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DUCF: Distributed load balancing Unequal Clustering in wireless sensor networks using Fuzzy approach

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ABSTRACT

Data gathering in wireless sensor networks (WSN) consumes more energy due to large amount of data transmitted. In direct transmission (DT) method, each node has to transmit its generated data to the base station (BS) which leads to higher energy consumption and affects the lifetime of the network. Clustering is one of the efficient ways of data gathering in WSN. There are various kinds of clustering techniques, which reduce the overall energy consumption in sensor networks. Cluster head (CH) plays a vital role in data gathering in clustered WSN. Energy consumption in CH node is comparatively higher than other non CH nodes because of its activities like data aggregation and transmission to BS node. The present day clustering algorithms in WSN use multi-hopping mechanism which cost higher energy for the CH nodes near to BS since it routes the data from other CHs to BS. Some CH nodes may die earlier than its intended lifetime due to its overloaded work which affects the performance of the WSN. This paper contributes a new clustering algorithm, **D**istributed **U**nequal **C**lustering using **F**uzzy logic (DUCF) which elects CHs using fuzzy approach. DUCF forms unequal clusters to balance the energy consumption among the CHs. Fuzzy inference system (FIS) in DUCF uses the residual energy, node degree and distance to BS as input variables for CH election. Chance and size are the output fuzzy parameters in DUCF. DUCF assigns the maximum limit (size) of a number of member nodes for a CH by considering its input fuzzy parameters. The smaller cluster size is assigned for CHs which are nearer to BS since it acts as a router for other distant CHs. DUCF ensures load balancing among the clusters by varying the cluster size of its CH nodes. DUCF uses Mamdani method for fuzzy inference and Centroid method for defuzzification. DUCF performance was compared with well known algorithms such as LEACH, CHEF and EAUCF in various network scenarios. The experimental results indicated that DUCF forms unequal clusters which ensure load balancing among clusters, which again improves the network lifetime compared with its counterparts.

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1. Introduction

In the real time world, wireless sensor networks (WSN) plays a vital role in environmental monitoring, traffic monitoring, disaster prevention, and national border surveillance [1]. The main activities carried over in a sensor node are sensing the required physical phenomena, computation (information processing) and communication with other nodes. Each sensor node will be having a non replaceable battery because of external hostile environmental conditions. Compared with sensing and computation, communication activities found to be consuming thousand times more energy [2] in individual sensor nodes. If the battery power of one node gets drained, the node became useless and literally called as dead node.

A wireless sensor node carries out its function in the following steps [3],

1. Geographically dispersed sensor nodes sense the surrounding environment. A node may have more than one type of sensor like temperature sensor, pressure sensor, etc. depending on the application need. This part of a node which is involved in sensing activities is generally referred as sensing subsystem.
2. The sensed analog raw data will be converted into digital data using analog to digital converter (ADC).
3. The digital data will be processed according to the specifications in the node's microcontroller unit. It is generally called as processing subsystem.
4. Then the processed data will be given to the radio transceiver IC in order to be sent to other nodes or to the BS directly. This unit is generally referred as communication subsystem.

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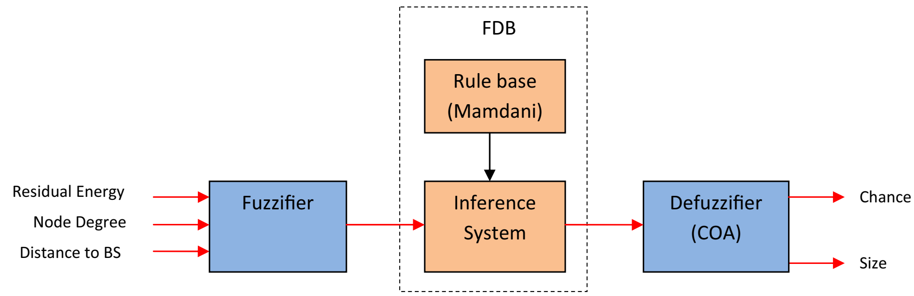

Fig. 1. Fuzzy inference system of DUCF.

The individual sensor nodes are capable enough for direct transmission of its information to BS, but it leads to higher energy consumption which ultimately affects the lifetime of the network. In order to reduce the overall energy consumption of the network, the nearby nodes or the nodes having the same characteristics are grouped together to form clusters [4,5]. A cluster head (CH) will be elected among the nodes to manage the activities carried over in the cluster. The responsibilities of the CH are data gathering from the cluster member (CM) nodes, aggregating the gathered data and transmitting it to the central BS.

The mechanism of forming clusters with equal number of member nodes is referred as equal clustering whereas with uneven number of members is referred as unequal clustering [6]. The idea of equal clustering sounds goods for the uniform distribution of nodes in the region of interest (ROI) [7]. But in most of the deployment scenarios, the uniform distribution is not possible. In those scenarios, equal clustering [8] schemes will lead to uneven energy consumption among the nodes, particularly on some CH nodes in the network. Again, when multi-hopping is followed, the CHs near to BS will involve in high data traffic and loses its energy compared to other CH nodes. In literature, this problem is stated as hot spot problem.

This paper proposes an unequal clustering algorithm DUCF based on fuzzy logic principle. The unequal clustering proves to be better than equal clustering in most forms of deployments [9]. Also, electing a CH node based on fuzzy approach is suitable for WSN where the degree of uncertainty is higher [10]. DUCF assigns maximum limit of number of members for a CH based on its residual energy, number of neighbors (node degree) and distance to BS. Because of the restriction in number of members for a CH even energy consumption is achieved and the hot spot problem is solved in DUCF.

Fuzzy approach: In recent state of art, Computational Intelligence (CI) algorithms [11] based on neural networks [12], ant colony optimization [13], PSO [14], genetic algorithm [15], fuzzy logic [16] have been applied for solving various kind of problems in WSN. Fuzzy logic (FL) [17,18] is one such CI technique used in the applications where lots of uncertainties are there. The cluster formation in WSN based on fixed rules may not be suitable because efficiency depends on various overlapping metrics. Electing the CH based on single parameter alone will lead to undesirable results. For example, electing the higher energy level nodes as CHs with no immediate neighbors increases the intra-cluster communication distance which again leads to increased communication cost of the networks.

FL mainly consists of four significant parts: they are (i) fuzzifier; (ii) inference system; (iii) rule base; and (iv) defuzzifier. The input to the system is usually a crisp value, which again converted into an appropriate fuzzy linguistic variable. The fuzzified values are sent to fuzzy decision block (FDB). FDB is made up of inference system and rule base. It maps the fuzzy output based on the given fuzzy rule base. Then the fuzzy output is converted into crisp output using defuzzification methods. Fig. 1 shows the fuzzy inference system (FIS) of DUCF.

Section 2 describes a brief survey on works related to clustering in WSN. In Section 3, the proposed work is explained in detail, Section 4 explains the simulation setup and Section 5 discuss the results.

2. Related works

LEACH [7] was the pioneer distributed clustering algorithm in WSN. Clustering is carried over in two phases: (i) setup phase and (ii) steady state phase. In the setup phase, each node will choose a random value between 0 and 1. Based on the value it decides itself to act as CH for current round or not. This decision is influenced by various factors like number of times it got elected as CH, current round and the percentage of allowed CHs in the network as specified in Eq. (1),

$$\mathrm{T}(m) = \begin{cases} \dfrac{p}{1 - p * (r \, mod(1/p))}, & n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

'm' represents individual sensor node, 'p' is the desired percentage of CH, and G is the set of nodes which are not elected as CH yet in recent 'r' rounds.

Then the self elected CH nodes advertise its election among the neighbor nodes. The other non-CH nodes join the nearby elected CH which is computed based on the received signal strength indicator (RSSI). Followed by this, TDMA schedule is created for the newly formed clusters by the respective CH. In Steady state phase, non-CH nodes forward its generated data to their respective CHs in its allotted time slot. The purest probabilistic way of election of CHs in LEACH, leads to election of non eligible CHs which affects the overall lifetime of the network. Also, it suffers a lot in scalability issue due to direct transmission of data from CHs to BS.

In the HEED algorithm [19], the remaining energy of each sensor node is the most important parameter for stochastic election of CHs. Node degree or average distance to neighbors is used to elect the CH when there is a tie between two nodes. HEED [19] provides better performance than LEACH due to its energy level consideration during CH election.

EECS [20] is one of the earlier unequal clustering algorithms in WSN. In CH election phase, each node will broadcast a control message, *COMPETE_HEAD_MSG* to neighbor nodes with its radio range R_{compete}. If there is any other node existing with a higher energy level than it within R_{compete}, it will withdraw from the competition. Otherwise the node declares itself as CH by broadcasting another control message *HEAD_AD_MSG* across the network. Generally the elected CH nodes directly communicate with BS, so the distant CH nodes have to spend more energy for transmission. EECS compensates this higher energy consumption in distant CH by accommodating the least number of member nodes using a weighting function. In large scale sensor networks, the single hop

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