

## A Novel Energy Entropy Based on Clusterhead Selection Algorithm for Wireless Sensor Networks

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### Abstract

*Energy is the primary constraint on designing wireless sensor networks (WSNs) practically, leading to limited network lifetime of WSN. Different communication protocols and algorithms are investigated to find ways to reduce power consumption. Cluster formation and clusterhead selection are critical issues in WSN, which can prolong the lifetime and also improve the network's performance. In order to maintain the stability of clusters, energy of wireless sensor nodes and connectivity are taken as the basis of clusterhead election. We consider the problem of appropriate clusterhead selection in WSNs. This paper proposes a Novel Energy Entropy Based on Clusterhead Selection Algorithm for WSNs (EE-CSAW). The protocol constructs a new metric of node stability and selects a stable clusterhead with the help of entropy metric to reduce the number of clusterhead reconstruction. It selects the nodes which have the most weight and stability to be the clusterheaders. Simulations demonstrate the performance benefits of our proposal EE-CSAW over SLEACH and Their's proposed algorithm in WSNs.*

**Keywords:** *Wireless sensor network; clusterhead; energy entropy*

### 1. Introduction

Wireless sensor networks (WSNs) are wireless, multi-hop, infrastructureless and self-organizing networks established by using a collection of wireless nodes, providing significant features to the modern communication technologies and services [1-3]. WSN do not rely on any existing or predefined network infrastructure, or terminal nodes randomly dispose. Nodes within transmission range can communicate directly with each other. Nodes outside the transmission range must communicate indirectly using a multihop routing protocol. Some of these problems include wireless node clustering, clusterhead selection and energy consumption. There are many research works that deal with these challenges [4-13].<sup>1</sup>

Energy of individual wireless sensor nodes is a major constraint and data gathering the core operation, and most of the research in data centric WSN is focused on energy efficient data gathering and selection of network architecture [4-13]. In conventional clustering, by dividing the network, wireless sensor nodes are organized into small groups called clusters and then one wireless node from each of them is selected to act as clusterhead which allows other wireless nodes to join it and then to form the cluster.

In WSN, clustering is an important technique to divide the large network into several sub networks. Cluster-based architectures effectively reduce energy consumption and

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enable efficient realization of MAC and routing protocols, security mechanisms and data aggregation. A cluster is a group of interconnected nodes with a dedicated node called a clusterhead. Clusterheads are responsible for cluster management, such as scheduling the medium access, dissemination of control messages, or data aggregation [2]. Therefore, the role of the clusterhead is critical for proper network operation. Failure of a clusterhead results in expensive clusterhead re-election and re-clustering operations. This is an important issue since frequent clusterhead changes adversely affect the performance of algorithms such as the stability of clusters, energy of wireless sensor nodes, and local topology. Choosing clusterhead algorithm is an NP-hard problem [4-9].

In this paper, we consider 1-hop clusters. All the member nodes in such a cluster are within the range of the clusterhead but not necessarily within range of each other. In the 1-hop cluster, any member node is at most within 2-hops away from any other member node via the clusterhead. This defines the cluster's diameter. The clusterhead is in charge of cluster maintenance, such as resource allocation to members and the acceptance of members into the cluster. Member nodes can join a cluster if the clusterhead accepts their join request [4-13].

This paper proposes a Novel Energy Entropy Based on Clusterhead Selection Algorithm for WSNs (EE-CSAW). Our strategy is to predict an appropriate node that remains as a clusterhead for a long period based on node energy. The proposed method discovers such node groups in a distributed manner and elects a clusterhead based on the energy entropy, and the wireless sensor node vector of each node group. We applied our proposed method to a distributed score based clustering algorithm and evaluated the proposed method by simulation experiments. Then we consider two parameters for the determination of the clusterheads — energy of the nodes and the number of neighbors a node is connected to. Through simulation experiments, we demonstrate the performance of our proposed scheme in terms of the average number of clusters, the average number of cluster changes, and the average connectivity.

The rest of the paper is organized as follows: In section 2 we briefly review the clusterhead selection algorithm for WSNs. In section 3 we propose a Novel Energy Entropy Based on Clusterhead Selection Algorithm for WSNs (EE-CSAW). Some simulating experiment results are provided in section 4. Finally, the paper concludes in section 5.

## 2. Related Work

Several clustering methods for WSN focusing on node's number and energy consumption have been proposed. Many existing solutions take into account various parameters of clusterhead suitability. In a WSN, the data gathered by the wireless sensor nodes is transmitted to clusterhead. The data from nodes within one cluster usually exhibit high correlation. Therefore, a clusterhead can aggregate data to remove redundancy and only send one packet to the sink.

The clustering algorithms construct clusters by determining the clusterheads and their affiliated clustermembers. Most recently, a survey of few clustering schemes primarily focused on their convergence time is presented in [4], of which aim is to discuss their objectives, features and complexity. Bednarczyk et al. [5] proposes a combined weight clustering algorithm to establish a stable clustering architecture. The proposed algorithm has a hierarchical structure that can maintain the topology of WSN as stable as possible, thereby optimizing network performance and making efficient resource allocation for nodes. Karunakaran et al. [6] proposes a service discovery architecture based on clustering in the cluster-based service discovery protocol for WSNs. It performs the clusterhead selection by allotting a combined weight value based on the factors power level, connectivity and stability, intended for WSNs.

Wu et al. [7] proposes a new cluster-constructing method that allows the mobile nodes in the mobile environment to form several clusters in single hop distance. Selvam et al. [8] design a new weight based clustering algorithm to improve the load balancing, transmission power, and the performance in the WSN. The clusterhead is selected efficiently based on these factors like high transmission power, transmission range, distance mobility, battery power and energy. Yang et al. [9] proposes a cluster-based multipath delivery scheme, called CMDS, which uses cluster and multipath to improve the capability of load balance, and thus prolonging the network lifetime. Lorincz et al. [10] proposes several integer linear programming (ILP) optimization models and corresponding heuristic algorithms that allow selection of optimal network configuration in terms of energy consumption. Zytoune et al. [11] proposes Stochastic Low Energy Adaptive Clustering Hierarchy (SLEACH). The mobile nodes are organized into a number of clusters in order to avoid such energy wastes. Cluster-based architectures improve the resource allocation and reduce the energy consumption, and thus prolong the network lifetime as much as possible. Each cluster is monitored and controlled by a node, called clusterhead. These clusterheads communicate directly with the base station. Other nodes send the data, sensed from the environment to these clusterheads. Clusterheads first aggregate the data from the multiple sensor nodes, and then finally send it directly to the base station. Thein et al. [12] proposes a modification of the LEACH's stochastic clusterhead selection algorithm by considering the additional parameters, the residual energy of a node relative to the residual energy of the network. Energy plays an important role for WSNs. Energy efficiency and load balancing are the significant challenges of clustering algorithm for energy WSNs.

### **3. 3 Energy Entropy Based on Clusterhead Selection Algorithm for WSNs (EE-CSAW)**

In this section, we use information entropy theory to analyze the energy consumption characteristics of the node. In this paper, the clustering stability of wireless sensor network is defined from the clusterhead node to the cluster number node to determine the energy entropy. In the clustering algorithm, each node is granted a priority, reflecting how the node is suitable to be the clusterhead. While determining the priorities, the following factors are considered: firstly, the energy of node is taken as one of the factors. The higher the energy is, the higher the priority is; secondly, clusterheads need more stability.

Information theory developed by Shannon [13] is a fundamental field in mathematical sciences to deal with transmission of information through communication systems. In information theory, the standard and basic quantity to deal with information is entropy. There are some common characteristics among self-organization, entropy, and the location uncertainty in wireless sensor networks [14-16]. Kim [15] proposes an entropy-based movement regulation algorithm as one of methods of the physical-oriented approaches, whereby mobile nodes can easily implement a stable autonomous physical movement using WSNs. Entropy metric from information theory is introduced to define and measure the stability of node movements. The difference change of relative node positions will strongly affect the service quality of WSNs, where it is important for a node to be consistently located within the transmission range of another node to provide the best quality network service. The corresponding methodology, results and observations can be used by the routing protocols to select the most stable route between a source and a destination, in an environment where clusters are available, and to create a convenient performance measure to be used for the evaluation of the stability and connectivity in WSNs.

### 3.1. Network Model

The network consists of  $N$  uniformly distributed mobile nodes in an area of  $l \times l$  square meters. The communication range is  $M$  meters for every node. We assume link existence is solely determined by the distance between nodes and ignore the link disruptions due to wireless signal interferences and obstructions. A cluster is constructed by determining the clusterhead and its affiliated cluster members. A cluster member is always connected directly to its clusterhead. Two clusters are neighbors if there exists at least one link that connects two nodes from the two clusters respectively. We illustrate the hierarchical network in Figure 1.

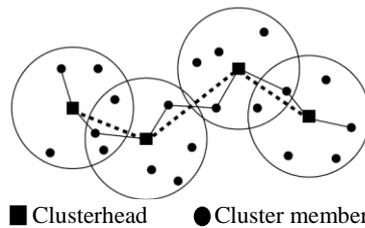


Figure 1. Cluster Architecture

### 3.2. Energy Consumption Model

We use the same radio model as Shiozaki [16] assumed a simple model where the radio dissipates  $E_{elec} = 50nJ/bit$  to run the transmitter or receive circuit and  $\epsilon_{amp} = 100pJ/bit/m^2$  for transmitting amplifier. We assume that there is  $d^2$  energy loss due to channel transmission.

The electronics energy ( $E_{elec}$ ) depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal. Whereas the amplifier energy,  $\epsilon_{amp} * d^\lambda$ , depends on the distance to the receiver and the acceptable bit-error rate. Transmitting a  $k$ -bit message a distance  $d$  using the above model radio expends:

$$E_{Tx}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^\lambda \quad (1)$$

where  $\lambda$  is path loss exponent and usually lies between 2 and 6, we assume that the radio channel is symmetric for a given Signal to Noise Ratio (SNR). Receiving the message, radio expends:

$$E_{Rx}(x) = E_{elec} * k \quad (2)$$

### 3.3. Energy Entropy Clusterhead Selection

SLEACH [11] randomly selects a few nodes as clusterheads and rotates this role to balance the energy dissipation of the sensor nodes in the networks. The operation of LEACH is broken up in two rounds and each round begins with set-up phase and followed by a steady state phase. As SLEACH, when clusters are being created for the first time, each node decides whether or not to become a cluster-head for the current round. This decision is based on the suggested percentage of cluster head for the network and the number of times the node has been a cluster head so far. This decision is made by the node  $n$  choosing a random number between 0 and 1. If the number is less than a threshold  $T(n)$ , the node become a cluster head for the current round. The threshold is set as:

$$T(n) = \begin{cases} \frac{p}{1 - p * (r * \text{mod}(1/p))}; & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

where  $p$ ,  $r$ , and  $G$  represent, respectively, the desired percentage of clusterheads, the current round number, and the set of nodes that have not been clusterheads in the last  $1/p$

rounds. The advantage of this formula is each node will be a cluster head at some point within  $1/p$  rounds, thus the probability that every node to be clusterhead must be increased.

To ensure an even energy load distribution over the whole network, additional parameters should be considered to optimize the process of cluster-head selection.

Thein *et al.* [12] stochastic cluster head selection algorithm by adjusting the threshold  $T(n)$  denoted in (3), relative to the node's remaining energy. Using this threshold each node decides whether or not to become a clusterhead in each round. They modify the formula as:

$$T(n) = \begin{cases} \frac{p}{1 - p * (r * \text{mod}(1 / p))} * \frac{E_{\text{residual}}}{E_{\text{initial}}} * k_{\text{opt}}; & \text{if } n \in G \\ 0 & ; \text{otherwise} \end{cases} \quad (4)$$

where the  $E_{\text{residual}}$  is the remaining energy of the node and  $E_{\text{initial}}$  is the initial energy of the node before the transmission.

$$k_{\text{opt}} = \sqrt{\frac{N}{2\pi}} \frac{M}{d^2} \quad (5)$$

where  $k_{\text{opt}}$  is the optimal cluster-head number,  $N$  is total number of sensor nodes,  $M$  is the length of nodes distributing fields,  $d$  is the distance between nodes.

Since, according to the above assumption, transmission energy is directly proportional to the energy consumed, the energy entropy can be calculated by transmission energy pdf. Shannon's entropy for a random variable with  $Y$  with pdf  $f_Y(y)$  is

$$H_S(Y) = \int_{-\infty}^{+\infty} T_Y(y) \log T_Y(y) dy \quad (6)$$

Thus, the energy entropy is given by

$$H(T_p) = \int_0^M (T_{R\Theta}(P_i^\alpha) \log T_{R\Theta}(P_i^\alpha) dP_i \quad (7)$$

To improve the above drawbacks, we present a new clusterhead selection algorithm to generate properly the number of cluster heads. The proposed clusterhead selection algorithm uses energy entropy selection method to select the clusterheads in each round. In selection, based on SLEACH [12], some nodes are selected as the candidates of clusterheads with a given parameter  $k$ . In our algorithm, each node has to send its location and energy information to base stations in setup phase so that base stations first reject the nodes that have energy less than the average energy of the MANET.

### 3.4. Clusterhead Election Process

In EE-CSAW, a clusterhead is selected based on the node's wireless entropy, and a node with larger weight is more likely to be selected as a clusterhead.

In EE-CSAW, clusterhead selection assumes that a wireless sensor node knows the energy entropy from the other sensor nodes, using messages received. It randomly selects clusterheads, at first considering the energy entropy between each clusterhead and the sensor nodes farthest from the clusterheads. After selecting clusterheads, this technique reorganizes the cluster to be fixed until the termination of one round for clustering.

The selected clusterheads broadcasts an advertisement message to the cluster member nodes that belong to each clusterhead. The clusterhead waits for responses, and when they receive a response from member nodes, they check this against the previous response. If the sensor node selected as the first clusterhead receives responses from all the nodes, it subtracts the energy entropy of the farthest sensor node from the distance of the closest head.

EE-CSAW randomly selects a few nodes as clusterheads and rotates this role to balance the energy dissipation of the wireless sensor nodes in the networks. Data collection is centralized to sink and performed periodically. EE-CSAW guarantees self-stabilization and robustness even when the network topology changes. The main motive of clusterhead election process is to select minimal entropy of wireless sensor nodes that dominate the whole network only by using 1-hop neighborhood information. If node  $i$ 's priority is higher than all of its 1-hop neighbors', then node  $i$  set itself as the clusterhead. Since the nodes use the same information and run the same algorithm, then if node  $i$  determines itself as the clusterhead, it means its 1-hop neighbor works out the same result; otherwise, node  $i$  elects one of its 1-hop neighbors with the highest priority as the clusterhead. In the clusterhead election process, node  $i$  sets the states of all of its 1-hop neighbors as FALSE, meaning they are not yet dealt with by node  $i$ . Each node decides whether or not to become a clusterhead for the current round based on the probability calculated by the suggested percentage of clusterheads for the network (determined in advance) and the number of times the node has been a clusterhead so far.

## 4. Simulation Experiments

### 4.1. Simulation Model and Performance Metrics

To effectively evaluate EE-CSAW's performance, we compare it with other famous clusterhead protocols SLEACH [11] and Their's proposed algorithm [12] for the average number of clusterheads, the number of clusterhead updates per unit time, and the number of nodes change events per unit time. To conduct the simulation studies, we have used randomly generated networks on which the algorithms were executed [17], ensuring that the simulation results are independent of the characteristics of any particular network topology.

To demonstrate random clusterhead selecting affect on communication energy consumption, we consider a network with 100 nodes randomly distribution in a play size field  $1000m \times 1000m$ . When a node uses energy down to its energy threshold, it can no longer send data and is considered as a dead node. The traffic type is constant bit rate (CBR) with a 512 byte data packet. The application agent is sending at a rate of 10 packets per second whenever a connection is made. The maximum data rate is set at 2 Mbps, the mobility rate has been varied from 0 m/s to 20 m/s, and the IEEE 802.11 distributed coordination function (DCF) is used as the media access control (MAC) layer protocol. Table 1 lists the simulation parameters which are used as default values unless otherwise specified. We conducted the simulation experiments 100 times and show the average results.

**Table 1. Simulation Parameters**

Number of nodes	100	The electronics energy $E_{elec}$	$50 \times 10^{-9} \text{J/bit}$
Field Size	$1000m \times 1000m$	The amplifier energy $\epsilon_{amp}$	$1.3 \times 10^{-15} \text{J/bit/m}^2$
Transmission range	250 m	Clusterhead probability	0.1
Average node degree	3-5	Initial node energy	30 J
Simulation time	600 S	Traffic type	CBR
Maximum transmit power $T_i^{\max}$	0.282 W	Examined routing protocol	SLEACH [11], Their's algorithm [12]

To measure the performance of our proposed entropy-based clustering scheme, we identify six metrics:

- 1) **The average number of clusterheads:** The average number of clusters shows the quality of clustering.

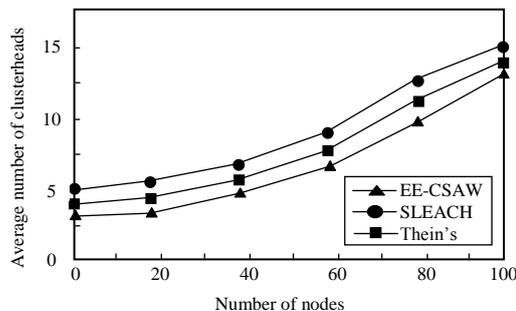
- 2) **The frequency of clusterhead changes:** The frequency of clusterhead changes counts the number of output state changes (from an ordinary node to a clusterhead and from a clusterhead to an ordinary node) for all nodes per step.
- 3) **The frequency of cluster member changes:** The frequency of cluster member changes counts the number that ordinary nodes move from one cluster to another per step.
- 4) **Range of residual energy:** Range of residual energy is defined the difference between maximum residual energy and the minimum residual energy of nodes, which reflects the distribution of the node residual energy.
- 5) **Cluster lifetime:** The longest cluster lifetime is achieved when the clusterhead undertakes its role without interruption until all of its affiliated cluster members have node energy exhausts.
- 6) **Network lifetime:** The network lifetime is defined as the round number when the first node runs out of energy. To maximize the network lifetime, it is required to prolong the time of first node dies as far as possible.

#### 4.2. Simulation Results

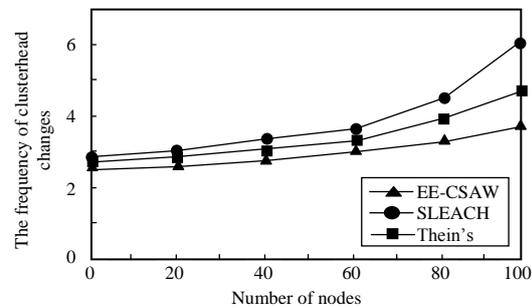
In order to evaluate the performances of our algorithm, we simulate the proposed mechanisms using NS-2 [18] extended by a complete implementation of IEEE 802.11.

Figure 2 shows that the average number of clusterheads varies as a function of the node's number. The improved resilience against node's number fluctuations is attributed to the quantitative consideration of the relative node's number and long-term node-stability measures. In the EE-CSAW, we limited the size of each cluster; therefore the number of clusterheads was relative stable, when the node's number is varied. The EE-CSAW has a lower cluster update rate than SLEACH and Their's algorithm.

The average number of clusterhead updates is related to the node's number, as shown in Figure 3. Upon increasing the maximum node's number beyond about 15%, the clusterhead remains capable of communicating with its cluster members. The EE-CSAW has a lower clusterhead update rate than SLEACH and Their's algorithm.



**Figure 2. Average Number of Clusterheads vs number of nodes**

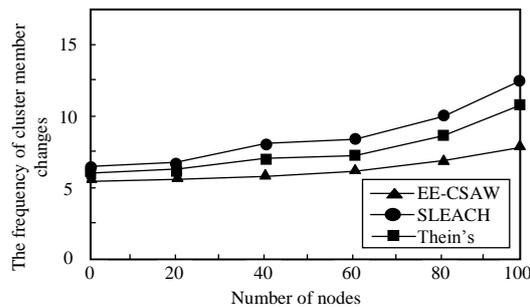


**Figure 3. The Frequency of Clusterhead Changes vs Number of Nodes**

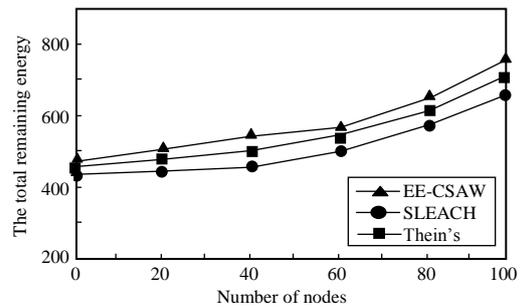
As the node's number is increased, the nodes roam more often outside the coverage range of their clusterhead, hence the cluster structure becomes more unstable. Again, as the node's number increases, the average numbers of cluster change events decreases monotonically. Similarly, the number of clusterhead updates and the cluster change events become increasingly more frequent. Observe in Figure 4 that our EE-CSAW significantly improves the stability of the cluster structure, hence reducing the frequency of clusterhead update events, as the node number is increased. The clusterhead changes and the cluster

member changes of EE-CSAW are lower than that of SLEACH and Their's algorithm, especially when the node number increases large enough.

Figure 5 shows that the total remaining energy of clusterheads varies as a function of the maximum node's number. We compared this scheme with EE-CSAW and SLEACH methods by using the remaining energy and number of surviving nodes as the metric elements. The network energy depletion is fast in SLEACH and Their's algorithm. As shown in the above figures, we can conclude that our proposed model provides best characteristics comparing to the SLEACH and Their's algorithm.



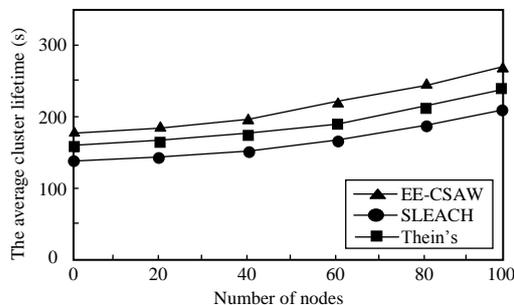
**Figure 4. The Frequency of Cluster Member Number of Nodes**



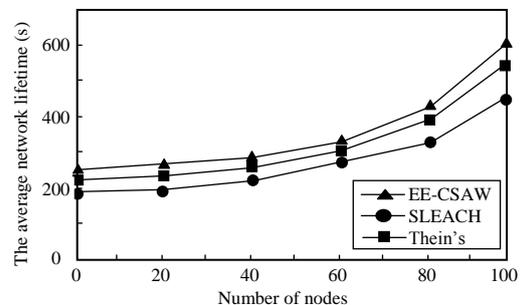
**Figure 5. The Total Remaining Energy vs Changes vs Number of Nodes**

The average cluster lifetime as obtained through the simulations is shown in Figure 6. In Figure 6, the average cluster lifetime of EE-CSAW is at most 10-20% larger than that of SLEACH and Their's algorithm and the corresponding improvement curve shows that the advantage of EE-CSAW in extending cluster lifetime is becoming more and more obvious with the increasing of node's movement speed. We see in Figure 6 that the cluster lifetime of the SLEACH and Their's algorithm is significantly shorter than the EE-CSAW.

The average lifetime of sensor network as obtained through the simulations is shown in Figure 7. It is evident that EE-CSAW exhibits the longest lifetime when the node's number increases. It is evident that EE-CSAW exhibits the shortest lifetime when the node's number increases. In SLEACH and Their's, the data transmission relies mostly on the optimal path, while alternative path is used only when the nodes on the primary route fail. Nodes in the optimal path die quickly because of exhausted energy. So, the network lifetime of SLEACH and Their's algorithm is the shortest. The lifetime of wireless nodes in Figure 7 is shown in normalized scale where the lifetimes are normalized to the longest observed lifetime during the simulations.



**Figure 6. The Average Cluster Lifetime vs Number of Nodes**



**Figure 7. The Average Network Lifetime vs Number of Nodes**

## 5. Conclusion

Energy is the primary constraint on designing wireless sensor networks in reality. Energy constraint is the main reason for networks life time of sensor networks to be limited.

In this paper, we propose a Novel Energy Entropy Based on Clusterhead Selection Algorithm for WSNs (EE-CSAW). The key idea of the algorithm is to find the minimal node energy entropy of each clusterhead in the process of selecting. Stochastic Low Energy Adaptive Clustering Hierarchy (SLEACH), Their's proposed algorithm, EE-CSAW assigns the construction of clusterhead selection it algorithmically simple, resulting in the improved performance of the average number of clusterheads, the number of clusterhead updates per unit time, the number of nodes change events per unit time incurred at intermediate nodes and network lifetime. The simulation experiments show that the considered EE-CSAW algorithm is able to cope with this type of dynamic networks, in particular its ability to improve the system performance which has been reflected in the model, since it reduces both the number of clusterhead update events and cluster change events. In the future, we will explore a more realistic joint system to improve the cluster-forming and update with the aid of the fuzzy controller.

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