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A distributed fuzzy logic-based root selection algorithm for wireless sensor networks ☆

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ABSTRACT

In this study, a distributed fuzzy logic (DFL) method with five input parameters namely, energy, centrality, distance to base station, number of hops and node density is proposed for efficient root election system. In order to prevent high energy consumption during message transmission, we made each node run fuzzy logic engine distributedly. We decrease the number of message transmissions from member nodes to root node by running DFL on intermediate nodes and by eliminating the messages of nodes that have less probability to be selected as a new root. The proposed system also includes fault tolerance, load balance, timeliness and the scalability mechanisms. To prove the efficiency of our algorithm, we compared it with the algorithms namely; Low Energy Adaptive Clustering Hierarchy (LEACH), Adaptive Clustering Algorithm via Waiting Timer (ACAWT), Cluster Head Election mechanism using Fuzzy logic (CHEF) and Gupta's Algorithm.

1. Introduction

In most of the sensor network applications [1], clustering techniques are used to decrease energy consumptions. In clustered networks, nodes are defined as either member or root nodes. While member nodes are responsible of sending their sensed data to the root node, root node is responsible of collecting, processing and sending this data to the base station [3]. Because of the role of root node, energy consumption in root nodes occurs much faster than in the member nodes. When a root node in a cluster consumes all its energy, the data sensed by its member nodes cannot be processed and becomes useless. In order to balance energy consumption and to increase lifetime of the clusters and the network, we propose a distributed clustering algorithm in which the role of root nodes changes dynamically in accordance with the energy, centrality, distance to base station, number of hops and node density parameters. In the proposed system, to inference which node should be selected as the root node, we used distributed fuzzy logic inference system. Our system is completely distributed that each node contains fuzzy logic inference engine and uses its own and the neighbors information in order to make accurate inferences. Number of message transmissions from member nodes to root node is also decreased by running distributed fuzzy logic system in intermediate member nodes.

Fault tolerance, load balancing, timeliness and scalability subjects are also considered while designing the proposed algorithm. Because of many facts, such as energy depletion or disruption, sensor nodes may not perform their responsibilities. In these cases, system must adapt to failures without delays. Our algorithm is fault tolerant that when a fault occurs in a node, alternative paths can be used. We also considered faulty cases that can occur in the current root node. During message

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transmissions between nodes, collisions can occur. In order to prevent this, we use a transmission scheduling model and back off time metric.

Main contribution of this algorithm is to select cluster head distributedly by using distributed fuzzy logic engine. Existing algorithms use fuzzy logic engine centrally, but we design the fuzzy logic engine in a distributed way. Another point is, number of message transmissions from member nodes to root node is decreased by running the fuzzy logic engine on intermediate member nodes and electing the messages of nodes that have less probability to be selected as a new root. Besides this, the proposed system is fault tolerant and includes load balancing, timeliness and the scalability mechanisms which are very important subjects for prolonging the network lifetime. To the best of our knowledge, the proposed study is the first cluster head selection study which uses fuzzy logic distributedly and includes fault tolerance, load balance, timeliness and scalability mechanisms all together.

Rest of this paper is organized as follows: In Section 2, related studies are summarized. System model is given in Section 3. In Section 4, the proposed system is explained in detail including distributed fuzzy logic-based clustering algorithm subsection that consists finite state machine, descriptions of states and the messages, pseudocode of the algorithm and the steps of fuzzy logic system subjects. This section also includes remarkable properties of the system including fault tolerance, load balancing, timeliness and scalability subjects. Analysis of message complexity and energy consumption are given in Section 5. We present the simulation results and the performance evaluations in Section 6. Finally, conclusions are given in Section 7.

2. Related works

There are many clustering techniques proposed for wireless sensor networks. Some of them are: In [2], Gupta proposes an algorithm in which base station collects all information from nodes and runs fuzzy logic centrally with the input variables of energy level, concentration and centrality. In [3], all nodes elect itself as a cluster head based on a probability method, in [4] each node uses a random waiting timer and local criteria to determine whether to form a new cluster or to join a current cluster, in [5] the fuzzy logic system is executed by the nodes locally for cluster head selection. In [6], a distributed dynamic clustering protocol that uses fuzzy logic technique to select root node is proposed. In this protocol, tentative cluster heads are selected based on remaining energy with a non-probabilistic fashion and cluster head selections are performed sporadically. Differently from [2], in [7], battery level, node density and distance to base station parameters are used by the base station to run fuzzy logic system. In [8], base station collects the data and runs fuzzy logic engine centrally to form clusters. In [9], cluster heads are selected by using fuzzy logic engine in a centralized way and clusters are formed periodically rather than considering the requirement.

Main difference of the proposed algorithm DFLC from the studies mentioned above is completely distributed structure of the proposed system rather than making the base station collect the data from all sensor nodes and run the fuzzy logic centrally. By this way, we overcome the computational overhead and prevent the huge amount of message transmissions from nodes to base station and base station to nodes. Hence, energy consumption of the network decreases and lifetime of the system increases considerably. Computational overhead is reduced by eliminating the nodes that have less probability to be selected as a new root. Hence, fuzzy logic engine is executed by root and parent nodes for only necessary nodes that have higher probability to be selected as a new root node.

3. System model

In this section, the system model is described in detail including the subsections of network and energy models.

3.1. Network model

In this system, nodes are determined as sink, root, member, parent and child nodes. Sink node corresponds to base station and it collects data from root nodes, root node corresponds to the leader of each cluster and it collects data from the nodes in its cluster and sends this data to the sink node, member node is a node that belongs to a cluster and it sends its sensed data to its root node, parent node is a member node that has leaf nodes (child) and forwards or processes the data which is sent by its child nodes, and lastly child node is a member node that has data to send to its root node via its parent node.

3.2. Energy model

Sensors consume energy mainly while packet transmitting, packet receiving, sensing and data processing. We used the energy model given in [3,11]. The consumed energy while sending k bytes packet is:

$$T_x = E_{elec}k + \varepsilon_{elec}kd^{o} \quad (1)$$

where E_{elec} (nJ/bit) and ε_{elec} (pJ/bit/m^{α}) are the energy coefficients of the radio circuit and the amplifier $\alpha\epsilon[2,4]$ is the path loss exponent; d is transmission distance.The receivers energy consumption is modeled as

$$R = E_{elec}k \quad (2)$$