Fuzzy based hierarchical optimized approach with connectivity in WSN using multiple conflicting factors for application in the supervision of pipeline

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Abstract. Wireless sensor network presents a real-time system different from its traditional infrastructure, which comprises of sensor nodes have limited computation, energy and storage space. The main issue of WSN is to maximize the network lifetime of WSN as sensor nodes began to die after a certain interval of time. To resolve this issue many algorithms have been proposed keeping clustering as the best solution. The best cluster head selection has extremely minimized energy consumption. We have worked on a hierarchical algorithm which deals with fuzzy logic approach rooted on four parameters- a) Delay, b) Connectivity to Sink, c) Average Lifetime of Member Nodes, d) Standard Deviation of Lifetime of Members. We have used these parameters for data communication regarding the hazardous activities in the pipelining like: leakage of gas, petrol etc. This algorithm is for low computational sensor networks in nature where we can’t compute a lot. Connectivity confirms the effective data communication between CH to BS. We have shown a graphical representation. The results and simulation depict the efficiency of the proposed algorithm with the base algorithm. A worthy increase in the existence of the network can be examined as compared to traditional ways of selecting the cluster head.

1. Introduction
WSN is made up of various tiny nodes [1] which are scattered/distributed over a specific area for human motion tracking, environmental monitoring, military, medical science etc. These nodes being capable of detecting, sensing and transmitting, sense the data and transfer it to the sink nodes. Sensing range clarifies the coverage of these nodes and hence defining connectivity of node to reach sink [2] [3]. Connectivity can be defined as an ability of the sensor node to sense the environment and transfer the information through the network to reach the data sink. Connectivity confirms that every node can directly communicate with at least one CH and every CH is connected with at-least one another CH or the sink.

Heterogeneous wireless sensor network consists of many sensor nodes with different energy, communication and sensing range. Each sensor nodes are provided power through batteries. Energy here plays a vital role as these power source could not be changed more often in remote and distant areas. Topology utilization and We can avoid the nodes losing connectivity due energy drain by dynamically clustering these nodes. Through efficient clustering mechanisms [5] [6], we can group nodes such that they reduce their energy consumption for certain connection paths and hence increase the lifetime of network. Here, our proposal is for fuzzy based approach utilizing some conflicting attributes simultaneously. Fuzzy provides effective fitness calculation.
for population. Best fit population is opt for CH role. 
Over the years, technology has been growing fast. There has been a tremendous advancement in digital electronics, wireless technology, and communications. In this growing era of technology, WSNs are predicted to be one of the emerging technologies moving towards widespread feasibility. WSNs have their applications in a variety of fields including health-care monitoring, environment, military surveillance, and biological threats, etc.
Wireless sensor network has sensor nodes which are inexpensive and portable with limited constraints of memory and computational power. As it is not possible to change batteries in the nodes of the WSNs once it is deployed, the issue arises in the designing topology of the network to as much increase the life of the nodes and lessen the energy consumption. This can be initiated by allowing only some nodes to directly communicate with the base station, which is referred to as cluster heads. Favorable cluster head selection leads to a noteworthy reduction in energy and intensify the lifetime of the network. In the proposed approach, we have used fuzzy logic for the cluster head selection which is based on four factors:
1. Delay
2. Connectivity to Sink
3. Average Lifetime of Member Nodes
4. Standard Deviation of Lifetime of Members
Fuzzy logic is a concept which follows multi values of variables that lies between 0 and 1, instead of focusing on binary values. Fuzzy resembles human reasoning. Use of fuzzy while selection of cluster head has led to a more efficient WSN. The node pursuing the greater chances of being elected as a cluster head is based on its value of the taken four descriptors. The process gives the output and selects the best cluster head using the fuzzy logic. The entire process of selection has been descriptive in methodology section. Fuzzy logic used, peruse the capability of taking the decisions in real-time environment with or without the complete information. The simulation shows that relying on the type of topology configuration, a noteworthy increase is being configured in the proposed algorithm when compared With Basic LEACH algorithm and the base algorithm [34]. LEACH is the most traditional algorithm which uses local clustering and selects the cluster head randomly. The other nodes join the cluster head depending upon their signal strength. The cluster head collects the data from the nodes, aggregates them and sends it to base station.

![Hazardous event communication in pipeline](image)

**Figure 1.** Hazardous event communication in pipeline
2. Related Work
Clustering is an important method for efficient data gathering by reducing energy dissipation. It uses topology management to make the collection of information efficient. Many clustering approaches have been developed by many authors. We are providing literature of some famous algorithms. LEACH is the main algorithm given by Heinzelman [7] using probabilistic model. It has two phases for data collection first is set-up phase in which the CHs are formed using probability in such a way that energy nodes will become a CH after particular number of rounds. So it distribute the role of CH among the nodes for balancing the energy dissipation. For this it divides the nodes as advanced nodes and normal nodes and choose the CH from advanced nodes using probability with randomness. After selection of CH, all other nodes join the nearest CH. After it, a TDMA schedule is assigned to the nodes for transmitting the data. Contrast to these advantages, randomness provides unbalance energy consumption and network died earlier. LEACH-C [8] is advancement to the LEACH by providing a concept that only those node will be able to work as CH whose residual energy be greater than the average network energy. So that only those nodes participate in CH selection procedure that have high residual energy. This improves the efficiency as compared to LEACH protocol but even it provides unbalanced energy consumption.
H-LEACH [9] is hybrid LEACH protocol that divides the whole area into some partitions and LEACH is used to select one CH in each partition. It provides the distributed CHs in whole area that provides the optimal energy consumption as compared to LEACH. But even it is based on randomness also no concept for partition, so it even consumes higher energy. Aditya et al. [10] tried to reduce the energy consumption in H-LEACH by improving the concept for clustering and also add re-clustering phase for making optimal clusters. HEED [11] utilizes member nodes for finalizing CH responsibility. Whereas, EEHC [12] provide clustering for heterogeneous WSN. Sharma et al. [13] suggested an approach for multi-hop clustering and routing. Some researchers [12] also suggested the view of centralized approach for CH selection as BS has large amount of power to compute. Connectivity [14], node deployment [15] [16], data compression [17], scheduling and coverage [18] are some main issues explained by various researchers and also provided some solutions using single hop and multi-hop communication in centralized and decentralized manner [19] [20] [21]. Target tracking clustering algorithms are also provided to optimize energy consumption [22] [23]. Other solutions are also provided for data collection using WSN in various applications [24] - [39]. Some authors have also suggested many conflicting attributes that affect the data gathering approach in our previous works [40] [41]. Base approach [34] is an effective technique for pipeline supervision. We have proposed our approach in detail in next section.

3. Proposed Work
The following steps describe the complete algorithm:
Step 1: We use the concept of LEACH-C for selecting the nodes with high residual energy:

\[ E_{\text{residual sensor}} > \text{Avg}_E_{\text{res network}} \]  

(1)

Step 2: After selection of high energy nodes, we generate total fifteen populations using k-mean algorithm. Every set of population contains optimal number of CHs needed for clustering. After this we have to choose the best set from the generated sets using fuzzy based fitness function also maintaining the connectivity with less delay. For this we have used four conflicting attributes and explained in next steps.
Step 3: Delay: Delay shows the time required to transmit the packet from node to destination.
It is inversely proportional to residual energy.

Step 4: Connectivity to Sink: It shows the percentage of CHs of particular population that are
directly connected with the Sink or capable of sending the data without distortion means these
CHs have no need to amplify the signals. Since amplification of signal needed when it travels
\(d_0\) distance, so we can find the connectivity percentage as:

\[
CH_{Connect} = \frac{\text{Count}_{\text{CH}_k (\text{Distance}_{\text{CH}_k-Sink}) \leq d_0}}{\text{Optimal}_{\text{CH}}_{Req}} \times 100
\]  

(2)

Step 5: Average Lifetime of Member Nodes: The nodes other than the CHs in particular set are
known as member nodes. This attribute counts the average of lifetime of these member nodes.
It helps in describing the time period till the member nodes can sense and send the data to the
relative CH without changing the topology. So it helps to ensure the time till we can continue
with the same clustering or same CHs. It can be given as:

\[
\text{Avg}_{Life, Mem} = \frac{\sum_{k=1}^{\text{Total}_{CH}} \sum_{i=1}^{\text{Total}_{Members}} \text{Member}_i.Life}{\text{Total}_{MemberInNetwork}}
\]  

(3)

where

\[
\text{Life}_{Member}_k = \frac{E_{res, Member_k}}{\text{Transmission}_{Energy}_{ReqMember-CH}}
\]  

(4)

Step 6: Standard Deviation of Lifetime of Members: It describes the Deviation in the lifetime
of member nodes of the network. It confirms the load balancing among the member nodes. For
this it needs the lower value of this attribute, low value of standard deviation means high load
balancing among member nodes. It plays an important role when dead of single sensor affects
the whole data gathering process. It can be given as:

\[
\text{Std}_{Mem, Life} = \sqrt{\frac{\sum_{m=1}^{\text{Total}_{Mem}} (\text{Life}_{Member}_m - \text{Avg}_{Life, Mem})^2}{\text{Total}_{Net}_{Members}}}
\]  

(5)

Step 7: After computing all the attribute values, normalize the values of attributes so that we
can compare the attribute value. After normalization process, we use fuzzy membership functions
and rules to find the fitness value for every population or CH sets. Fuzzy uses fuzzification
and defuzzification procedure to calculate fitness value. Here, triangular membership functions
are used. We made 81 rules to calculate the fitness of population. Fuzzy membership functions
and rules are shown in Figure 2-3.

Step 8: Finally, we select the population with highest fitness value and mark the nodes as
Figure 2. Fuzzy overview for fitness calculation

Figure 3. Graph view of rules for fitness calculation with a calculation

final CHs present in that set. These CHs will be responsible for the data collection process and computation on collected data. Now the selected CHs sens the advertisement message that they have selected as the CHs.

Step 9: **Cluster Formation:** Remaining nodes are known as member nodes and receive the advertisement message. Every member joins the cluster of that CH whose signal is received with highest intensity.

Step 10: **Data Communication:** All CHs in tier2 transmits the data to nearby tier1 CH and then CHs in tier1 directly sends the data to BS.

4. Result and Experimental Simulation

We have simulated our technique using MATLAB. MATLAB provided a realistic framework for comparing our techniques with previous techniques. We have collated with LEACH and old algorithm proposed. We have used two characteristics to compare- number of dead nodes and residual energy of network. Network energy comparisons are shown using Figures 5, and 7 and
dead sensor comparisons are shown in 4, and 6.

CASE 1: Position of Sink: Outside at one end; Sensors: 100; Rounds: 100;

**Figure 4.** Dead sensors’ compare at $R_{\text{max}}=100$

CASE 2: Position of Sink: In middle but one side of pipeline; Sensors: 100; Rounds: 500;

**Figure 5.** Residual power compare at $R_{\text{max}}=100$

**Figure 6.** Dead sensors’ compare at $R_{\text{max}}=500$
Conclusion
The proposed algorithm insures the hazardous event information necessary for with minimum energy consumption. Delay consideration verifies that the minimum delay to transfer the packet with higher residual energy of CH. Connectivity consideration ensures that maximum CHs are connected with sink. Lifetime verifies that the member nodes are also having nearest CH and standard deviation ensures the load balancing among member nodes that ensures that equal importance is given to each and every member node to ensure higher lifetime. Result and Simulation verifies that our technique is able to minimize the energy consumption with less node die and higher residual energy as compared to other previous algorithms.

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