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A Cognitive Multi-hop Clustering Approach for Wireless Sensor Networks

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Abstract Wireless sensor networks (WSNs) exert a pull on the modern research community towards many design challenges, especially, constraints on their lifetimes. Solutions proposed to save energy in WSNs posses their own merits and limitations. The trends evolved from the perspective of improving performance and scalability of conventional clustering approaches. They emerge by adopting cognitive techniques to handle uncertainty and instability present in the application atmosphere. This paper proposes a clustering approach for WSNs, namely, energy aware fuzzy clustering algorithm (EAFCA) which achieves lifetime enhancement in CH election, data aggregation and inter-cluster traffic phases of a multi-hop WSN environment. This algorithm contributes the process of cluster head (CH) election in a cluster in an energy-efficient manner by considering the residual energy, mean distance to 1-hop neighbors and 2-hop coverage of the competing nodes. The elected CH aggregates the data from all the sensor nodes of its cluster and forwards the same to the base station. Performance evaluation of the proposed EAFCA is done with popular clustering algorithms and the experimental results show improvement in terms of lifetime of WSNs under first node dies and half of the nodes alive scenarios.

Keywords Wireless sensor networks · Clustering · Fuzzy logic · Multi-hop network · Energy consumption

1 Introduction

A Wireless Sensor Network consists of homogenous/heterogeneous types of sensor nodes which work together to accomplish a common set of objectives. These nodes typically equipped with limited, non-rechargeable power resources which are seldom under human

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monitoring. The lifetime of a WSN is defined with respect to the application-specific requirements of sensor networks. Invariably, energy preservation in the sensor nodes becomes the dominant and monolithic constraint on achieving lifetime efficiency under all these scenarios.

The energy consumption occurs during sensing, computation and communication phases of a sensor node. In many sensor applications, it is observed that communication overhead conquers the key role in determining the energy conservation of a network as a whole which makes other two even negligible from macroscopic perspectives.

Due to their memory and processor constraints, sensor nodes are limited to their coverage regions. This demands the self-organization and an autonomous mode of cooperation among the sensor nodes to collect the required data and report the same to the sink/observers. In order to gain energy efficiency in data gathering, sensor nodes are partitioned into clusters in many sensor applications. A typical clustered wireless sensor network is presented in Fig. 1. In each of these clusters, a cluster head (CH) is elected and contributed to gather, aggregate and report the data. In addition to improvise the quality-of-service (QoS) parameters of a WSN, the clustering ensures the scalability of the sensor applications. The phenomenon of clustering benefits from both centralized organization and localized decision making [1].

There has been a substantial quantum of research contributions made on CH election process from the perspective of achieving energy efficiency. Many of these approaches consider only the residual energy of a sensor node and they exhibit inefficiency owing to the lack of their consideration over the location of the base station (BS) which leads to hot-spot issues, especially in a multi-hop environment. CHs near to the BS faces higher energy depletion compared to the CHs which are located far from the BS. Some emerging research works propose unequal clustering in which clusters of different sizes are formed. The

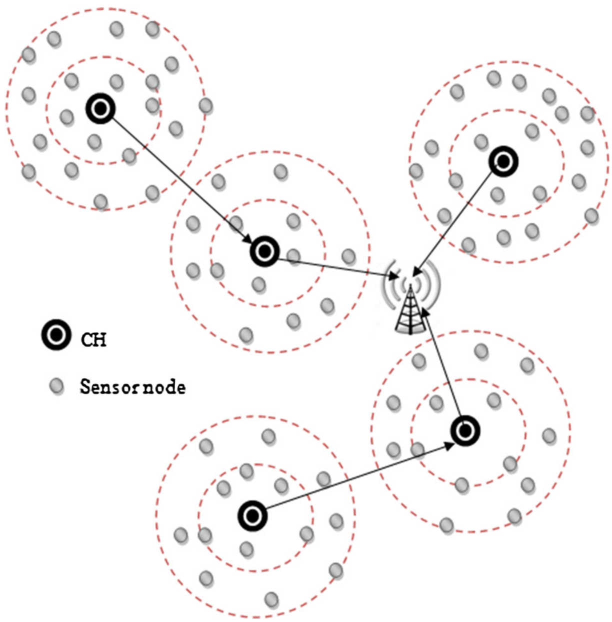


Fig. 1 A clustered wireless sensor network

clusters near to the BS are smaller in their size compared to the clusters that are far from the BS to reduce intra-cluster relay in these clusters and hence they can be balanced to accommodate the heavier inter-cluster relays [2, 3].

There have been multiple clustering approaches proposed which are focusing and emphasizing versatile requirements of WSNs. Among them, one of the most traditional clustering approaches, namely, low energy adaptive clustering hierarchy (LEACH) rotates the CHs in a cluster periodically for each round from the energy perspective [4]. Here, a round refers to an interval that exists been two consecutive cluster formation processes. Many variants of the LEACH approach have been observed in the literature focusing various performance constraints [5–8]. Each of these variants composes of its own merits and demerits towards the QoS requirements of the WSN on a comprehensive perception. The pure probabilistic model used by LEACH to select the CH leaves entropy and uncertainty of the solutions abandoned and hence reveals many sensible challenges from the real-time viewpoints.

To handle the uncertainty in the process of CH election, some approaches put forward the idea of fuzzy based decision making. These fuzzy clustering approaches such as cluster head election mechanism using Fuzzy logic (CHEF) consider residual energy of the competing nodes and their distances to the BS. These approaches impose additional overhead on CHs owing to the intensive inter-cluster relays. These solutions address the need of a relay node in each of these clusters to share a part of the load from the CH. The election of CH becomes critical and often yields additional overheads in these approaches since a CH has to concentrate on data aggregation and relay simultaneously which indicates the need for a relay node to share the load of the CH.

This paper proposes energy aware fuzzy clustering algorithm (EAFCA) for WSNs which addresses the issues raised above. It combines the advantages of many research works and contributes a hybrid model which benefits from the multifaceted analysis on WSN performance factors. This paper contributes a CH election process with respect to three constraints: the residual energy of CHs, node centrality and 2-hop node coverage. The communication to the BS is done through the selection of a relay node. The role of relay node is rotated for every time the CH changes.

The lifetime of a sensor network is defined on various degrees depending upon the nature of the application, traffic pattern and the availability of resources. A sensor node conserves energy during transmission, reception and idle states. When a sensor node drains off its total energy, it is considered to be a 'dead' node.

Handy et al. [9] employs three metrics to measure the lifetime of a sensor network: first node dies (FND), half of the nodes alive (HNA) and last node dies (LND). The first definition among them estimates the lifetime of a WSN till the first node dies in the network. The second definition extends the lifetime of a WSN till half of the population drains off the energy. The final metric scales up the lifetime of a WSN till the last node in the network dies [22]. The definition chosen for a WSN should be justified against the application-specific requirements and pragmatic constraints. This paper examines the efficiency of the proposed approach under first node dies (FND) and half of the nodes alive (HNA) scenarios against selected representatives of conventional and modern clustering approaches and demonstrates improvement in the lifetime of WSNs with respect to various scenarios.

The remainder of this paper is organized as follows: Sect. 2 discusses the research works related to this proposed work. The system model for our proposed algorithm is illustrated in Sect. 3. Our proposed clustering algorithm is introduced and elaborated in Sect. 4. Section 5 experiments the competency of the proposed approach against existing clustering algorithms and presents the results. Section 6 concludes and explores the further possible enhancements of the proposed work.

2 Related Work

It is observed from the literature that many research works have been proposed to form energy-aware clusters in WSNs. This section addresses the some significant works on the evolutionary phase of these research works and explores their benefits and limitations.

LEACH is a prominent ancestor clustering work which elects CHs based on local decisions. The state of permanently being in the role of CH leads them to drain their energy completely off and soon they die. To prevent this, LEACH rotates CH for every round randomly among the sensor nodes in a cluster and attempts towards uniform distribution of energy dissipation over the cluster members [24]. This probabilistic model lacks of topological knowledge of the cluster and works for elementary level of assumptions. LEACH [23] also reduces the data traffic from the CH to BS by compressing the data within the cluster. The component of randomness involved in CH election results in uneven load distribution and absence of energy awareness.

The limitations of LEACH motivate the researchers to revisit and improve the LEACH protocol to adopt QoS requirements of WSNs. A version of LEACH namely, M-LEACH proposed by Mhatre and Rosenberg [10] discusses the extension of this probabilistic model to a multi-hop sensor environment and demonstrates better performance. Heinzelman et al. [11] present LEACH-C, another variant of LEACH which depends upon the BS to collect location and energy level information of sensor nodes, selects the CHs and broadcasts this information. This centralized architecture fails to cope up the scalability of the WSNs. Manjeshwar and Agrawal [12, 13] propose two event-driven, hierarchical structures on LEACH namely, threshold sensitive energy efficient sensor network protocol (TEEN) and adaptive threshold sensitive energy efficient sensor network protocol (APTEEN). In these protocols, transmission is performed while reaching certain thresholds. Lindsey and Raghavendra [14] propose a chain based variant of LEACH protocol named Power-Efficient Gathering in Sensor Information Systems (PEGA-SIS) which employs a greedy approach in determining the path from the source to the BS. Eventhough it effectively administers network scales in a typical multi-hop environment, it demands all the nodes to acquire the global knowledge of the entire network which is practically infeasible in many sensor applications. Also, this protocol imposes threats on network reliability. In general, LEACH [25] and its variants suffer from scalability and load balancing despite their simplicity.

Hybrid energy efficient distributed clustering (HEED) elects the CH by considering the residual energy level as the essential parameter [20]. In the case of a tie among the competing nodes, either the mean local distance or node degree is used to determine the CH. Despite the favorable features of HEED, it suffers from increased overhead due to its iterative broadcasting scenario.

Sert et al. [21] have proposed a multi-objective particle swarm optimization (MOPSO) algorithm which estimates the optimal number of clusters in a mobile WSN. This algorithm considers the node degree, transmission power and energy consumption of mobile nodes to regulate and reduce intra-cluster and inter-cluster traffic. In this approach, inter-cluster and intra-cluster traffic is handled by the CHs.

Modern clustering algorithms tend to solve the uncertainty involved in the process of CH election using fuzzy logic. Fuzzy logic models the human decision making behavior and expresses the input–output relationships as a set of linguistic rules or relational expressions. One of the forerunner works in this area proposed by Gupta and Sampalli attempts to improve the performance of LEACH by evaluating three parameters for a fuzzy logic based CH election process: residual energy, centrality and node degree [15]. It becomes a centralized approach and hence exhibits lack of scalability. CHs are elected either at the BS or in a distributed manner. In [16], the authors proposed an algorithm named cluster head election mechanism using fuzzy logic (CHEF) which estimates residual energy and local distance using fuzzy descriptors to identify the CHs. Local distance refers to the total distance between the tentative cluster-head and the nodes within a predetermined competition radius. This algorithm does not consider the distance of the elected CH to the BS and hence consumes more energy due to heavy relay traffic in multi-hop environments.

The cluster heads closer to the BS are exposed to heavy network traffic since they are massively engaged in forwarding the data from the nodes which are far from the BS. This leads to hot-spot issues. One popular solution to this hot-spot problem is to form unequal clusters in WSN which makes the clusters near to the BS smaller in their size to the clusters far from the BS. When the cluster size is reduced, it drives to reduced rate of data dissemination, limited degree of data aggregation and hence reduced intra-cluster communication overhead. This idea compensates the heavier inter-cluster relay experienced in the CHs near to the BS and balances the energy consumption in the networks.

Taheri et al. [19] propose an energy-aware clustering protocol using fuzzy-logic (ECPF) which is an extension over HEED protocol and uses a fuzzy system with the input variables on node degree and node centrality to form on-demand clusters. This work inspires the researchers to re-estimate the role of CHs from the intra-cluster perspective in a hierarchical sensor environment. It exposes obscurity in achieving the energy efficiency owing to the presence of hot-spot issues.

A modern fuzzy based clustering algorithm, named, energy-aware unequal clustering algorithm (EAUCF) is proposed by Bagci and Yazici [17] to incorporate the idea of smaller clusters for the CHs either near to the BS or having low remaining battery power. The competition radii of the tentative CHs are determined through two fuzzy variables representing the aforementioned factors. This approach demands the pre-estimation of cluster sizes and hence increases the complexity and the overhead in the process by and large.

In summary, the literature on the proposed research work indicates the scope of an efficient fuzzy based clustering algorithm which addresses the optimal CH election and traffic load distribution in the WSN clusters. The proposed work is further expected to produce improvised and scalable solution in prolonging the lifetime of a WSN bound to the traditional definitions.

3 System Model

The proposed system has been designed from the perspective of achieving lifetime enhancement through energy reduction in WSNs. The following set of assumptions is made about the characteristics of energy model and network model for the proposed algorithm.

3.1 Energy Model

The energy consumption model for this work is adopted from the communication model that is employed in [6]. Equation (1) represents the amount of energy required to transmit 'L' bits of data to a distance of 'd'. The energy components of Eq. (1) are calculated at transmitter circuitry and RF amplifier.

$$E_{txr}(L,d) = \begin{cases} LE_{elec} + L\varepsilon_{fs}d^2 & d < d_0 \\ LE_{elec} + L\varepsilon_{mpf}d^4 & d \geq d_0 \end{cases} \tag{1}$$

where 'd' is the transmission distance, ε_{fs} and ε_{mpf} are the amplifier energy factors for free space and multi-path fading channel models, respectively. 'd_0' represents the threshold distance that differentiates these two fading models.

Equation (2) calculates the amount of energy dissipated in receiving 'L' bits of data in the receiver side.

$$E_{rxr}(L) = LE_{elec} \tag{2}$$

3.2 Network Model

The WSN environment is modeled with the following set of assumptions:

- Sensor nodes are randomly deployed and unattended after deployment.
- All sensor nodes and BS are stationary.
- All sensor nodes are homogenous and equipped with same amount of energy at the initial deployment.
- Each node is assigned with a unique ID.
- The distance between any two nodes can be computed from the received signal strength and the links are symmetric.

Consider the distributed unconnected graph, G is

$$\mathrm{G} = \{\mathrm{V(G)}, \mathrm{E(G)}\}$$

where V(G) is vertices and E(G) as edges which is used to connect the different nodes in the network.

$$\mathrm{V(G)} = \{n1, n2, n3, \ldots, nn\}$$

where n denotes the number of nodes in the distributed network.

E(G) = {e1, e2, e3,…, en} and e is the link which is used to connect as well as disconnect the nodes in the network.

Ψ (G) denotes the connected node using the link. For example, Ψ(e1) = n1, n2.

The node n1 and n2 is connected through the link e1 and that is denoted as Ψ.

4 Proposed Clustering Algorithm

4.1 Cluster Formation

During the sensor network deployment phase, the BS broadcasts a beacon signal to all the sensor nodes. The sensor nodes compute the distance to the BS by received signal strength. According to the node density, the BS determines a fraction of 'f' nodes as temporary CHs from the network. A threshold 'T' is calculated and communicated to all the sensor nodes for every round to determine the eligibility of a tentative CH according to LEACH. Each sensor node computes a random number in the interval (0, 1) and compares the same against then threshold 'T'. If the computed value is more than the threshold, it declares itself as a CH and broadcasts the same to other nodes. Otherwise, it considers itself to be a non-CH node.

The fuzzy logic is introduced to elect eligible CHs from this set of tentative CHs. It is proposed to form the clusters in the WSN in such a way that any node can reach the CH with a maximum of 2-hop distance. For every tentative CH, the following set of parameters is computed.

- Remaining residual energy (represented as 'Energy'):

This parameter is expected to be higher for an eligible CH in a competition phase since it is heavily engaged to intra-cluster and inter-cluster data traffic.

- Node degree at its 2-hop coverage(represented as '2-Hop ND'):

This parameter stands for the total number of neighbours in the 2-hop distance from the tentative CH is calculated as in Eq. (3) which is expected to be higher for an opt CH.

$$2\text{-}hop\,node\,degree = \frac{|s_{2\text{-}hop\text{-}nbr}(i)|}{\#\,nodes} \tag{3}$$

where $s_{2\text{-hop-nbr(i)}}$ represents the set consisting of all neighbors of node I which can be reached at a maximum of 2-hop distance.

- Centrality of the CH (represented as 'Node Centrality'):

For an effective CH, this parameter should yield low values to reduce energy consumption during the data aggregation and flooding processes. Centrality of a node is calculated using Eq. (4).

$$Node\,centrality = \frac{\sqrt{\frac{\left(\sum_{j \in s_{2-hop-nbr}(i)} d^{2(i,j)}\right)}{|s_{2-hop-nbr}(i)|}}}{A} \tag{4}$$

where the parameter 'd(i, j)' represents the distance between nodes 'i' and 'j' in which node j is a member of the set 2-hop- nbr. The variable 'A' represents area of the network.

The process of fuzzification maps each crisp input value on the above three parameters for every tentative CH to a set of the corresponding fuzzy membership functions. The output variable 'chance' represents the possibility of a tentative CH to become a CH. The fuzzy sets for the input and output variables are presented in Table 1. Input fuzzy membership functions are presented in Figs. 2, 3 and 4. Output fuzzy membership function is provided in Fig. 5.

Table 1 Fuzzy sets for input and output variables

Energy	2-Hop ND	Node centrality	Chance
Low	Low	Far	Very weak
Low	Low	Medium	Weak
Low	Low	Close	Little weak
Low	Medium	Far	Weak
Low	Medium	Medium	Little weak
Low	Medium	Close	Little weak
Low	High	Far	Little weak
Low	High	Medium	Little weak
Low	High	Close	Medium
Medium	Low	Far	Little weak
Medium	Low	Medium	Little medium
Medium	Low	Close	Medium
Medium	Medium	Far	Little medium
Medium	Medium	Medium	Medium
Medium	Medium	Close	High medium
Medium	High	Far	Medium
Medium	High	Medium	High medium
Medium	High	Close	Little strong
High	Low	Far	Medium
High	Low	Medium	High medium
High	Low	Close	Little strong
High	Medium	Far	High medium
High	Medium	Medium	Little strong
High	Medium	Close	Strong
High	High	Far	Little strong
High	High	Medium	Strong
High	High	Close	Very strong

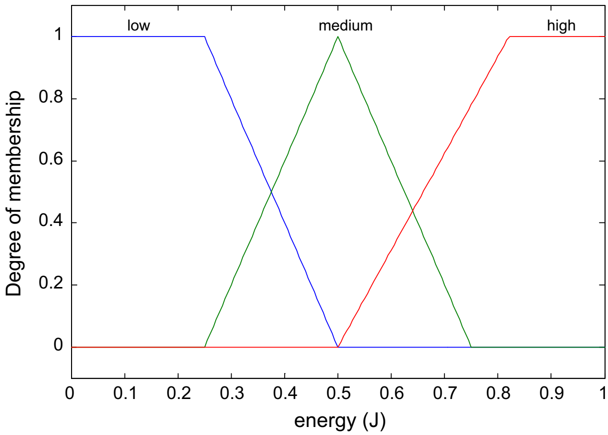


Fig. 2 Membership function for residual energy

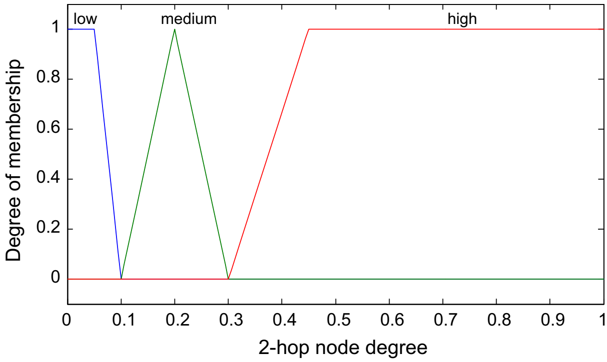


Fig. 3 Membership function for 2-hop node degree

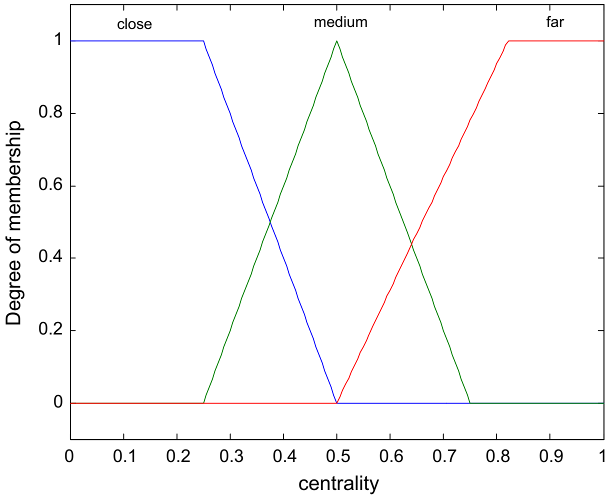


Fig. 4 Membership function for node centrality

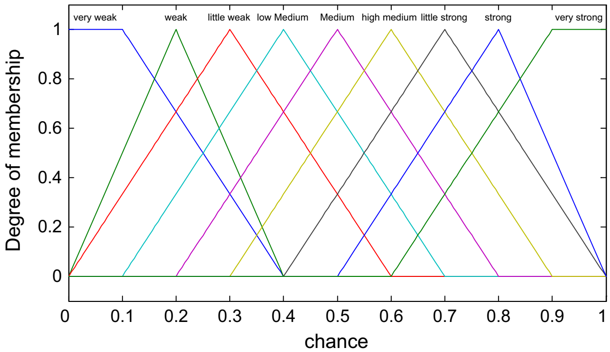


Fig. 5 Membership function for chance

Fuzzy if–then rules are processed in the fuzzy inference engine using Mamdani method. For each rule, an output is produced and the all the outputs are aggregated finally.

The centre of area method is used in the process of defuzzification to obtain crisp values, from the fuzzy logic rules. Each tentative CH broadcasts the value of 'chance' to all of its 1-hop neighbours. The same is forwarded to its 2-hop neighbours through the process of flooding and hence the size of each cluster is restricted with 2-hop coverage.

Suppose, a tentative CH has received advertisement with a higher value of 'chance' from any other competitor within a fixed period of time, then it declares itself to be a non-CH node; otherwise, it declares itself to be a CH elected and the same is communicated to all its 1-hop and 2-hop neighbours to form clusters. Now, every non-CH node in the WSN prepares itself to become a member of a cluster. It looks for the arrival of advertisements from the CHs. Under these circumstances, a non-CH node has a chance to receive the advertisement from more than one CH. In this case, a non-CH node joins the nearest CH. In the case of a tie in selecting its CH, it joins the CH whose advertisement comes first. Thus, clusters are formed in the WSN environment without any degree of overlapping.

4.2 Data Aggregation

After the clusters are formed, the required data is generated and disseminated by the cluster members, i.e., non-CH nodes of a cluster. In our experimental environment, all the clusters are formed in such a way that any cluster member can forward its data to the CH at a maximum of 2-hop distance. The CH is responsible for collecting and aggregating the data received from the sensor nodes. An aggregation ratio of 10 % is set for the WSN environment for this work as followed in many popular protocols such as CHEF [16].

4.3 Inter-cluster Relay

After data aggregation, the CHs have to report the aggregated data to the BS. Unlike LEACH and many conventional algorithms, our algorithm inherits the presence of multi-hop relay between the CH and the BS which is proposed in [17]. This multi-hop relay favors the selection of any one path based on certain probability among the multiple choices which is not necessarily to be an optimal path as followed in many approaches. When the same path is employed for multi-hop inter-cluster relay in a WSN, nodes on this path deplete their energy and soon die. This multi-hop relay balances energy dissipation involved in these operations and hence the energy gain of this relay becomes scalable across the network size. Either the CH directly delivers the data to the BS or the data reaches the BS through a multi-hop relay in this work.

4.4 EAFCA Algorithm

The list of steps involved in the proposed energy aware fuzzy based clustering algorithm (EAFCA) are summarized as follows:

Energy Aware Fuzzy Clustering Algorithm (EAFCA)

```
Input: A randomly deployed WSN with N sensor nodes
Output: Clusters with Cluster Heads
Begin
S ← Set of Sensor Nodes, |S|= N
Status (S[i]) ← M, i=1,2,…N
T ← Number of Tentative CHs
CH ← Set of Temporary Cluster Heads | CH[i], i=1,2,…T selected from S
S ← S - CH
Chance[j] ← Probability of CH[j] to become a Cluster Head, j=1,2,…..,T
For every Tentative Cluster Head CH[j], j=1,2…T
        Calculate Chance[j] using fuzzy if-then mapping rules
        Broadcast Advertisement (Chance[j]) to all its 1-hop and 2-hop neighbours
        While (timer)
            If (Advertisement from any CH[x] & (Chance[j] < Chance[x]))
                    Add CH[j] to S
                    CH← CH- {CH[j]}
            End if
            Else
                    Status (CH[j]) ← H
                       Broadcast Advertisement (Status (CH[j])) to all its 1-hop and 2-hop neighbours
            End else
        End While
End For
For every sensor node S[i]
        If Advertisement(Status(CH[k])) received form exactly one Cluster Head CH[k]
                    Add S[i] to CH[k]
        End if
// To avoid overlapping of clusters
        Else If (CHAdvertisement() message received from N number of Cluster Heads)
                    If there is exactly one Cluster head among these N ClusterHeads, namely, CH[k] yielding minimum
hop-distance
                          Add S[i] to CH[k] for the CH with minimum hop-distance
                    End if
                    Else
                              Add S[i] to CH[k] | Where First CHAdvertisement() message was received from CH_k
                    End Else
        End Else If
End For
End
```

5 Simulation and Results

5.1 Simulation Environment

In order to analyze the performance of the proposed clustering algorithm, a series of simulation experiments were conducted using MATLAB2014a.The performance of the proposed algorithm is compared with LEACH, ECPF and EACLE. To evaluate the performance, FND and HNA metrics are selected. Since the WSN becomes almost undeserving in many applications when more than half of the nodes die, the LND metric is not considered here.

The performance has been experimented under three different scenarios. In the first scenario, 100 sensor nodes are deployed. In scenarios 2 and 3, it has been increased to 200 to test scalability of the proposed algorithm. In the first two scenarios, the BS is situated at the centre of the WSN. In the last scenario, it is placed outside the boundary of the WSN. In all these scenarios, CHs in LEACH forward the aggregated data to the BS directly. ECPF, EACLE and EAFCA adopt a typical multi-hop relay as done in [18] to transmit the aggregated data to BS in all the scenarios. This multi-hop relay technique votes for choosing any one among the possible paths from the CH to BS, rather than always choosing the minimal cost route. This technique defends its idea based on the argument that the CHs on the shortest paths deplete their energy frequently and die soon. Hence the path from the CH to the BS is chosen based on certain probability which is incremented periodically and reaches zero when the CH happens to be on the relay path.

LEACH directly transmits the aggregated data from the CHs to the BS in all the three scenarios. In LEACH and ECPF, clusters possess 1-hop intra-cluster communication. In EACLE and EAFCA, clusters are formed with 2-hop intra-cluster relay.

The common set of simulation parameters of LEACH, ECPF, EACLE and the proposed EAFCA algorithm are presented in Table 2. The size of a data packet is set as 50 bytes.

5.2 Scenario 1 (BS is Positioned at the Centre of the WSN, Network Size: 100)

In this scenario, the BS is located at the centre of the WSN (100 m, 100 m). The proposed work inherits the common set of simulation parameters and compares the performance against LEACH, ECPF and EACLE algorithms.

As seen in Fig. 6, LEACH shows highest energy consumption of all in both FND and HNA metrics among the protocols compared. This happens due to the pure probabilistic nature of LEACH in selecting the CHs.

LEACH considers neither the remaining energy levels of the nodes nor their geometric positions to elect optimal CHs. EACLE periodically changes the probability of a competitor node to become a CH by increasing its waiting time. It stands for 2-hop intra-cluster communication which is practically meaningful and efficient in many sensor applications. As guided in its basic mechanism, EACLE generates “power low” messages for intra-cluster communication and “power high” messages for inter-cluster communication in our simulations. EACLE also assigns different roles to its CHs across various time-division slots. However, this algorithm ignores the impact of node centrality and node degree in electing most favorable CHs and hence is exposed to certain degree of lifetime inefficiency. ECPF addresses the CH election with a fuzzy process that emphasizes node centrality and node degree. In practical scenarios, the maximum hop distance for an intra-cluster communication is limited to 2 which is not followed in this algorithm.

In comparing with LEACH and EACLE, ECPF shows betterment in its outcome with respect to FND and HNA metrics. ECPF gains efficiency owing to the dynamic clustering in which CH elections are done sporadically rather than for each round. The same consumes considerable quantum of overhead and energy consumption in the overall process. The proposed EAFCA reduces energy efficiency by considering necessary and sufficient parameters for a CH election and assumes a feasible configuration in which 2-hop coverage

Table 2 Simulation parameters

Parameter	Value
Network size	200×200 m^2
Initial energy level of sensor nodes	1 J
Transmission range of sensor nodes	5 m
Energy consumption during amplification	100 pJ/bit/m^2
Energy consumption at transmitter and receiver	50 nJ/bit
Energy consumption at idle state	13.5 mW/s
Aggregation ratio	10 %

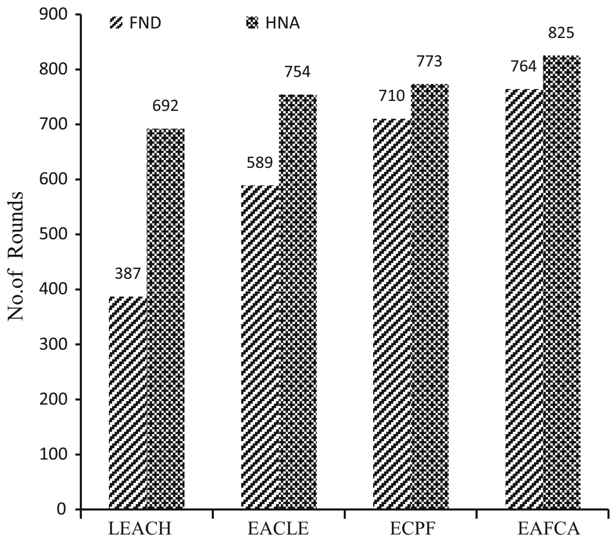


Fig. 6 Scenario 1: Arrival of FND and HNA states

is given for every CH and multi-hop relay is done for inter-cluster communication. The results demonstrate that EAFCA keeps WSN stable for longer time than the other algorithms.

5.3 Scenario 2 (BS is Positioned at the Centre of the WSN, Network Size: 200)

In scenario 2, the density of the WSN is increased from 100 sensor nodes to 200 nodes and the scalability of the proposed solution is tested. Common set of simulation parameters is inherited form Table 2.

As in the previous scenario, LEACH assumes a single-hop transmission for transmitting the aggregated data to the BS. EACLE, ECPF and EAFCA adopts multi-hop relay for the same. EACLE and EAFCA form clusters with a maximum intra-cluster hop distance of 2 between CH and any other cluster member as done in the previous scenario. As shown in Fig. 7, the results demonstrate poor performance of the LEACH and the reasons for the first scenario apply here also. In addition to that, LEACH has its inherent constraints on scalability and hence it exhibits extensive fall in its performance. EACLE adopts scalability but it suffers from its simple CH election mechanism which does not emphasize the residual energy.

From the results obtained, ECPF and EAFCA stand against scaling in this scenario. Both of them handle this scenario since the 'node centrality' becomes an essential parameter in determining the CH and only a closer margin is observed between them.

5.4 Scenario 3 (BS is Located Outside the WSN Boundaries, Network Size: 200)

In scenario 3, the BS is located at (250 m, 250 m) which is outside the WSN boundaries to monitor the impact of the location of the BS in the environment. It inherits all the features

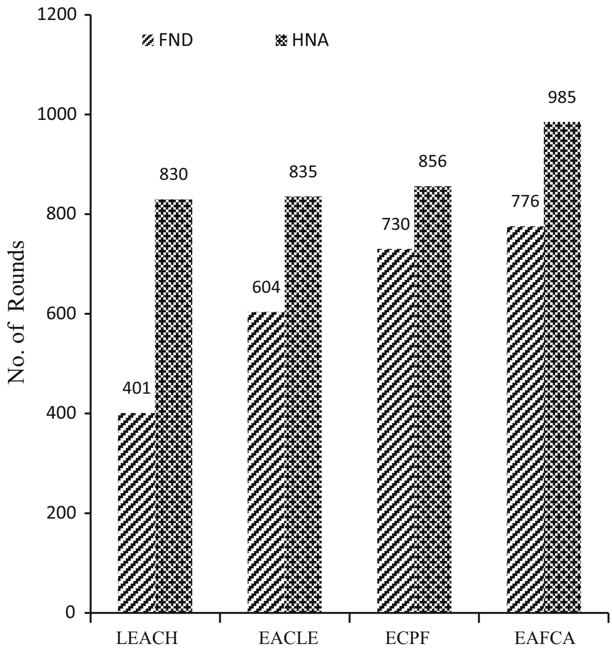
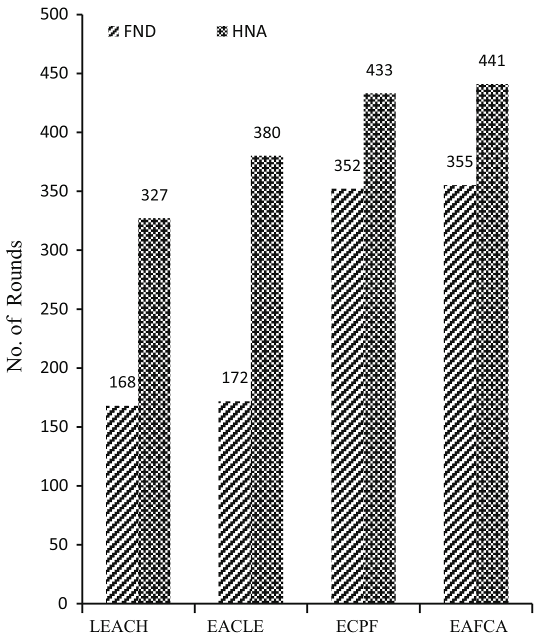


Fig. 7 Scenario 2: Arrival of FND and HNA states

Fig. 8 Scenario 3: Arrival of FND and HNA states



from Table 2. Since the BS is placed outside the boundaries, all CHs consume more energy in this scenario and which is reflected in the results based on FND and HNA metrics. The observed results are plotted in Fig. 8.

As depicted from the results presented in Fig. 8, EAFCA outperforms the LEACH, EACLE and ECPF algorithms considering both of these metrics in prolonging the network lifetime across both FND and HNA metrics. As it is indicated from the former scenarios, EAFCA achieves improvement and handles the location change of the BS by combining the advantages of competent CH election process, formation of feasible, succinct, non-overlapping clusters and efficient multi-hop routing.

Figure 9 shows that the drop rate analysis and it is defined as the ratio of number of packets send to the difference between number of packets received and number of packets send. Compared to other algorithms such as LEACH (Low Energy Adaptive Clustering Hierarchy), EACLE, ECPF (Energy-aware Clustering Protocol using Fuzzy-logic), proposed EACA (Energy Aware Fuzzy Clustering Algorithm) reduced the drop rate.

Throughput is defined as the number of packets successfully received with respect to the simulation time and this throughput analysis is shown in Fig. 10. The other algorithms like as low energy adaptive clustering hierarchy (LEACH), EACLE, energy-aware clustering protocol using fuzzy-logic (ECPF) has low throughput. These algorithms does not utilize the more channel bandwidth. But the proposed energy aware fuzzy clustering algorithm (EACA) increases the throughput with the help of cluster head and it increases the throughput of 1.7 Mbps from the available channel bandwidth between the sensor nodes in the wireless sensor network.

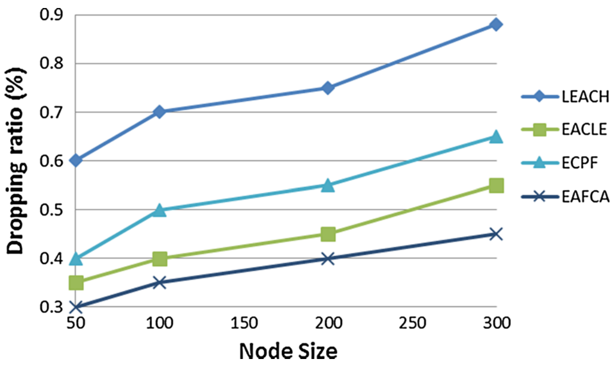


Fig. 9 Drop rate versus node size

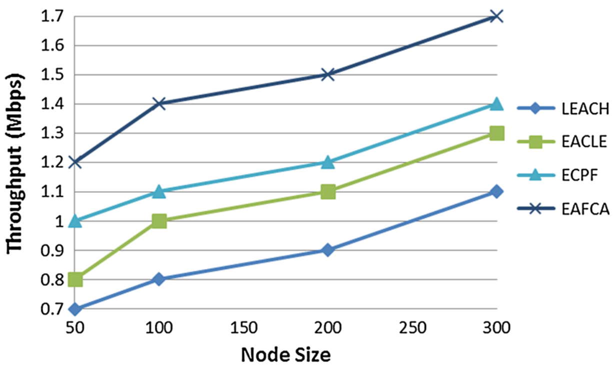


Fig. 10 Throughput analysis

5.5 Energy Consumption in WSN

The remaining energy level of the WSN is calculated for various number of simulation rounds. The initial energy of all these sensor nodes is fixed as 1 J. Hence, the initial energy of the WSN, as a whole, is 100 J, when there are 100 sensor nodes. After the execution of 'n' number of rounds, the total remaining energy of the WSN is computed by adding the remaining energy levels of each alive node in the WSN.

The observed results in the simulation of the three aforementioned scenarios are presented in Figs. 11, 12 and 13. LEACH consumes more energy compared to the rest of the algorithms in all these scenarios. EACLE deserves the next rank in energy consumption among the competing algorithms. ECPF shows significant energy reduction due to the

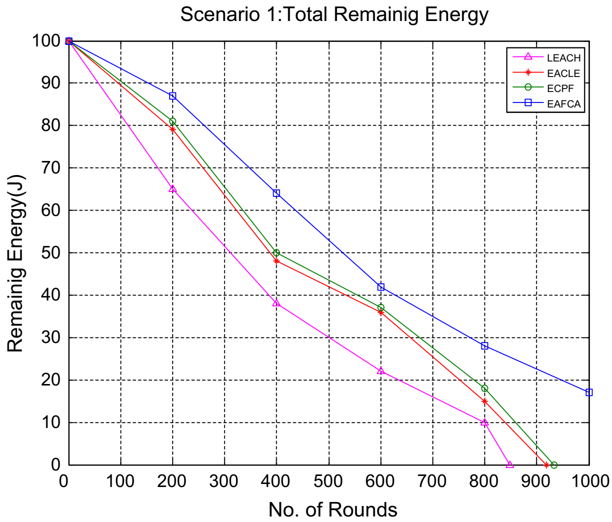


Fig. 11 Total remaining energy of sensor network in Scenario 1

Fig. 12 Total remaining energy of sensor network in Scenario 2

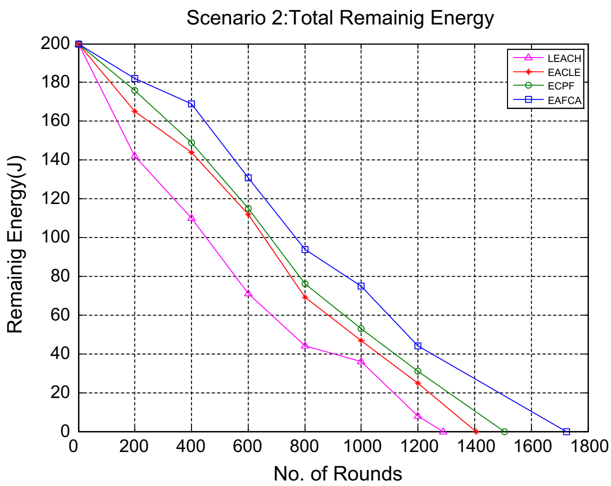
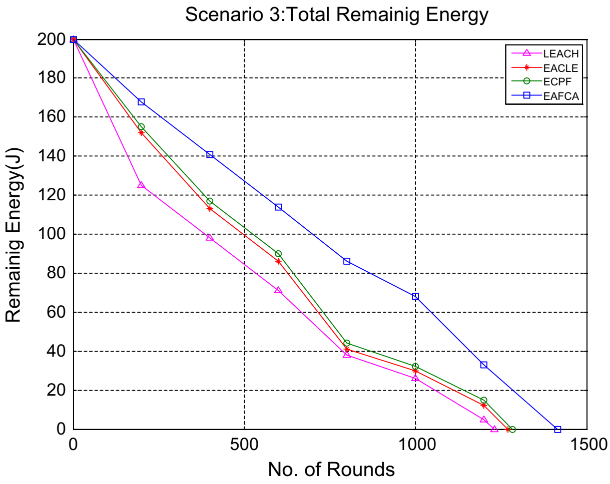


Fig. 13 Total remaining energy of sensor network in Scenario 3



energy ambitious CH election mechanism assisted through fuzzy logic. It is observed from the results that EAFCA reduces energy consumption considerably in all the three scenarios and is proven to be scalable in a WSN environment.

6 Conclusion

The lifetime of a wireless sensor network is determined and controlled through the effective load balancing of the network. Majority of the conventional and modern algorithms proposed for WSNs handle this issue by adopting specific-clustering architectures and complex relay models which imposes additional overhead and scenario-dependent solutions. The proposed EAFCA aims at providing a competent CH election process concerning all the essential features assisted with a simple inter-cluster relay model. From the results taken across FND and HNA strategies prove the longevity of the sensor network and hence certify the distribution of the load throughout the functioning of the network. Also, the energy consumption of the EAFCA algorithm is observed to be competent and considerably less to the compared algorithms across various scenarios irrespective of the density and location of BS in the networks. This ensures the adaptability and scalability of EAFCA to various types of wireless sensor applications. The present scope of the algorithm can further be extended to a sensor environment that contains either total or partial population of mobile nodes. The proposed algorithm is designed to effectively elect CHs and aggregate the data from the sensor nodes. The efficiency of this solution can be tuned by considering spatio-temporal relationships present among the data generated by sensor nodes to effectively suggest a sleep/wakeup schedule for these nodes.

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