A Cluster Head Selection Method for Wireless Sensor Networks based on Fuzzy Logic

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Abstract— **Sensor networks supported by recent technological advances in low power wireless communications along with silicon integration of various functionalities are emerging as a critically important computer class that enable novel and low cost applications. There are many fundamental problems that sensor networks research will have to address in order to ensure a reasonable degree of cost and system quality. Cluster formation and cluster head selection are important problems in sensor network applications and can drastically affect the network's communication energy dissipation. However, selecting of the cluster head is not easy in different environments which may have different characteristics. In this paper, in order to deal with this problem we propose a power reduction algorithm for sensor networks based on fuzzy logic. We evaluate the proposed method by simulations and show that proposed system makes a good selection of the cluster head.**

I. INTRODUCTION

Recent developments in technologies such as wireless communication and microelectronics have enabled Wireless Sensor Network (WSN) applications to be deployed for many applications such as battlefield surveillance and environment monitoring. An important aspect of such networks is that the nodes are unattended, resource-constrained, their energy cannot be replenished and network topology is unknown. The resource-constrained limitations make it essential for these sensor nodes to conserve energy to increase life-time of the sensor network [1], [2], [3], [4].

In WSN the nodes are sensors, which are micro-devices with limited computation capacity and with on-board specific transducers. Recently, there are lot of research efforts towards the optimization of standard communication paradigms for such networks. In fact, the traditional Wireless Network (WN) design has never paid attention to constraints such as the limited or scarce energy of nodes and their computational power. Also, in WSN paths can change over time, because of time-varying characteristics of links, local contention level and nodes reliability. These problems are important especially in a multi-hop scenario, where nodes accomplish also at the routing of other nodes' packets [4].

There are many fundamental problems that sensor networks research will have to address in order to ensure a reasonable degree of cost and system quality. Some of these problems include sensor node clustering, Cluster Head (CH) selection and energy dissipation. There are many research works that deal with these challenges [5], [6], [7], [8], [9], [10], [11], [12], [13].

The cluster based algorithms could be used for partitioning the sensor nodes into subgroups for task subdivision or energy management. Cluster formation is one of most important problems in sensor network applications and can drastically affect the network's communication energy dissipation. Clustering is performed by assigning each sensor node to a specific CH. All communication to (from) each sensor node is carried out through its corresponding CH node. Obviously one would like to have each sensor to communicate with the closest CH node to conserve its energy, however CH nodes can usually handle a specific number of communication channels. Therefore, there is a maximum number of sensors that each CH node can handle. This does not allow each sensor to communicate to its closest CH node, because the CH node might have already reached its service capacity. CHs can fuse data from sensors to minimize the amount of data to be sent to the sink. When network size increases, clusters can also be organized hierarchically.

In the conventional cluster architecture, clusters are formed statically at the time of network deployment. The attributes of each cluster, such as the size of a cluster, the area it covers, and the members it possesses, are static. In spite of its simplicity, the static cluster architecture suffers from several drawbacks. The fixed membership is not robust from the perspective of fault tolerance. If a CH dies of power depletion, all the sensors in the cluster render useless. Also, fixed membership prevents sensor nodes in different clusters from sharing information and collaborating on data processing. Dynamic cluster architectures, on the other hand, offer several desirable features. Formation of a cluster is triggered by certain events of interest.

In this work we deal with the CH selection. When a sensor with sufficient battery and computational power detects (with a high Signal-to-Noise Ratio: SNR) signals of interest, it volunteers to act as a CH. This is a simple method, because no explicit leader (CH) election is required and, hence, no excessive message exchanges are incurred. However, selecting of the CH in this way is not easy in different environments which may have different characteristics such as error rate, SNR, throughput and so on.

In order to deal with this problem, we propose a CH selection algorithm for sensor networks based on Fuzzy Logic (FL). The heuristic approaches based on FL and Genetic Algorithms (GA) can prove to be efficient for wireless networks [14], [15].

The paper is organized as follows. In Section II, we discuss

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the related work. In Section III, we introduce the proposed system design. In Section IV, we present the simulation results. Conclusions of the paper are given in Section V.

II. RELATED WORK

In this section, we review related work in clustering algorithms. Several clustering methods such as weighted clustering [5], hierarchal clustering [6] and dynamic clustering [7] algorithms have been proposed to organize nodes as a cluster. Most algorithms elect leaders based on certain weights or iteratively optimize a cost function or use heuristic to generate minimum number of clusters. The Distributed Clustering Algorithm (DCA) [8] assumes quasi-stationary nodes with real-valued weights. The Weighted Clustering Algorithm [5] elects a node based on the number of neighbors, transmission power and so on. The Max-Min d-Clustering Algorithm [9] generates d-hop clusters with a run time of O(d) rounds. This algorithm does not minimize the communicating complexity of sending information to the information center.

The hierarchal clustering scheme [6] uses spanning tree-based approach to produce cluster with certain properties. However, energy efficiency is not addressed in this work. In [10], the authors have proposed an emergent algorithm that iteratively tries to achieve high packing efficiency, however negotiation among nodes to be CH and join cluster based on degree and proximity leads to high amount of communication overhead, thus wastage energy.

LEACH [11], [12] uses two-layered architecture for data dissemination. In this scheme, sensors periodically elect themselves as CHs with some probability and broadcast an invitation message for nearby nodes to join the cluster. The nodes that do not intend to be CHs join the cluster based on the proximity of CH, thus minimizing the communicating cost. However, LEACH and PEGASIS [13] require the apriory knowledge of the network topology.

The most closed work with ours is one proposed in [16]. The authors propose a self-reconfiguring protocol for Wireless Personal Area Networks (WPAN) using an unsupervising clustering method. A fuzzy logic system is used to select the master/controller for each cluster. We show by simulation results that the selection surface of our proposed system is better than this system.

III. PROPOSED SYSTEM MODEL

The Fuzzy Logic Controller (FLC) is the main part of the proposed system and its basic elements are shown in Fig. 1. They are the fuzzifier, inference engine, Fuzzy Rule Base (FRB) and defuzzifier. As shown in Fig. 2, as membership functions we use triangular and trapezoidal membership functions because they are suitable for real-time operation [17].

In Fig. 2, x_0 in $f(x)$ is the center of triangular function; $x_0(x_1)$ in $g(x)$ is the left (right) edge of trapezoidal function; and $a_0(a_1)$ is the left (right) width of the triangular or trapezoidal function.

The input parameters for FLC are:

- Distance of Cluster Centroid;
- Remaining Battery Power of Sensor;

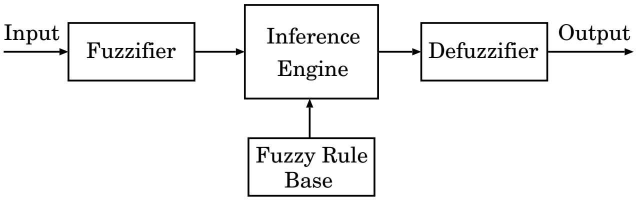

Fig. 1. FLC structure.

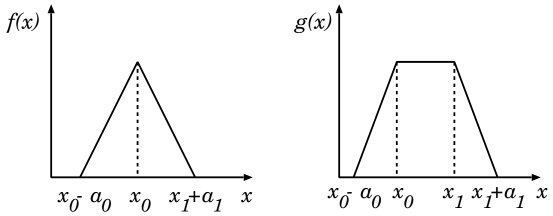

Fig. 2. Triangular and trapezoidal membership functions.

- Network Traffic.

We write for short as D, SP, and NT. The term sets for each input linguistic parameter are defined respectively as:

$$\begin{aligned} T(D) &= \{Near, Moderate, Far\}; \\ T(SP) &= \{Low, Moderate, High\}; \\ T(NT) &= \{Light, Moderate, Heavy\}. \end{aligned}$$

The output linguistic parameter is the Probability (Possibility) of CH Selection. We write for short as $PCHS$. We define the term set of $PCHS$ as: $\{Very\ Weak, Weak, Little\ Weak, Medium, Little\ Strong, Strong, Very\ Strong\}$.

The linguistic parameters and their term sets are shown in Table 1. The fuzzy membership functions for input parameters are shown in Fig. 3, Fig. 4 and Fig. 5, while for output parameter in Fig. 6. The FRB is shown in Table 2 and forms a fuzzy set of dimensions $|T(D)| \times |T(SP)| \times |T(NT)|$, where $|T(x)|$ is the number of terms on $T(x)$. The FRB has 27 rules. The control rules have the following form: IF "conditions" THEN "control action".

TABLE I

LINGUISTIC PARAMETERS AND THEIR TERM SETS.

Parameters	Term Sets
Distance	Near, Moderate, Far
Remaining Battery	Low, Moderate, High
Traffic	Light, Moderate, Heavy
Probability (Possibility)	Very Weak, Weak, Little Weak, Medium, Little Strong, Strong, Very Strong

IV. SIMULATION RESULTS

In this section, we present the simulation results. We evaluate by computer simulations the performance of the previous system [16] and the proposed system. In our system, we decided the number of term sets by carrying out many simulations.

In Fig. 7 is shown the performance evaluation of the previous system. The graph in 3 dimensions shows the relation between the possibility of a sensor to be selected as a CH versus the distance and the remained sensor power. As shown by the figure, with the increase of the remained sensor power

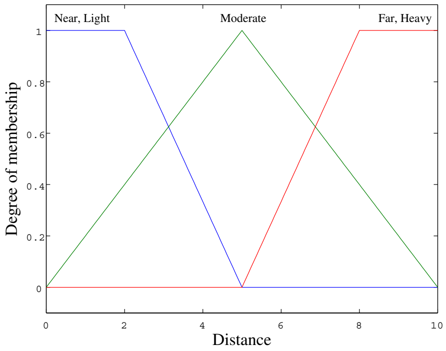

Fig. 3. Membership functions for distance.

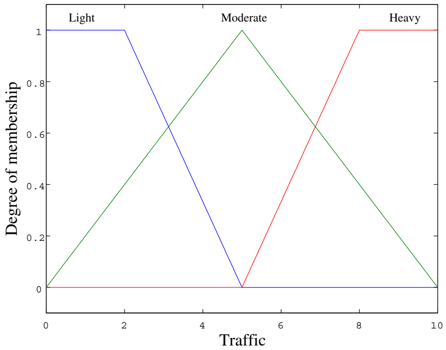

Fig. 4. Membership functions for network traffic.

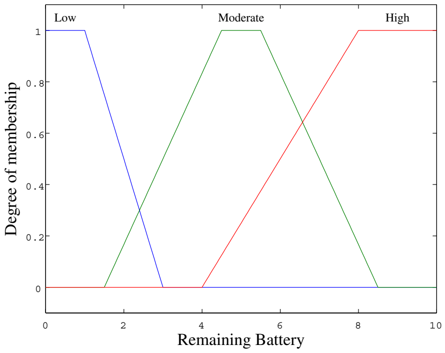

Fig. 5. Membership functions for remaining sensor power.

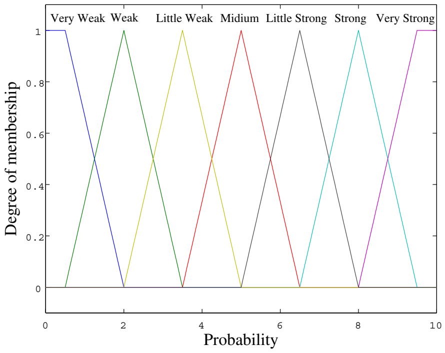

Fig. 6. Membership functions for output parameter.

and the decrease of the distance between the sensor and sink, the possibility of a sensor to be selected as CH is increased. However, the graph surface is increased almost proportionally with the changes of both parameters.

The performance evaluation of the proposed system is shown in Fig. 8 and Fig. 9. In Fig. 8 is shown the relation between the possibility of a sensor to be selected as a CH versus the distance (network traffic) and the remained sensor power. This is the same relation with the previous system. With the increase of the remained sensor power and the decrease of the distance between the sensor and the sink, the possibility of a sensor to be selected as CH is increased. However, when the remaining power battery of the sensor is less than 2 units the possibility of a node to be selected as CH in our proposed system is zero. This shows that our system selects in a better way the CH, which results in the increase of the network lifetime.

In Fig. 9 is shown the relation between the possibility of a sensor to be selected as a CH versus the distance and the network traffic situation. With the increase of the network traffic and the increase of the distance between the sensor and sink, the possibility of a sensor to be selected as CH is decreased. In different for the results in Fig. 8, we see that the shape of the surface is changed proportionally with the changes of parameters. This shows, the remained battery power of a sensor is more important for the selection of a CH than the traffic conditions.

V. CONCLUSIONS

In WSNs where nodes are likely to operate on limited battery life, power conservation is an important issue. Conserving power prolongs the lifetime of a node and also the lifetime of the whole network. Clustering is one of the energy-efficient techniques for extending the lifetime of a sensor network. Clustering techniques organize the nodes into clusters where some nodes work as CHs and collect the data from other nodes in the clusters. Then, the CHs can consolidate the data and send it to the data center as a single packet, thus reducing the overhead from data packet headers. However, CH selection is very difficult when many parameters are used for making the decision. For this reason, we proposed a CH selection method based on FL.

In this paper, we proposed a FL-based CH selection system for WSNs. We evaluated the proposed system by computer simulations. From the simulation results we concluded as follows.

- With the increase of the remained sensor power and the decrease of the distance between the sensor and the sink, the possibility of a sensor to be selected as CH is increased.
- With the increase of the network traffic and the increase of the increase of the distance between the sensor and sink, the possibility of a sensor to be selected as CH is decreased.
- In different from the previous system, in our proposed system, when the remaining power battery of the sensor is less than 2 units the possibility of a node to be selected as CH is zero.
- The remained battery power of a sensor is more important for the selection of a CH than the traffic conditions.

We are working now to extend our work for large-scale WSNs.

TABLE II

FRB.

Rule	D	SP	NT	PCHS
1	Near	Low	Light	Little Strong
2	Near	Low	Moderate	Medium
3	Near	Low	Heavy	Little Weak
4	Near	Moderate	Light	Strong
5	Near	Moderate	Moderate	Little Strong
6	Near	Moderate	Heavy	Medium
7	Near	High	Light	Very Strong
8	Near	High	Moderate	Strong
9	Near	High	Heavy	Little Strong
10	Moderate	Low	Light	Medium
11	Moderate	Low	Moderate	Little Weak
12	Moderate	Low	Heavy	Weak
13	Moderate	Moderate	Light	Little Strong
14	Moderate	Moderate	Moderate	Medium
15	Moderate	Moderate	Heavy	Little Weak
16	Moderate	High	Light	Strong
17	Moderate	High	Moderate	Little Strong
18	Moderate	High	Heavy	Medium
19	Far	Low	Light	Little Weak
20	Far	Low	Moderate	Weak
21	Far	Low	Heavy	Very Weak
22	Far	Moderate	Light	Medium
23	Far	Moderate	Moderate	Little Weak
24	Far	Moderate	Heavy	Weak
25	Far	High	Light	Little Strong
26	Far	High	Moderate	Medium
27	Far	High	Heavy	Little Weak

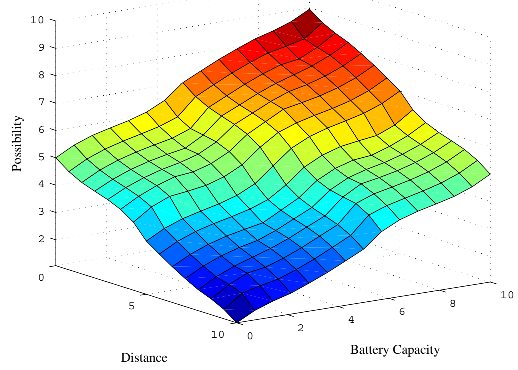

Fig. 7. Previous system simulation results.

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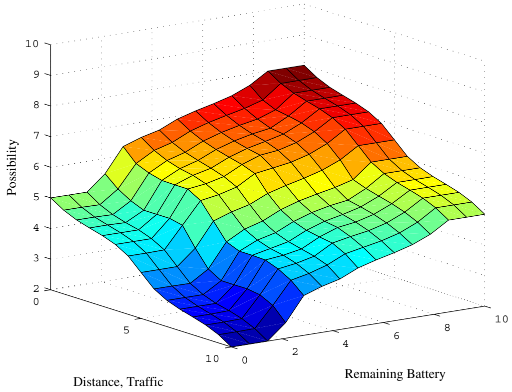

Fig. 8. Proposed system results (case 1).

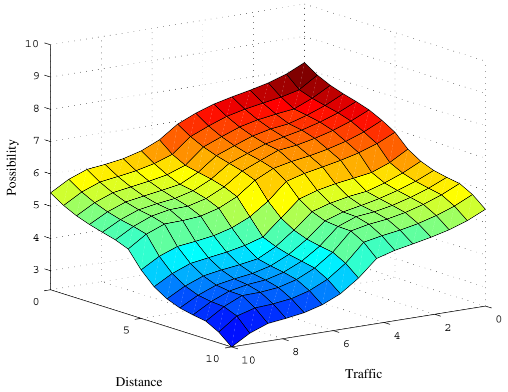

Fig. 9. Proposed system results (case 2).

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