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A METHOD FOR OPTIMIZING OF THE ENERGY CONSUMPTION IN WIRELESS SENSOR NETWORKS BY DYNAMIC SELECTION OF CLUSTER HEAD USING FUZZY LOGIC

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ABSTRACT

Clustering is an effective approach for organizing wireless sensor networks into a load balancing and prolonging the network lifetime. Selecting appropriate cluster heads, the number of clusters and how they are formed are always important parameters for proposed clustering algorithms. Due to the lack of complex computation in fuzzy systems, fuzzy logic can be a proper method for clustering which reduces the calculating overheads. In this paper, by using fuzzy logic a method,is proposed for optimized network clustering. In this method, each sensor node calculates a suitability degree for itself by fuzzy inference system with the residual energy, number of neighbors and centrality parameters. Unlike most methods that perform re-clustering in all rounds, In this method re-clustering occurs only when there is a relative decrease in the energy level of cluster head nodes. Simulation results demonstrate that the proposed method performs better than well-known LEACH and CHEF protocols in terms of extending network lifetime and saving energy.

KEYWORDS: Wireless Sensor Networks - Clustering - Fuzzy Logic- Energy - Network Lifetime

Recent advances in miniaturization and low-power design have led to the development of small-sized battery operated sensors that are capable of detecting ambient conditions such as temperature and sound. Sensors are generally equipped with data processing and communication capabilities. The sensing circuitry measures parameters from the environment surrounding the sensor and transforms them into an electric signal. Such technological development has encouraged practitioners to design the limited capabilities of the individual sensors in a large scale network that can operate unattended [Abbasi, 2007].Wireless sensor networks have plenty of advantages. The deployment of WSNs are easier and faster than the wired sensor networks or any other wireless networks, because they do not need any fixed infrastructure. Wireless sensor networks do not require a central organization and they are self-configuring. Sensor nodes consume energy for receiving, processing and transmitting information while in most of the cases, these sensor nodes are equipped with batteries which are not rechargeable[Bagci,2010]. Despite sensor nodes with constrained energy and their non-rechargeable batteries, it is obvious that specialized energy-aware routing and data gathering protocols offering high scalability should be applied in order that network lifetime be preserved acceptably high in such environments. Naturally, grouping sensor nodes into clusters has been widely adopted by the research community to satisfy the above scalability objective and generally achieve high energy efficiency and prolong network lifetime in large-scale WSN environments. In the hierarchical network structure each cluster has a leader, which is also called the cluster head (CH) and usually performs the special tasks such as composition and aggregation of data, and several common sensor nodes as members [Zhang,2010].A Cluster head collects data from nodes within the cluster and aggregates the data and report the aggregated information to the base station. By making only the CH communicate with the base station, the overheads that can be occurred if all nodes in that cluster communicate with the base station would be reduced.[Kim,2008] Because CHs often transmit data over longer distances, they lose more energy compared to member nodes. Changing cluster heads among the network nodes is a solution for balancing energy consumption in the network [Younis,2006].

Dynamic nature of wireless sensor networks and changing cluster heads in each round of network activity have led to their modeling are difficult with the classical methods of mathematical. Because of the influence of various parameters on increasing lifetime of WSN, Intelligent techniques with high flexibility can be a good alternative for mathematical systems. Fuzzy logic, as one of the artificial intelligence techniques, is capable of making real time decisions, even with incomplete information. Merging different environmental parameters according to predefined rules and then making a decision based on the result is another important application of fuzzy logic. [Gupta,2005.Taheri,2012]

This paper proposes an optimized method to reduce energy consumption and increase the lifetime of WSN by using fuzzy logic. The proposed method uses a

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fuzzy inference system and "if -then" rules for clustering and selecting cluster heads. The rest of this paper is organized as follows: section 2 presents an overview of the related works, the proposed method is described in section3, section4 presents the simulation and evaluation results and finally the conclusions are given in Section 5.

RELATED WORKS

Many researchers have been done on clustering sensor nodes which offer novel methods of clustering. The main difference between these methods is how to select cluster heads. The first and most popular clustering protocols proposed for WSN is the LEACH [Heinzelman,2000].LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. The operation of LEACH is divided into rounds and each round consists of setup phase and the steady state phase. In the setup phase, the clusters are organized and cluster heads are selected. Each sensor node generates a random number between 0 and 1. If this number is smaller than the threshold value T(n), the sensor node elects itself as a CH. Equation (1) defines the T(n) where P is the requested ratio of the cluster heads in the WSNs and r is the count of current round. The G is the set of sensor nodes that were not elected as a cluster head in last 1/p rounds.

$$\begin{cases} T(n) = \frac{P}{1-P\left[r \bmod \left(\frac{1}{P}\right)\right]} & n \in G \\ 0 & \text{else} \end{cases} \quad (1)$$

After cluster heads election, the CHs broadcast an advertisement message to the whole network and other nodes select the closest CH based on the received signal strength and join to it. Despite the good performance of the LEACH, the protocol has some problems. Because of probability model, the elected cluster heads in some places may be very close each other and in some places may not be any cluster head. LEACH does not consider the energy remains of each node so the nodes that have relatively small energy remains can be the CH.

The improved LEACH algorithm [Tang,2011] mainly considers the network lifetime and makes improvement on LEACH. This algorithm like LEACH is divided into rounds that during the start-up phase each node generates a random number between 0 and 1 and has a threshold value. If the random number is smaller than the threshold value, the node identifies itself as cluster head. In other words, the threshold value decides which nodes can be cluster heads. This algorithm is improved LEACH function as follows:

$$T(n) = \frac{P}{1-P\left[r \bmod \left(\frac{1}{P}\right)\right]} * \frac{E_{current}(n)}{E_{max}} * \frac{\left\lceil \frac{r}{\frac{1}{P}} \right\rceil}{time_{ch}(n)+1} \quad (2)$$

Where $time_{ch}(n)$ is the number of times for which node n has been selected as a CH in the past rounds. In this method, the base station is presented as a cluster head and broadcasts a message with a zero ID in the network like other cluster heads. Improved algorithm by considering the residual energy of each node as compared to LEACH increases the network lifetime effectively, however, has been unable to fix some disadvantages of LEACH.

The HEED [Younis,2004] is different from LEACH in the manner in which CHs are elected. It proposes an iterative and distributed clustering. A candidate cluster head declares its status only the nodes that are in its radio range. Both electing CHs and joining clusters are performed based on the hybrid combination of two parameters. The primary parameter depends on the node's residual energy and selects candidate cluster heads. The alternative parameter is the intra-cluster communication cost and determines the final cluster heads. This cost are related to the cluster characteristics such as its size and power levels of data transmission. This algorithm uses a probabilistic model for CH elections.

The Gupta [Gupta,2005] introduces a cluster head election method using fuzzy logic to overcome the defects of LEACH. In this method, each node is aware of its location coordinates. Cluster heads are elected by the base station, based on the chance of each node in each round. For each node, a chance value is calculated using fuzzy inference system with input parameters: remaining energy, concentration and centrality by the base station. Base station selects the node with the highest chance as CH and broadcast the entire network. The generated overhead of sending and receiving information is much in network and there is only one selected CH for each round, whereas more CHs are needed for balancing energy consumption.

The CHEF [Kim,2008] is a fuzzy approach which performs cluster head election in a distributed manner. In every round, each node generates a random number between 0 and 1. If the random number is smaller than the predefined threshold, then that node becomes a candidate CH. Each candidate node calculates threshold value using a fuzzy inference system and two fuzzy descriptors: residual energy and local distance. CHEF prevents that any two cluster heads can exist within r distance using the candidate method. This method applies a probabilistic model for CH elections. Therefore, it is possible that cluster heads are not well distributed in the field.

The LEACH-FL [Ran,2010] protocol is the same as Gupta protocol for improving on LEACH protocol. The base station selects nodes with higher chance as cluster heads. This method uses three descriptors: node residual energy, node degree and distance from base station to calculate the chance value. If the chance is smaller than the predefined threshold, then that node becomes a cluster head.

The FLCFP algorithm [Mhemed,2011] presents a method for forming clusters. This algorithm operates much like LEACH and they differ in how the clusters are formed. In FLCFP non cluster head nodes calculate a value with fuzzy logic for each CHs. Three descriptors for this method are: energy level of the cluster head, distance from the base station and the distance between the cluster heads. A node joins the cluster head which is the highest value obtained.

The LEACH-ERE algorithm [Lee,2012] uses two descriptors: residual energy and expected residual energy (ERE) of the sensor nodes for calculating the chance value with fuzzy logic. The bigger chance means that the node has more chance to be a CH. In order to estimate the ERE, the expected energy consumption (EEC) is required. ERE in each round is difference between node residual energy and node EEC. In this algorithm, the number of clusters is fixed and determined at the start of networking.

The Two-Level clustering algorithm [A.Torghabeh,2010] uses fuzzy logic for clustering too. In this algorithm a two-level fuzzy logic is proposed to evaluate the qualification of sensors to become a cluster head. In local level the qualified nodes are selected based on their energy and number of neighbors of them. Then, in the global level these three parameters are considered as the inputs to the fuzzy system: centrality, distance from cluster heads to the base station and distances among all cluster heads. In this method using different input parameters lead to a better selection of CHs. However implementation of the two-stage fuzzy inference system wastes the time.

METHODOLOGY

Some assumptions about the sensor nodes and network model are:

- Sensors and the base station are all stationary after deployment.
- All nodes are homogeneous (i.e. the same energy resources) and have unique ID.
- The distance can be measured based on the wireless radio signal power.
- The base station has unlimited energy, computing power and high memory
- SensornodesarenotequippedwithGPSantennastheref oreunawareoftheircoordinates.

The process of network is broken up into rounds. Each round consists of start-up phase and data transfer phase.

Start-up phase

In start-up phase clusters are organized, the cluster heads are selected with fuzzy logic. At the end of this phase, each node is a CH or a member of the cluster. For selecting cluster head, each sensor node calculates a suitability degree using fuzzy logic. In the proposed method, the most commonly used fuzzy inference technique, called the Mamdani method is employed. The fuzzy system input variables are: residual energy, number of neighbors and centrality of each node. In every moment each sensor node is aware of its remaining energy.

The number of node neighbors is determined by the ADV message. In the beginning of network operation, each node publishes the ADV message around, Then using the return signal power and reply to messages, calculates its distance to the responding node. This is done using Received Signal Strength Indication (RSSI)technique [Vanheel,2011].

The neighbors of a node are sensor nodes that are located within a circle with radius R and the center of that node. A node's centrality parameter is the sum of distances between that node and its neighbors [Kim,2008].Because the nodes do not move, the number of neighbors and centrality parameters do not change during the network activity. Thus, these two parameters are calculated only at the beginning of network operation.

The membership functions of input parameters are depicted in Figures 1 to 3 and the membership function of output is depicted in figures 4. Triangular or trapezoidal membership functions are used to represent membership functions.

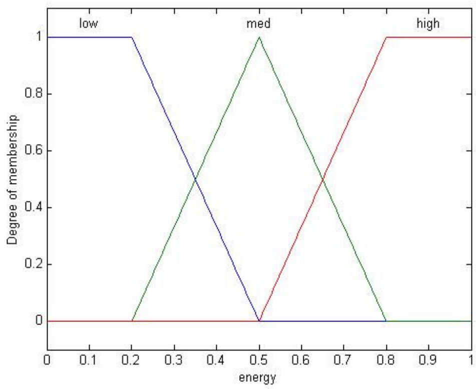

Figure 1: Energy

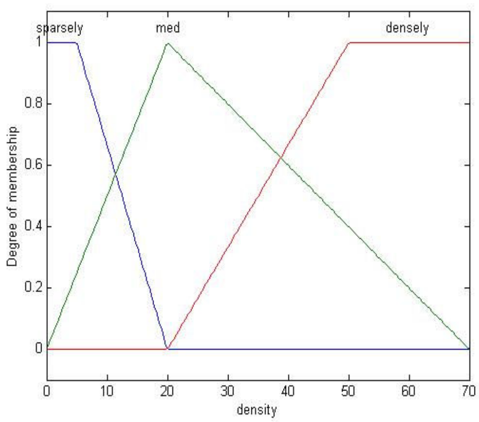

Figure 2: Number of neighbors (density)

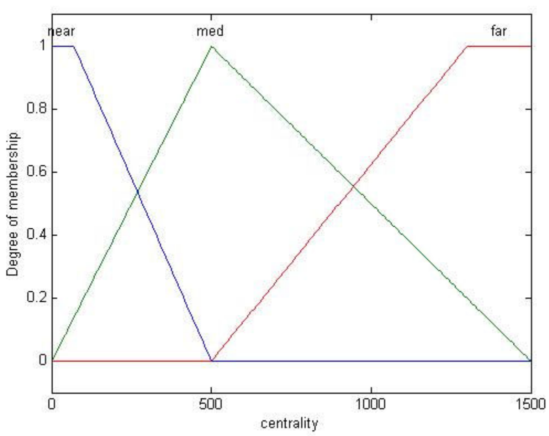

Figure 3: Centrality

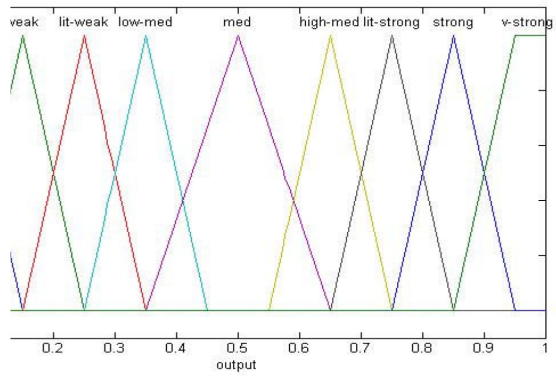

Figure 4: Output (suitability degree)

Since there are three parameters, each divided into three levels, 3^3=27 possible values can be computed using fuzzy "if-then" rules. These fuzzy if-then mapping rules are given in Table 1.From the fuzzy if-then rule, the fuzzy variable is produced. This fuzzy variable has to be transformed to the single crisp number until is used as a suitability degree for each node. This process is called defuzzification and the proposed method applies the COA (Center of Area) as a defuzzification method as demonstrated in the following Equation 3.

$$\mathrm{COA} = \frac{\int_Z \mu_A(z) z dz}{\int_Z \mu_A(z) dz} \qquad (3)$$

Table 1: Fuzzy Inference System if-then rules

energy	Density	Centrality	output
low	Sparsely	Far	very_weak
low	Sparsely	Med	weak
low	Sparsely	Near	little_weak
low	Med	Far	weak
low	Med	Med	little_weak
low	Med	Near	lower_medium
low	Densely	Far	little_weak
low	Densely	Med	lower_medium
low	Densely	Near	medium
med	Sparsely	Far	little_weak
med	Sparsely	Med	lower_medium
med	Sparsely	Near	medium
med	Med	Far	lower_medium
med	Med	Med	medium
med	Med	Near	higher_medium
med	Densely	Far	medium
med	Densely	Med	higher_medium
med	Densely	Near	little_strong
high	Sparsely	Far	medium
high	Sparsely	Med	higher_medium

high	Sparsely	Near	little_strong
high	Med	Far	higher_medium
high	Med	Med	little_strong
high	Med	Near	Strong
high	Densely	Far	little_strong
high	Densely	Med	Strong
high	Densely	Near	very_strong

To determine the cluster heads, each sensor node calculates the waiting time T by using equation 4 [Taheri,2012] where sd is the amount of the suitability degree of each sensor node and t_0 is a fixed value which is determined according to the physical conditions of the sensor circuit and minimum waiting time to start broadcasting cluster head ADV message [Tashtarian,2007].

$$T = \frac{1}{sd} * t_0 \qquad (4)$$

In this equation, since the suitability degree of each node is in the denominator so the sensors with higher sd obtain smaller T and can be cluster head. Each node waits time T. If in this period, the node does not get the ch_msg message from its neighbors as CH, it will send this message to neighbors in R radius. The nodes that receive this message do not send that. If a normal sensor node receives several messages, based on the received signal strength are joined to the closest cluster head. The largest signal strength is the CH to whom the minimum amount of transmitted energy is needed for communication[Heinzelman,2000].

During the clustering process, the non cluster head nodes must keep their receivers on to hear the advertisements of all the CH nodes. For message transmission over the network, sensor nodes use a CSMA/MAC protocol. Thus the cluster heads and cluster members are identified and completed start-up phase.

Data transfer phase

Similar to LEACH algorithm, in data transfer phase the network status is fixed and sensor nodes transmit data to the CHs and cluster heads send them to the base station.

Request re-clustering

After completing data transfer phase, re-clustering is begun in the new round. The best time for re- clustering can be when a relative reduction occurs in energy level of cluster heads. This decrease in energy level is determined by testing [Enami,2010].

Proposed method decreases overhead by performing the start-up phase on demand instead of in each round [Taheri,2012].So after completion of clustering at the end of each start-up phase, every CH saves its residual energy in a variable like Ech. Until the residual energy of each cluster head is greater than α*Ech(α is a constant number and $0 < \alpha < 1$), in each round just data transfer phase is run. During the data transfer phase, whenever a CH finds that its residual energy is smaller than α*Ech, it sets a predetermined bit in a data packet which is ready to be sent to the base station. Upon receiving this packet, the base station informs the sensors to run the start-up phase at the beginning of the next round. When every node receives this message, it prepares itself to perform clustering. As a result, the overhead created by start-up phase is reduced. This leads to a decrease in the energy dissipation of nodes and increase in network lifetime.

Simulation and evaluation results

The simulation of proposed method has been done in MATLAB and its fuzzy logic toolbar box and compared with clustering protocols of LEACH and CHEF. The Heinzelman proposed model [Heinzelman,2002] is used for energy dissipation model in simulations. The 100 number of sensor nodes are randomly distributed in the 100*100 m^2area. The base station is located at a point (50, 50). The parameters used in the simulation are described in Table 2.

Table 2:. Simulation parameters

Parameter	Value
Efs	10 pJ/bit/m^2
Emp	0.0013 pJ/bit/m^4
Eelec	50 nJ/bit/signal
Eda(Data Aggregation Energy)	5 nJ/bit/signal
Initial energy per node	1 J
Data Packet	4000 bit
Advertisement	500 bit
Aggregation Rate	10%

Neighborhood radius variable (R)

The R variable is considered for proper distribution of CHs in the network. To obtain desired R value, with different values of R, the rounds in which the first node died is measured. Figure 5 demonstrates that with R=30 or R=35, the result is better. This paper considers the value of R=35.

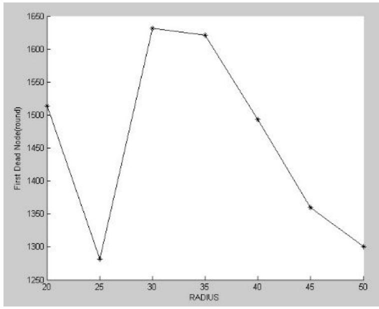

Figure 5: R value

α value

As mentioned before, re-clustering is performed when base station receives a demand from one of the CHs. This demand happens when residual energy of a cluster head becomes smaller than α*Ech. In order to obtain the proper α, proposed method was run for three times which led to α change from 0 to 1 and number of rounds was 400. Evaluation criteria was the death of the first node. Figure 6 shows results of these experiments. According to figure with α=0.7 approximately better results are gained.

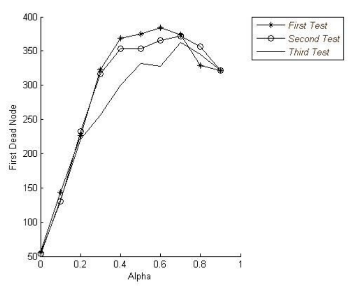

Figure 6: α values

Residual energy comparisons

The main energy in proposed method, LEACH and CHEF algorithms is consumed by cluster heads when data is sent to the base station. Figure 7 shows the comparison of residual energy rate of the three algorithms. In the proposed method and CHEF the residual energy of network is much more than LEACH because in these two algorithms use the neighborhood radius to form clusters and post messages but LEACH broadcasts messages on the network. Proposed method is better than CHEF because CHEF applies a probabilistic model for cluster head elections that leads to CHs are not well distributed in the network.

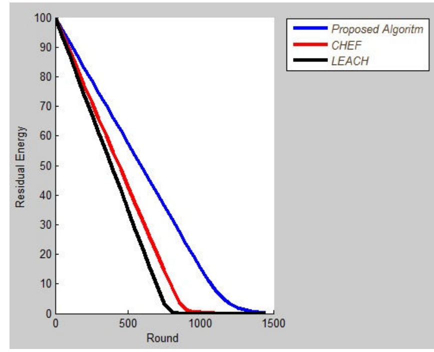

Figure 7: Residual energy

Network's lifetime comparisons

Several techniques have been proposed to evaluate network lifetime. In this paper, lifetime is considered as the time when the first node dies. Figure 8 shows the number of alive nodes for three algorithms: proposed method, LEACH and CHEF in different rounds.

It is easy to find out that the proposed algorithm prolongs the death time of the first sensor compared with other algorithms. Comparisons of the three methods indicate that the proposed method has improved the network lifetime by 14% relative to CHEF and by 34% relative to LEACH.

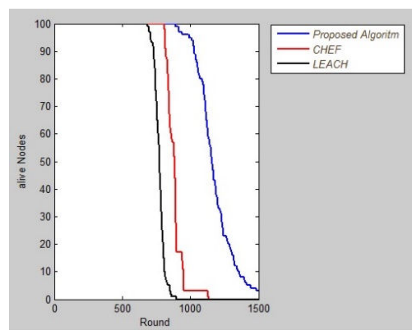

Figure 8: Number of alive nodes

Total distances between cluster heads to the base station

One of the most important issues about energy consumption is data transfer from CHs to the base station which is related to distance between cluster heads and the base station. Figure 9 shows total distances between cluster heads to the base station on three algorithms. According to figure, average of total distances in proposed method is smoother than CHEF and LEACH and its value is too less that means the number of cluster heads and their distribution in proposed method are suitable.

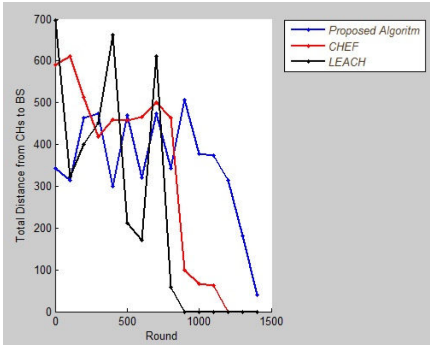

Figure 9: Total distances between CHs to BS

Number of clustering performance

As mentioned before, re-clustering is performed only with a demand in proposed method. While CHEF and LEACH algorithms perform re-clustring in every round. Figure 10 compares number of clustering performance in the three algorithms. Number of clustering performance in proposed method is less than the others.

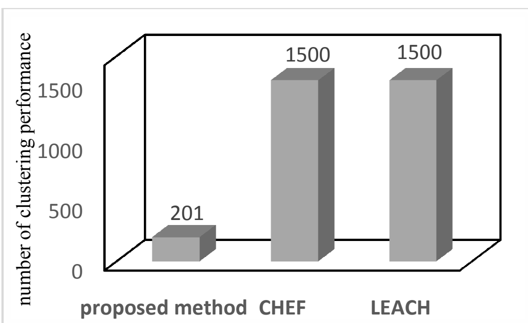

Figure 10: Number of clustering performance

CONCLUSION AND FUTURE RESEACRH

One of the reasons for high energy consumption in WSNs is data direct transfer to the base station by each sensor node. Exchanging messages using broadcast decreases the energy of sensor nodes rapidly. Using network nodes clustering techniques and data transfer to base station by cluster heads are prevented from wasting nodes energy and creating data redundancy and as a result energy consumption is balanced in the network.

In this paper, fuzzy logic for network clustering is used. In this method, each sensor node calculates a suitability degree for itself by fuzzy inference system with three parameters: the residual energy, number of neighbors and centrality. The value of suitability degree determines priority of nodes for being CH in distance of radius R. Also re-running start-up phase with a request of cluster heads decreases the overhead of exchange information during the clustering. The proposed method was compared with two similar protocols LEACH and CHEF in energy consumption, network lifetime, distance between CHs and base station and number of clustering performance. Simulation results demonstrate the proposed method gives a higher network lifetime by reducing the energy consumption when compared to existing clustering protocols.

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