Energy Efficient Fuzzy Logic based Clustering Algorithms in Wireless Sensor Network: A Survey

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Abstract –Wireless sensor network (WSN) is a network comprised of distributed autonomous devices called sensor nodes which are capable of sensing or monitoring environmental or physical conditions. Wireless sensor networks come across many challenges such as limited battery life, data aggregation and fusion, energy aware routing, security, task scheduling, localization and optimal deployment. In wireless sensor network, fuzzy logic has been successfully used in various disciplines such as clustering, MAC protocol and deployment. This paper presents a survey of clustering techniques with fuzzy logic which associates advantages of scalability, energy conversation and localized control.

Index Terms –Wireless Sensor Network; Energy; Fuzzy Logic; Cluster Head; Clustering

1. INTRODUCTION

Wireless sensor network (WSN) is a network comprised of distributed autonomous devices called sensor nodes which are capable of sensing or monitoring environmental or physical conditions. Sensor nodes are equipped with computing and sensing devices, power components and a radio transceiver which enable nodes to communicate using radio signals .WSNs are designed for specific applications ranging from small-size healthcare surveillance systems to large scale environmental monitoring. Sensor nodes have major constraints in terms of memory storage, computational capabilities, low communication bandwidth and limited power supply. The foremost concern in WSN is to control power consumption as being a microelectronic device, sensor node is equipped with a limited power source (<0.5 Ah, 1.2 V) [1]. These nodes will simply be discarded once their energy source is exhausted. The strategy applied to energy consumption is affected by the fact that whether the battery can be recharged or not. In case of non-rechargeable batteries, wireless sensor node should function until its mission time has passed. The interval of the mission time depends on the type of application. In various applications, when nodes are deployed in harsh conditions; replenishment of battery becomes a difficult task. Sensor node involves the detection of events in sensor field then performing local data processing and last but not the least transmitting the collected data to the destination. Therefore, energy consumption can be divided into three domains: sensing, processing of data and communication [1].

Typically, clustering is the technique chosen to reduce the energy consumption and extend the network lifetime. In clustering, nodes are grouped into clusters. Each cluster contains cluster head. All nodes pass their sensor information to cluster head which perform data aggregation and send only relevant data to sink as shown in figure1.

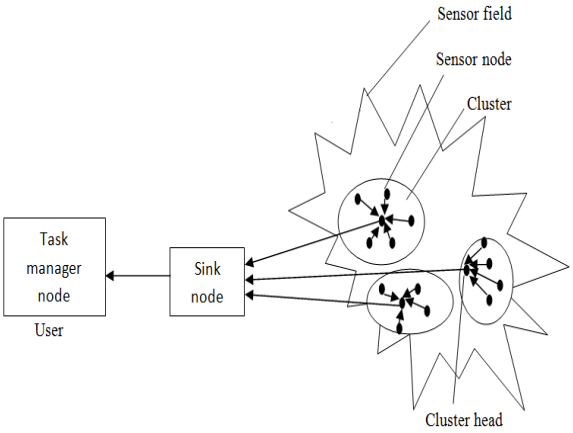

Figure 1: Clustering in WSN

LEACH (Low Energy Adaptive Clustering Hierarchy) [2] is the basic protocol for selecting cluster head which in turn increase network lifetime. Fuzzy logic is defined as logic underlying approximate, rather than exact, modes of reasoning. It is an extension of crisp logic. Fuzzy logic system for selection of cluster head can manipulate linguistic rules in mathematical form which makes real time decision.

Rest of the paper is organized as follows: Section 2 provides you a brief overview of fuzzy logic. Section 3 gives detailed view of different clustering algorithms. Section 4 summarizes this paper.

2. OVERVIEW OF FUZZY LOGIC IN WSN

The approximate reasoning which is measure of uncertainty that is defined by the use of linguistic variables such as most, high, medium, close etc is modeled by fuzzy logic. Fuzzy

logic provides flexibility of using partial set membership to draw conclusions. Fuzzy logic control constitutes fuzzifier, fuzzy rules, fuzzy inference engine and a defuzzifier as shown in figure2.l.

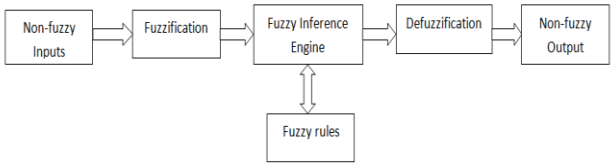

Figure 2: Elements of Fuzzy Logic

Crisp values are provided at the input. Mapping of the non fuzzy inputs to their fuzzy representation occurs in the process of fuzzification which is given to fuzzy inference system. Fuzzy inference system consists of fuzzy sets and fuzzy rules .The fuzzified output is then converted into crisp or non fuzzy output by defuzzifier. Fuzzy logic is relatively simple, adaptive and less sensitive to system fluctuations. These features have made fuzzy logic suitable for giving its contribution in various areas such as deployment [3], clustering [4] and redundancy reduction [5]. There are various routing protocols such as FEAR (Fuzzy- based energy aware routing) [6] which use fuzzy model.

correctly.

3. VARIOUS CLUSTERING ALGORITHMS USING FUZZY LOGIC

In algorithm [7] zone formation along with cluster formation is done. The zones are considered to be collection of clusters. To balance the actual time load of network clusters or zones are reformed. After resources are checked, zone denies the request of new node for joining it, as that cluster or zone is unable to accommodate a new node. On the other hand if it has adequate resources, it allows the new node to join the cluster or zone. Fuzzy logic is used by the node to decide its best parent when it receives multiple advertisement messages from cluster heads or zone heads to be the part of their clusters. Energy level, quality of link, mobility and quality of received signal are the fuzzy variables which decide the reliability of cluster head. Chance is the ratio of reliability to the level with different levels of cluster heads which indicates node at low level has high chance of selection.

Algorithm [8] is a centralized algorithm in which a fuzzy logic approach for cluster head selection is there in which the base station has ability of deciding cluster heads. In this algorithm, each node sends its location information to base station. Cluster head election is based on three fuzzy input parameters - node concentration, node energy and centrality. With these three input parameters and (3^3) 27 fuzzy rules, Mamdani method is used by fuzzy inference engine for calculating the chance to become a cluster head. This approach is more apt for cluster-head election for medium sized clusters.

In most of the algorithms expected residual energy is not considered. In this algorithm [9], a clustering approach based on fuzzy logic with extension to energy prediction is present.The serious disadvantage of LEACH [2] is that it does not consider the energy of node during selection of cluster head and a node with poor energy could be chosen as the cluster head. For successfully dealing with this shortcoming, residual energy and expected residual energy are the two fuzzy parameters taken under consideration in this algorithm. The expected residual energy (ERE) of node to be cluster head after a steady-state phase is given by equation (1).

$$E_{expResidual} = E_{residual} - E_{Consumed} \quad (1)$$

where $E_{residual}$ is residual energy of sensor node before the cluster head selection, l bits of data gives the size of messages, d is distance to base station which is calculated on the bases of received signal strength and n is number of neighbors and $E_{Consumed}$ is expected consumed energy of a node which is to be cluster head after steady state phase. The calculation of chance is done by using predefined fuzzy if–then mapping rule in order to avoid uncertainty. In order to have high probability for node of being cluster head, higher should be the chance.

HERF [10] being considered a routing algorithm performs cluster head selection process prior to routing. Clustering is carried out by using the fuzzy logic concept with three fuzzy variables energy of node, node centrality and node concentration as in [8]. In this algorithm the node energy is given preference while cluster head selection process is carried out. Node energy is defined as the ratio of residual energy to final energy. A node cannot broadcast itself as a candidate if this ratio becomes zero. Fuzzy inference engine having 27 fuzzy rules decides chances of nodes to be cluster head and the node with highest chance is chosen to be cluster head. Sensor node assigned as cluster head advertise by sending message to other nodes present in cluster to represent itself as cluster head.

In algorithm [11], an enhanced LEACH protocol using fuzzy logic is proposed. It is one of the centralized algorithm in which cluster head selection is done by base station. The three fuzzy input parameters energy of node, node density and node concentration are taken which decides the possibility of node to become the cluster head. Calculation of node density is done on the bases of distance of node to the base station and this leads to unevenness to head selection method. Here the node with close density, high energy and high concentration is

preferably chosen to be the cluster head. Base station is responsible for cluster head selection on the basis of global information but lot of energy is consumed in sending sensor node information to base station.

Algorithm [12] is a centralized algorithm which applies fuzzy logic for selecting cluster head. Head selection mechanism is carried out in base station. In order to select suitable cluster head, energy level of node and its distance to the base station are the two parameters considered by base station and they act as the two inputs to fuzzy inference system. According to fuzzy rules, fuzzy inference system computes and gives output in terms of fitness of each node to be cluster head then based on fitness for each node, base station selects cluster head according to $p \times$ total number of nodes. In linguistic terms, if the energy of one of the node is high and its distance is middle then fitness is very large and that node has more chance of becoming cluster head.

In algorithm [13], distributed approach is considered. Local distance which is given as sum of distance between node and nodes within the distance 'r' and energy are the two fuzzy variables taken as inputs for calculation of chance. Here $'r'$ is the radius of preferred cluster head and is given as in equation (2), where n is the total number of nodes.

$$r = \sqrt{\frac{a}{(\pi.n.p)}} \qquad (2)$$

Wireless sensor nodes generate random number between 0 and 1.When the random number generated by the node is less than P_{opt} which is calculated as in equation (3) then chance with fuzzy rules is calculated.

$$P_{opt} = p * \alpha \qquad (3)$$

Where, α is the constant and p is defined as the ratio of preferred number of cluster heads. The node with the value of chance advertises for itself by sending a candidate message and making itself as one of the contender of becoming a cluster head. The node waits for some limited span of time for the acknowledgement from other nodes, and if no acknowledgement in form of candidate message having higher value of chance than itself is received by the node then that node broadcasts itself as cluster head. When talking in linguistic terms, a node with low local distance and high energy is selected as cluster head.

Algorithm [14] uses significant features of both LEACH and fuzzy logic and is categorized as one of the distributed clustering approach for homogenous network. Number of neighbors, energy remaining, centrality, rounds which have not been cluster head and number of received signals are the five fuzzy input variables taken in account to obtain output in terms of chance of node to be cluster head. The output is given as very low, low, medium high, very high. Centrality is calculated as the sum of distance between provisional cluster head and its neighbors. The node is more central when the distance is less. Defuzzification is done using method of Center of area.

Algorithm [15] is an improvement on LEACH protocol which combines various metrics to adjust its setup phase. The probability of becoming a cluster-head candidate is determined by each node on the bases of two input variables the distance of nodes to base station and the energy remaining of node using fuzzy logic through Takagi-Sugeno system which deals with various uncertainties in the estimations. Each node generates a random number between 0 and 1, then a decision whether that node could be cluster head is made according to the judgment in which generated random number is compared with the probability and a sampling rate α given by equation (4).

$$\alpha = 2 \times \frac{nClH}{100} \qquad (4)$$

The desired number of cluster head of a network is given as $nClH$. If that random number is less than probability and sampling rate α, node presents itself as a cluster head candidate for the ongoing round and an advertisement message having information of probability is broadcasted by node, then the received probabilities are sorted by each node after which is performed sampling according to α and then that node went to become the cluster head. This algorithm gives better distribution of nodes of network on clusters.

Algorithm [16] is engaged in choosing cluster-head by performing calculations of the probability for every node, which deals with the fuzzy rule uncertainties better than in algorithm [15] and also a fixed competition radius is introduced to make cluster heads more balanced. For calculating the competition radius, multiple of the best radius of clusters denoted as R_{opt} is used and R_{opt} is given as in equation (5).

$$R_{opt} = \sqrt{\frac{a}{\pi \times C_{opt}}} \qquad (5)$$

In equation (5), a is the area of wireless sensor network and C_{opt} is the optimal number of cluster heads. It is a centralized clustering algorithm in which base station elects the cluster heads by considering three parameters—the residual energy, the distance to base station and the number of neighboring nodes of each node within a fixed radius. Probability of every node to be cluster head is computed by base station using a type-2 TSK FLS (Takagi-Sugeno-Kang Fuzzy Logic System) and the final cluster heads are selected as per the probability and the competition radius.

Algorithm [17] is reliable clustering algorithm which uses fuzzy petri nets for cluster head selection. The number of the neighbors, residual energy and centrality of each node are the input variables for fuzzy production rules and output variable is the chance of node to be elected as cluster head. An example of fuzzy petri model is given as in figure 3 [17]. The chance is obtained when transition t is enabled and fires. Here, f is the threshold of a transition firing.

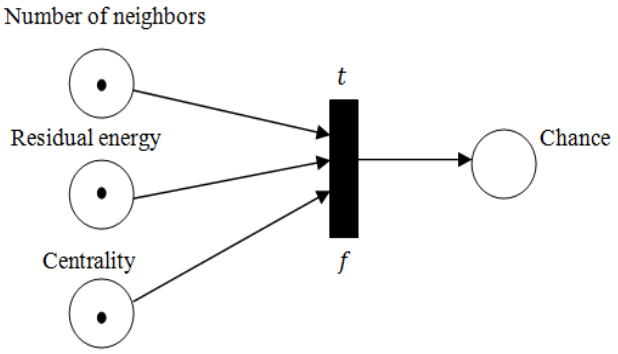

Figure3: Fuzzy petri nets model for cluster head selection.

Each node gets the fuzzy variable chance. As per the cluster head selection chance, every node gets some definite amount of time to broadcast an advertisement message for declaring itself as a candidate to be cluster head. When a sensor node does not receives advertisement message before that definite phase of time, it broadcasts itself as a contender of being cluster head and if node receives some advertisement message before the time expires it withdraw itself from the competition for cluster head. A table having all the candidates cluster head is constructed and node with maximum chance is elected as cluster head. In some cases when a number of nodes have maximum chance to be cluster head, the node with more energy is elected as cluster head. in this section. This section gives the original contribution of the authors. This section should be written in Times New Roman font with size 10. Accepted manuscripts should be written by following this template. Once the manuscript is accepted authors should transfer the copyright form to the journal editorial office. Authors should write their manuscripts without any mistakes especially spelling and grammar.

4. CONCLUSION

Primarily, overview of wireless sensor network along with the basic definition of clustering is stated. This paper gives the description of the basics of fuzzy logic. Various clustering algorithms which use the concepts of fuzzy logic in wireless sensor network are given in this paper. Applications of fuzzy logic in wireless sensor networks are also mentioned in the paper. Furthermore fuzzy logic along with other computational techniques could be combined to form hybrid techniques for energy efficient clustering.

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