distributing the workload. To achieve this goal, the focus is on selecting proper CHs from existent sensor nodes. LEACH-ERE selects the CHs considering expected residual energy of the sensor nodes.

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