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A new multi-objective distributed fuzzy clustering algorithm for wireless sensor networks with mobile gateways

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ABSTRACT

In the clustered wireless sensor networks (WSNs) studied, each cluster head (CH) transmits aggregated data from cluster members to the static base station by means of intermediate communication nodes in name mobile gateways. In order to reduce energy consumption along with reducing delays in packet delivery in the mentioned WSNs, two approaches are proposed: (1) designing a completely distributed fuzzy system to determine the eligibility of the node for being CH with two input factors, namely the general state of a sensor node in the WSN (GSoSN) and location of a sensor node relative to mobile gateway nodes (LoSNRtMG). By defining two early discussed factors, not only the accuracy of decision making in selecting the CH node enhances but also the computation overhead decreases; and (2) reducing communication overhead by applying the linear prediction method to estimate the next locations of the moving gateway nodes instead of periodical broadcasting of their location messages. The experimental results demonstrate that the proposed idea has better performance in terms of reducing both energy consumption and delays in packet delivery metrics.

1. Introduction

Wireless sensor networks (WSNs) consist of a number of operational nodes that work together to transfer data obtained from the environment to the base station (sink). A sensor node is capable of collecting data from an area located within its sensing radius. The sensed data are transmitted to the sink for further processing and analysis. The load on the sensor nodes near the sink will be higher in comparison to distant sensor nodes as the proximity sensor nodes have to do dual work of transmitting their own data and also forwarding (or relaying) data from distant sensor nodes. This may result in the early death of proximity sensor nodes (in comparison to distant sensor nodes) and increase the probability of disconnecting the remaining operating sensor nodes from the sink. So, in addition to energy efficiency, which has traditionally been one of the most critical design issues of WSNs, uniform energy consumption in the WSNs should be ensured. Also, packet delivery time is another issue that is affected due to the traffic of sensor nodes close to the sink and the premature death of network nodes. Two common approaches to solve these problems which result in minimizing energy consumption and reducing delays in packet delivery in WSNs are the use of clustering techniques [1] and the use of mobile sinks.

In a clustered WSN, a sensor node is defined as a cluster head or a cluster member. Each cluster member transmits its sensed data to the cluster head to which it belongs. Next, the received data are aggregated by each cluster head. Finally, the aggregated data are transmitted to the distant base station (sink) by the cluster head nodes. The cluster head can directly transmit the data to the base station or can use intermediate cluster heads. Clustering in WSNs not only ensures the exact performance required by many sensor nodes but also improves the scalability of wireless sensor network [2]. As stated in [3]: “in addition to network scalability, localization of path settings, communication bandwidth protection by reducing relayed packet, reduction of energy consumption and stability of network topology are the other advantages of clustering”.

Mobile sink based WSNs showed great advantages over the static sink based WSNs for saving energy and increasing both the network lifetime and packet delivery ratio [4]. In this study and according to the benefits of mobile data collectors, a number of mobile gateway nodes are considered. Mobile gateway nodes are nodes moving within a certain area to collect data of the cluster heads and transfer them to the sink. These nodes enable access of wireless sensor network to the static base stations through communication technologies (such as 3G, 4G, and WiFi). Handheld devices such as smart phones and tablets fall into the category of mobile gateways.

According to the benefits of the two mentioned approaches of clustering and using of mobile gateway nodes (as communication

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intermediates between the cluster heads and base station) in minimizing energy consumption and reducing the packet delivery time in wireless sensor networks, this paper is focused on selecting cluster heads (CHs) in a wireless sensor network that uses mobile gateway nodes as communication intermediate nodes for transferring the aggregated data to static base station.

To infer which nodes should be selected as cluster head nodes (i.e., *Being_CH_Chance* computation), a fuzzy-based approach is utilized. To minimize energy consumption and reduce delays in packet delivery in WSNs (i.e., the aims of this research), cluster head is selected based on the following seven fuzzy descriptors: (a) residual energy, (b) number of neighbors, (c) mean distance between a sensor node and its neighbor nodes, (d) number of gateways within a sensor transmission range, (e) distance from the nearest gateway within a sensor transmission range, (f) distance from the most faraway gateway within a sensor transmission range, and (g) mean distance between a sensor node and gateways within its transmission range. While the computation of *Being_CH_Chance* based on the seven early discussed fuzzy descriptors increases the accuracy of decision-making in the selection of CH, it results in an increase in the number of fuzzy system's inputs which leads to increase in both the size of computations and difficulty and impracticability to form a complete fuzzy rule base. Large-volume of the computations increases the energy consumption of sensor nodes, which causes early death of the sensor nodes. To reduce the number of computations required to infer which nodes should be selected as CH nodes while maintaining the effectiveness of each fuzzy descriptor, the number of inputs of the fuzzy system (FS) is logically reduced to two. That is, instead of having early discussed seven parameters as inputs to our FS, first of all, we divide the parameters (a)–(g) into two new-defined groups (i.e., factors) in names (1) the general state of a sensor node in the WSN (GSoSN) and (2) location of a sensor node relative to the mobile gateways (LoSNRtMG), based on the meaning and the role of each parameter. In making GSoSN (and respectively, LoSNRtMG) parameters (a)–(c) (and respectively, parameters (d)–(g)) are applied. Then, a weighted linear combination method [5] is used to combine the decision criteria of GSoSN factor (and respectively, LoSNRtMG factor). In this way, not only the effect of each parameter on the inference is maintained, but also by reducing the number of inputs of fuzzy-based inference system, the size of required computations is significantly reduced.

In addition, in order to reduce the required messages to select CH (and thus reducing the energy consumption in the sending/receiving of messages), two techniques are proposed. First, instead of a central approach in the selection of CH, a completely distributed approach is introduced. That is, each node is equipped with a fuzzy inference engine and uses its own and the neighbors' information in order to make an accurate inference. Secondly, to be aware of the location of each mobile gateway node at the decision-making time to select CH, instead of programming mobile gateway nodes to broadcast the messages corresponding to their locations in a periodical manner which increases the overhead of control messages in the network, a cluster of sensor nodes is formed to predict the next location of each mobile gateway node. A linear prediction method (which is precise and imposes little computational load) is applied to predict mobile gateway node's next location. It is worth mentioning that when mobile gateway nodes are sensitive to energy consumption, the linear prediction method is so efficient at estimating the next locations of them.

In summary, the distinguishing features of this work are that:

(a) Design of a new factor in name general state of a sensor node in the WSN (GSoSN) which is determined based on a weighted linear combination of three parameters: (1) residual energy, (2) number of neighbors and (3) mean distance between a sensor node and its neighbor nodes,
(b) Design of a new factor in name, location of a sensor node relative to mobile gateway nodes (LoSNRtMG) which is determined based on a weighted linear combination of four parameters: (1) number of gateways within a sensor transmission range, (2) distance from the nearest gateway within a sensor transmission range, (3) distance from the most faraway gateway within a sensor transmission range, and (4) mean distance between a sensor node and gateways within its transmission range.
(c) Design of a fuzzy system which is named as FBCHCDS (Fuzzy Being_CH_Chance Determination System) to compute the *Being_CH_Chance* of each sensor node based on two input factors (a) and (b) aimed at minimizing energy consumption and reducing delays in packet delivery in WSNs.
(d) Energy efficiency in the proposed CH selection approach due to: (1) providing a completely distributed approach for CH selection, (2) reducing the overhead of control messages in the WSN by providing a mechanism to estimate the next locations of the moving gateway nodes (as communication intermediate nodes) using a linear prediction method instead of programming of the gateway node to broadcast the messages corresponding to their locations in a periodical manner and (3) considerable reduction in the size of required computations due to logically reduce the number of inputs of fuzzy system that determines *Being_CH_Chance* of each sensor node.

The paper is structured as follows: system model and the proposed approach to transmit sensed data to the base station by means of mobile gateway nodes are covered in Sections 2 and 3, respectively. The main sub-sections of Section 3 are distributed fuzzy logic-based cluster head selection algorithm (DFLBCHSA), prediction method to estimate the next location of a mobile gateway node and details of a designed fuzzy system (FS) in name Fuzzy Being_CH_Chance Determination System (FBCHCDS). The computation time complexity of the proposed DFLBCHSA is covered in Section 4. The simulation results to study the performance of the proposed DFLBCHSA are given in Section 5. Section 6 reviews the related works. Finally, the conclusion and future works are presented in Section 7.

2. System model

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

2.1. Network model

We have three types of components: (1) sensor node (static), (2) gateway (mobile) and (3) base station (static). In this model, collecting and sending of sensed data from the environment occur in a hierarchical manner. The lowest level of the hierarchy is composed of static sensor nodes, which are assigned the task of collecting data and then sending the collected data to the CHs. CHs are sensor nodes, which are selected based on determined criteria to perform tasks such as collecting data from static sensors within its specified range, data integration, and data compression. At the next level of the hierarchy, each CH transmits aggregated data to its nearest mobile gateway. Mobile gateways are nodes moving within a certain range to collect data from the CHs. In the last level of the hierarchy, mobile gateways transmit the collected data from CHs to the static base station.

After deployment of sensor nodes in a two-dimensional area, the initial size of the given area is divided into several sub-areas (which are equal in size) and the results of the proposed hierarchical approach in sending of the collected data from sensor nodes to the base station are reported. We continue the division process of the areas into a further number of sub-areas and report the results of the proposed hierarchical approach in sending of the collected data from sensor nodes to the base station in each new division pattern of the given area. By comparison of the reported results, the suitable number of sub-areas in the given area is chosen. In other words, to determine the near-optimal (suitable) number of sub-areas for a given area, we act in