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A Fuzzy Logic based Joint Intra-cluster and Inter-cluster Multi-hop Data Dissemination Approach in Large Scale WSNs

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***Abstract*:** *Improving network lifetime in wireless sensor networks (WSNs) is a major concern in the recent years. Currently, various approaches have been proposed with having many concepts in this context. The main problem seems in the recent proposed approaches is that these approaches use direct communication among nodes with the rotation of cluster heads (CHs) periods to distribute energy consumption. However, energy saving mechanisms based only on metric related to nodes' residual power cannot be directly applied to find stable CHs. The reason is that a sensor node or a CH having more residual power is willing to accept all requests, because it has enough residual battery power, therefore, much traffic will be injected to that node. In this case, the energy decay rate of that particular node will tend to be high and causes a sharp decay of its backup battery power. As a consequence, node exhausts its energy quickly and cause nodes' death rate high in the network. Hence, it causes uneven energy dissipation among the nodes in the network. Moreover, it decreases information transmission efficiency of the network drastically. In this research paper, a Multi-criterion Fuzzy logic based intra-cluster and inter-cluster multi-hop data dissemination protocol is proposed to make balance among the nodes and chooses more stable nodes as CHs for efficient data dissemination. The simulation results have been confirmed that our proposed approach is more efficient than state-of-the-art approaches.*

Keywords: *Node energy decay rate, Expected node stability, residual power, fuzzy logic system.*

1. Introduction

The demand of WSNs in today's scenario is increasing due to advancement in wireless technologies and cheaper in cost. One specific use case of WSNs is providing emergency communication services between the members of a rescue team in disaster like scenario [1]. In such scenario, saving of human life depends on the proper functioning of the communication network such that information about the survivors can be delivered in real time and accordingly rescue operation may be taken. Due to limited resources available in WSNs, sensor nodes have to rely on their limited battery power. Moreover, replacing these resources in an unattended environment is practically impossible. Researchers have suggested several approaches to maximize network lifetime while doing basic operations of sensing and data communication in energy efficient manner. Clustering of nodes is one of the most efficient ways among them. However, nodes have to transmit their data in an energy efficient way to prolong network lifetime. Use of computational intelligence in clustering can also further improve the efficiency of network by selection of stable nodes as CHs. Recently, in some research works [2-4], fuzzy logic concept is used to elect CHs in WSN based on various parameters like residual node energy, distance between CHs etc. This paper proposes an approach that utilizes intra-cluster and inter-cluster based fuzzy logic system to evaluate the eligibility of the sensor nodes as CHs based on their expected stability index. In the outset, 2 level of criterion is used to elect and select CHs in the network in our proposed approach. At level 1, node expected stability index is used to elect the CHs among the neighbour nodes (i.e. intra-cluster criteria). Similarly, at level 2, various parameters like distance to sink node, centrality and distance between CHs are used to further enhance the eligibility of nodes for a particular round (i.e. inter-cluster criteria). In the nut shell, sensor nodes pass both criterion will elect as CHs to transmit aggregated data to sink node. The remainder of the paper is organized as follows: In section 2, related works is discussed. Section 3 gives energy model, problem formulation and methodology of our proposed approach. In section 4, simulation results of our proposed approach are shown to prove its effectiveness. In Section 5, the article is concluded with future scope.

2. Related Works

Significant research efforts have been made towards solving the problem of uneven distribution of energy dissipation in WSNs. Some protocols have been proposed to elect CHs with more residual power nodes [2]. Other proposed protocol in [3] relies on unequal clustering for reducing uneven distribution of energy dissipation. The key idea is to elect CHs according to node's residual power. However, each node needs to know the total energy dissipation of the current round to determine its chance for CH, which requires complete network knowledge. This involves excessive overhead in the cluster formation phase. In [5], the authors introduced a CH election method using fuzzy logic to overcome the constraints of LEACH protocol. They investigated that the network lifetime can further be enhanced by using linguistic variables. Indeed, only two parameters are considered for CH election, i.e. node energy and its distance to sink. The authors of [6] proposed a centralized clustering approach called fuzzy C-mean (FCM) which uses location information of nodes with its residual power and degree of belongingness of each node for the CH rather than becoming the complete part of each cluster. The fuzzy logic principles are used for fuzzifying the degree of belongingness after it is calculated. Due to centralized nature, FCM is less scalable, but shows good result only in small networks. In [7], the authors have proposed a new approach called F3N that uses three main parameters for the election of CHs. These parameters are: (i) distance to the cluster centroid (DCC), (ii) degree of number of neighbor nodes (D3N) and (iii) remaining power of the sensors (RPS). The authors have shown that the eligibility of a sensor node to become CH increases with the decrease of distance as well as with increase of residual power and number of neighbor nodes. Another parameter, i.e. network traffic (NT) is included in their modified work [8]. The authors of [9] have proposed new neuro-fuzzy technique that involves sensor memory, available power and processing speed to evaluate the node eligibility as CHs. The approach does not require the complete information about the networks and shows excellent scalability in large network. In [10], the authors offer cluster head election mechanism using fuzzy logic called CHEF approach. CHEF generates a random number for each sensor like LEACH and determines node eligibility as CH. However, there may be some eligible nodes in the current round that lost their chance on random manner. The authors in [11] considered a fuzzy descriptor i.e. distance to BS during CH election. The idea is to reduce the cluster size when getting close to BS to avoid quick exhaustion of battery power of nodes closer to BS. Recently, in [4], the authors have proposed two-level fuzzy logic system to elect CH based on various parameters in each level. The idea is to choose only those sensor nodes as CHs that satisfy the conditions at level 1 as well as level 2. The authors have chosen only 5% of such nodes randomly as CHs in each round without any reason which we found in the simulation experiments that some of the most eligible nodes have lost their chance in random manner and consequently, these nodes are left without clustering in the network i.e. uneven cluster formation exists in the network that reduces network lifespan drastically. Therefore, to improve the proposed protocol given in [4], we use a novel intra-cluster and inter-cluster based concept by taking optimal set of CHs depending on the stability index of the neighbor nodes in each round and also include far zone concept as proposed in [12]. More details about our proposed approach are shown in the next section.

3. Proposed Protocol

System Model

In WSNs, the network topology can be modeled as an undirected graph $G(N,E)$, where $N \in n_1,...,n_i$ and $E \in e_1,...,e_i$. A node n_i in the network is represented with vertex v_i in graph G. An edge (e_i) exists between v_i and v_j if there is communication link between corresponding nodes n_i and n_j i.e. $e_i \in E, \forall(i,j) \in E, d_{ij} \le r, \forall n_{i,j} \in N$.

Energy Model

In this research study, we assumed that each node has the capability to forward an incoming packet to its neighbouring nodes and to receive information from a transmitting node. The energy needed to transmit a packet P_c from node i is: $E_{tx}(P_c,i) = Ivt_b$ joules, where i is the current (in amperes), v is the voltage (in volts) and t_b is the time taken to transmit packet (in sec). Therefore, the energy consumption is modelled as [13].

$$E(P_c,i,j) = E_{tx}(P_c,i) + E_{rx}(P_c,j) \quad (1)$$

Where E_{tx} and E_{rx} energy spent to transmit the packet from node i to node j and to receive the packet at node j respectively. In the proposed model, the power consumption is determined by taking power consumption at transmitter i.e. T_{ij} , power consumption at receiver i.e. R_{ij} and power consumption due overhearing. In particular, the transmission power T_{ij} is modeled as:

$$T_{ij}(t) = c_{ij} r_{ij} \tag{2}$$

Where r_{ij} is the data stream rate sending from node i to node j , and coefficient c_{ij} represents power expenditure cost per bit associated with edge $e_i \in E, \forall(i, j) \in E$ and it is modeled as:

$$c_{ij} = \gamma \Psi d_{ij}^{\eta} \tag{3}$$

Where γ is a distance independent parameter used according to network characteristics, η represents the path loss index and having value $2 \le \eta \le 4$, d_{ij} denotes the Euclidean distance between node i and node j, and Ψ is a distance-dependent coefficient and takes according to average distance between nodes in the network. In particular, Ψ is modeled as:

$$\Psi = d_{ij}^{avg} r \tag{4}$$

Where d_{ij}^{avg} represents average distance between node i and node j at time t and r is the transmission of a sensor node.

Similarly, the energy consumption during the packet reception at the node is modeled as:

$$R_{ij}(t) = \zeta r_{ij} \tag{5}$$

Where ζ represents the energy dissipated to receive one bit of information. In the proposed model, it is assumed that ζ is constant and same for every node and r_{ij} is the data rate from node i to node j.

Furthermore, energy saving mechanisms based only on metric related to residual power cannot be used directly to find stable nodes as CHs. The reason is that a node is willing to accept all requests, because it has enough residual battery power, much traffic will be injected to that node. In this sense, the energy decay rate of that particular node will tend to be high and causes a sharp decay of its backup battery power. As a consequence, it could exhaust that nodes' energy quickly, causing the node to die sooner. To mitigate this problem, metric based on traffic load characteristics from its neighbor nodes can be used along with node residual energy metric. In particular, minimum node energy decay rate as described in [14] is applied as cost function that takes into account node energy decay rate index (DR) and residual energy of nodes to measure the node energy dissipation rate. Each node i monitors its energy consumption due to transmission, reception and overhearing activities, and computes its energy decay rate DR_i for every T second. The expected value of DR_i is calculated by using a well known method called Exponential Weight Moving Average (EWMA) and can be applied on both previous energy decay rate as well as on the current decay rate which is modeled as follow:

$$DR_{curr,i} = DR_i(t) \tag{6}$$

$$DR_i(t) = \alpha DR_i(t-1) + (1-\alpha) DR_{curr,i} \tag{7}$$

To take current condition of energy expenditure of a node, the proposed approach takes the ratio of residual battery power at node i to the energy decay rate $DR_i(t)$ at time t which is represented by $s_i(t)$. It can be modeled as:

$$s_i(t) = E_{res_i}(t) \big/ DR_i(t) \tag{8}$$

Therefore, the expected stability index to find the stability index of sensor nodes to become CH can be modeled as:

$$s_{\exp_i}(t) = E_{res_{\exp}}(t) \big/ DR_i(t) \tag{9}$$

The expected residual power is calculated as follow:

$$E_{res_{\exp}}(t) = E_{res}(t) - E_{\exp Consumed}(t) \tag{10}$$

3.3 Problem Formulation

The problem of finding the optimal number of stable CHs in WSNs is formulated as a multi-criterion model. However, the number of efficient solutions may be exponential with the problem size. Consequently, it is not possible to define an efficient method to determine optimal number of stable CHs in polynomial time. Therefore, in this paper, we consider fuzzy logic system to elect stable nodes as CHs. Our problem can be defined as follows: "*N numbers of sensor nodes know their location using some localization algorithm is randomly deployed in an area of interest. Our goal is to implement a localized energy efficient approach that ensures that only most stable nodes based upon multi-criterion will be chosen as CHs with the constraint that only one node act as CH in one cluster for a particular round*".

3.4 Contribution of the Proposal

The objective of our proposed approach is to find the more stable nodes in the clusters such that these can become CHs in the current round of operation. After applying one of the metrics proposed in [15] i.e. node residual power, a multi-criterion intra-cluster and inter-cluster fuzzy logic system based on nodes' local neighborhood information is applied. Indeed, a stable sensor node among the neighbor nodes will be chosen as CHs and it will also maximize the joint node-stability-energy metric to enhance network lifetime. Due to local scope of our proposed approach, it has good scalability as well as low message overhead in the large scale network. In the outset, our main contributions are:

- A multi-criterion intra-cluster and inter-cluster mathematical formulation for joint expected node stability and residual energy metric based on node energy decay rate for CHs election is proposed.
- Our proposed protocol is different from other state-of-the-art approaches (i.e. LEACH-E, Far Zone LEACH and CHEF) due to account of joint expected node stability and residual energy metric in the implementation.
- Our protocol is different due to account of limited communication overhead at different levels (i.e. level 1 and level 2).

3.5 Motivation and Methodology

3.5.1 Motivation

This section outlines the motivation behind the implementation of our proposed protocol. A major drawback of currently proposed 2-level fuzzy logic based CHs election protocol is that it does not elect all stable nodes as CHs so that some CHs deplete their energy very quickly as compared with other stable nodes. This cause unbalanced dissipation of energy in the network and consequently decreases the overall network lifetime. Therefore, a new approach, i.e. joint multi-criterion based intra-cluster and inter-cluster data communication based on fuzzy logic is proposed by us to elect the stable nodes as CHs to prolong the network lifetime. Our proposed approach uses expected node stability index and expected residual power (it is also based on number of neighbor nodes of a node) at level 1, and distance between CHs, distance of CH to sink through multi-hop and centrality at level 2 to choose CHs to transmit the data in an energy efficient manner. Fig. 1 shows schematic diagram of our proposed approach**.**

3.5.2 Fuzzy Inference System

To handle uncertainties in WSNs, we use multi-criterion fuzzy logic system to evaluate the eligibility of each node as CH. Level 1 evaluates the local level eligibility of nodes based on expected node stability index and number of nodes in the neighborhood (i.e. 1-hop neighbors). Level 2 calculates the eligibility of nodes to transmit data in an energy efficient manner. The fuzzy set that describes the final eligibility is depicted in Fig. 2. The fuzzy set that describes the expected node stability condition are high, medium and low. A triangular membership is used for medium value and trapezoidal member function is used for high and low. The output variable is local eligibility of a node as CH (i.e. at level 1). The fuzzy set that describes the distance between CHs, proximity and centrality are low, medium and high respectively. A trapezoidal member function is used for high, medium and low. To give our incidence feature of flexibility, we divide the fuzzy set into linguistic variables of nine levels to calculate the final eligibility as follow: *very small, small, rather small, medium small, medium, medium large, rather large, large and very large*. Once again trapezoidal membership function represents both sides, and triangle membership function represents other eligibility level (i.e. level 2) as shown in Fig. 2. In particular, the main objective is to elect a sensor node as CH having good stability condition and consumes low energy for data transmission in the network.

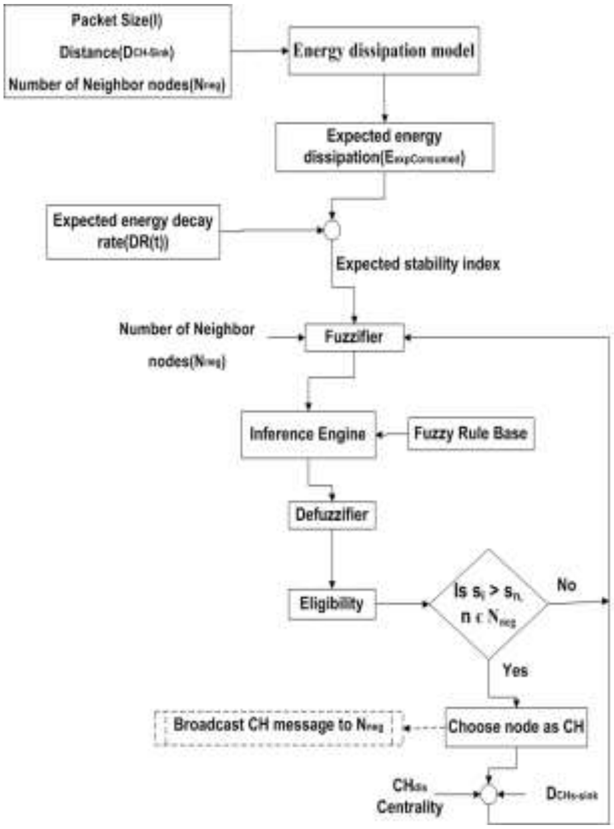

Fig. 1: Schematic chart of our proposed approach

TABLE 1: Simulation parameters

Parameters	**Value**
Simulation Area	2000m X 2000m
Nodes	10-100
Radio Model	Two Ray Ground Model
MAC Layer	IEEE 802.15.4
Communication Range (r)	50m
Node Initial Energy (E_i)	0.1 joule
Simulation Time	500-4000 seconds
α	0.3
Channel Frequency	2.4 GHz
Path Loss Model	Two Ray Model
Data packet Size	512 bytes
Antenna Model	Omni-directional
DR_i	1.5 x 10^{-9} J
Broadcast packet size	16 bytes
Probability(P)	0.07
E_{elec}	50 nJ/bit
E_{amp}	100pJ/bit.m^2
Data Fusion Rate	100%
Base Station Coordinates	100, 250

4. Simulations and Result Discussions

The purpose of simulation experiment is used to act as a proof for the designed protocol. Using simulations, it can be determined whether the designed protocol adheres to the defined criterion and requirements. This section shows the performance of our proposed approach through simulations. The goal of the simulations is also be used to show that our proposed approach outperforms other approaches like LEACH-E, CHEF and FZLP. Our proposed approach is validated in a simulation environment MATLAB-2013 on i7 machine. Table 1 shows the simulation parameters taken during our implementation. Sensor nodes are randomly deployed in an area of 2000m x 2000m consisting of varying numbers of sensor nodes (10 to 100) with fixed transmission range (r = 50m). The results of the individual experiments are averaged over 30 trials at 95% confidence interval. The following metrics are used to measure the performance of our proposed approach.

a) Number of Alive Nodes

This metric is used for observing the lifetime of the network. A node can be dead due to some physical damage or might be out of battery power due to its complete battery exhaustion. A network is called reliable if the node death rate is low. A reliable network will have better data gathering efficiency i.e. data received at base station will be quite high. Fig. 3 illustrates the number of rounds for last node death as function of number of nodes in the network. Our proposed approach outperforms due to use of stable nodes as cluster heads (CHs) to transmit data through multihop paths instead of direct transmission to BS. Moreover, as the network size increases, the probability to find eligible stable nodes is more which is also confirmed in Fig. 3.

b) Number of half Alive Nodes

The authors of [15] proposed a new metric called half of the nodes alive (HNA) to evaluate the energy consumption of nodes in the network. It describes the number of rounds at which half of the sensor nodes are died. This metric is very useful in densely deployed networks like WSNs to evaluate the network performance. Fig. 4 illustrates that our proposed approach has excellent energy consumption distribution over the nodes in the network as compared to CHEF, LEACH-E and FZLP.

c) Stability Period

Stability period illustrates the time period until first node dies in the network. This metric is a good parameter to judge the efficiency of any data dissemination protocol. Large stable period means more number of nodes is alive for long period of time and proposed protocol is better. Fig. 5 confirmed the effectiveness of our proposed approach over LEACH-E, CHEF and FZ LEACH having longer stable period, because first node dies later than other proposed approaches, thus the network is more stable with large number of alive nodes. Moreover, CHEF illustrates equal stability period for small network, but our approach shows excellent stability in bigger network.

d) Energy Consumption

Fig. 6 shows the energy consumption of network as a function of number of rounds vs. number of nodes. It is clearly illustrated from the simulation graph that in our proposed approach results are much better as compared to CHEF, Far Zone LEACH protocol (FZLP) and LEACH-E due to selection of stable nodes as CHs for energy efficient data communication. Through above simulation analysis, we observe that our proposed approach outperforms over the state-of-the-art approaches (i.e. LEACH-E, CHEF and FZLP). Moreover it is more efficient than LEACH-E about 53%, FZLP 46% and CHEF 21%. LEACH-E has poorest performance due to uneven energy consumption of the nodes in the network. CHEF has good performance over LEACH-E but it generates a random number for each sensor and determines node eligibility as CH. Thus, there may be some eligible nodes that lose their chance on random manner. Moreover, FZLP further improves its efficiency over LEACH-E by including far zone nodes in separate clusters instead of taking long distance communication between nodes.

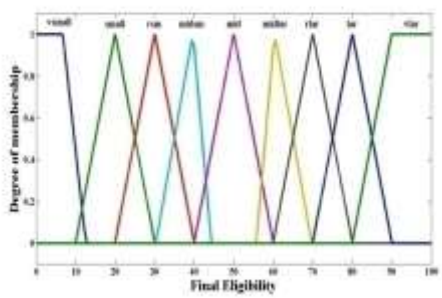

Fig. 2: Fuzzy set for output variable: final eligibility

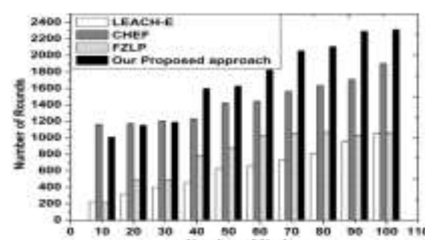

Fig. 3: Last node death (LND) vs. number of nodes

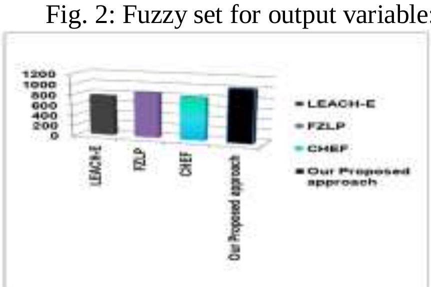

Fig. 4: Rounds at which half of nodes alive for LEACH-E, CHEF, FZLP and Our proposed approach

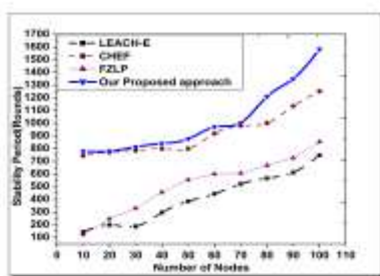

Fig. 5: Stability period vs. number of nodes

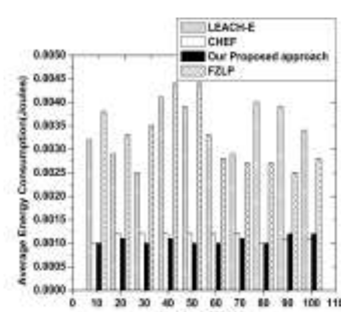

Fig. 6: Energy Consumption vs. number of nodes

5. Conclusion and Future Scope

Energy conservation is a major concern in designing of unattended WSNs. To achieve this target, many fuzzy logic based energy efficient CH election approaches have been proposed recently. A 2-level fuzzy logic based approach is the latest among these approaches. This approach used local level and global level (i.e. two levels) parameters to evaluate the eligibility of a node to become CH. However, it uses parameters directly without considered the node stability. Therefore, some of more eligible nodes lost their chance to become CH in the current round and shows uneven energy dissipation. Hence, in this paper, we propose an improved approach that uses multi-criterion fuzzy logic intra-cluster and inter-cluster based stable cluster head election approach to elect the stable nodes as CHs. The main objective of or proposed approach is to prolong network lifetime by evenly distributing the energy consumption over most stable CHs. As observed in simulation results, the proposed algorithm raises the residual energy of nodes effectively due to election of stable nodes as CHs in every round and consequently, prolongs network lifespan. Moreover, our proposed approach performs better even in large scale network i.e. having good scalability. In the future, we will try to make our proposed approach more robust and fault tolerant by taking care of unexpected intermittent failure of CHs during steady state phase of network to avoid the loss of important data in the network.

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