Energy-Efficient Multi-Mode Clusters Maintenance (M^2CM) for Hierarchical Wireless Sensor Networks

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Abstract: How to energy-efficiently maintain the topology of wireless sensor networks (WSNs) is still a difficult problem because of their numerous nodes, highly dynamic nature, varied application scenarios and limited resources. An energy-efficient multi-mode clusters maintenance (M^2CM) method is proposed based on localized and event-driven mechanism in this work, which is different from the conventional clusters maintenance model with always periodically re-clustered among the whole network style based on time-trigger for hierarchical WSNs. M^2CM can meet such demands of clusters maintenance as adaptive local maintenance for the damaged clusters according to its changes in time and space field., the triggers of M^2CM include such events as nodes' residual energy being under the threshold, the load imbalance of cluster head, joining in or exiting from any cluster for new node or disable one, etc. Based on neighboring relationship of the damaged clusters, one can start a single cluster (inner-cluster) maintenance or clusters (inter-cluster) maintenance program to meet diverse demands in the topology management of hierarchical WSNs. The experiment results based on NS2 simulation show that the proposed method can significantly save energy used in maintaining a damaged network, effectively narrow down the influenced area of clusters maintenance, and increase transmitted data and prolong lifetime of network compared to the traditional schemes.

Keywords: hierarchical; iterative clustering; multi-mode; event-driven; adaptive; energy-efficient

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I. INTRODUCTION

Wireless sensor networks (WSNs) are battery-powered ad hoc networks in which sensor nodes that are scattered over a region connect to each other and form multi-hop networks. Since these networks consist of a large number of micro sensor nodes that are battery operated and wireless communication, care has to be taken so that these sensors use energy efficiently. WSNs have been widely applied in many fields for their advantages of networking flexibility, scalability, etc[1-3]. The sensor nodes are generally battery powered and work in harsh environments, therefore, they have to energy-efficiently work to prolong lifetime of network as far as possible[4].

Hierarchical clustered topology of WSNs is the most popular networking mode, which has a great number of advantages, such as easy management, efficient energy utilization, simple data integration, etc[5-6]. WSNs have many sensor nodes with characteristics of strongly dynamics, which determines the maintenance tasks of cluster structure and can become very heavy, therefore, multi-mode clusters maintenance is necessary for the damaged clusters because they perhaps have many cases such as single damaged cluster, several damaged clusters which is whether adjacent or not, the damaged node is perhaps cluster head (CH) or ordinary node, the dimension of damaged cluster is too big or too small and so on. The conventional method of clusters maintenance is just periodically re-clustered, which does not distinguish the damaged state of network structure and the scope of changed clusters. This will result in many shortcomings, such as excessive maintenance, high maintenance costs, energy wastage, periodic service interruptions, tardy response and so on.

To solve the above-mentioned problems, this paper proposes a new algorithm and its implementation mechanism called multi-mode clusters maintenance (M^2CM) for hierarchical WSNs. Adaptive local cluster maintenance is the main goal, the clustering operation among whole network only occurs when the system is established, and then the maintenance of cluster structure is triggered by an event and is only within the scope of the damaged clusters, that is to say, the cluster maintenance operation is based on events and local, therefore, it is non-periodic and instead of whole network. The local cluster maintenance operations will start when it is detected that the cluster head has failed, the residual energy of CH is below the set threshold, CH load is imbalanced or new nodes are added or the damaged cluster members (CM) to quit. In addition, according to the number of clusters and affected neighboring relations, this paper proposes two cluster maintenance programs: single cluster maintenance (inner-cluster) and multi-cluster maintenance (inter-cluster), which built up multi-mode clustering mechanisms to deal with different situations of damaged clusters. It's better to avoid energy wastage, service interruptions, and prolong the network lifetime as far as possible to protect the stability of the cluster structure.

II. Related Work

LEACH is the most representative of the clustering routing algorithm for WSNs[7], it is able to achieve good scalability of cluster structure from which some clustering routing algorithms draw their ideas. For example, a hybrid network topology is given by introducing node residual energy during the formation of the cluster head[8], which is a two-wheeled clustering protocol based on LEACH. Heinzelman proposed two centralized cluster head generation algorithm[7]: LEACH-C algorithm completes the work of cluster heads selection at the base station, and only the node with higher residual energy than the average energy is likely to become cluster head. In LEACH-F algorithm, the structure of cluster is no longer changed once formed, cluster nodes are constructed around clusters without circulating around to reduce the cost of constructing clusters. Thu et al. points out that the number of members in the cluster has a significant impact on the survival time of the network[9]. Too many cluster members will increase the burden of the cluster head, resulting in the death of the cluster head prematurely.

With further research, traditional method uses periodic re-clustering mechanism to fit and maintain the network, but "re-clustering" leads to larger maintenance energy consumption and is not targeted, is "periodic" and difficult to determine, some algorithms have improved this. Yan and Li mention the centralized algorithm[10], which is similar to LEACH-C. It introduces cluster similarity in the cluster head rotation; when the similarity is less, the cluster head rotates in the cluster, otherwise the whole network is re-clustered. Huang et al. proposed an energy-efficient cluster head rotation mechanism, re-clustering of whole network when the energy of any cluster head reduces to the remaining 4% of current energy of all the nodes[11]. Enam et al. uses the energy threshold mode, where, the whole network re-clustering will trigger when the remaining energy of a cluster head is below the threshold or a cluster head is detected

In order to improve energy utilization rate, prolong the network survival time and improve the network service performance, this paper presents an energy-efficient M^2CM algorithm for clusters maintenance based on event-driven and local mechanism in hierarchical WSNs.

dead[12]. Gao et al. proposed the cluster head to rotate in the cluster when the residual energy is below the threshold, and the whole network to be re-clustered when more than half of the clusters have been cluster head rotated[13]. Hu and Wang proposed a method of secure clusters maintenance for the sensing layer in the Internet of things, which protects the security and stability of clusters by means of encryption and authentication, evaluation of node's credibility and maintenance on demand[14]. Elsaid, Shaimaa Ahmed et al. proposed an optimized hierarchical routing technique which aims to reduce the energy consumption and prolong network lifetime. In this technique, the selection of optimal cluster head (CHs) locations is based on artificial fish swarm algorithm that applies various behaviors such as preying, swarming, and following to the formulated clusters and then uses a fitness function to compare the outputs of these behaviors to select the best CHs locations[15]. Gherbi, Chirihane et al. proposed a novel hierarchical approach, called Hierarchical Energy-Balancing Multipath routing protocol for Wireless Sensor Networks (HEBM), it is a routing protocol in which load traffic is shared among cluster members in order to reduce the dropping probability due to queue overflow at some nodes. The HEBM approach aims to fulfill the following purposes: decreasing the overall network energy consumption, balancing the energy dissipation among the sensor nodes and as direct consequence: extending the lifetime of the network. In fact, the cluster-heads are optimally determined and suitably distributed over the area of interest allowing the member nodes reaching them with adequate energy dissipation and appropriate load balancing utilization. In addition, nodes radio are turned off for fixed time duration according to sleeping control rules optimizing their energy consumption [16].

In summary, the existing cluster maintenance methods research is mostly focused on the generation and optimization of cluster head exclusively and balancing the energy dissipation among the sensor nodes, and a small amount of algorithms are developed for the problems of "periodical re-clustering". However, the work done has been simple, one-sided, and has not developed cluster maintenance solutions such as event-driven and local clustering algorithms which are important to the WSNs.

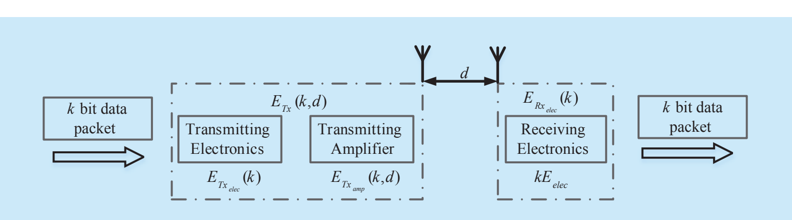


Fig. 1 *Radio communication energy model*

III. ENERGY MODEL

To mainly discuss efficient cluster maintenance problems in WSNs, here, the energy consumption model only involves simple communication, and the energy wastage in the calculation, storage, etc. is not considered[17]. The model is shown in Fig. 1.

Energy of nodes involved in communication is divided into two parts: energy consumption in data sending and receiving. Energy consumption in sending data comprises the expenditure of energy by the radio frequency transmitter circuit and the signal amplifier circuit. Energy consumption in the nodes receiving data includes the receiving circuit only. Among them, signal amplifier power consumption can use a free-space model and multi-path fading model according to the distance between the sender and receiver side. In fading model of free-space path, loss exponent is 2, i.e., energy loss is proportional to the distance squared. In the multipath fading model, the path loss exponent is 4.

Assuming that the channel is symmetric, when k bit information transmitted through the process of distance d, the energy consumption for the transmission can be given by

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx_{elec}}(k) + E_{Tx_{amp}}(k,d) \\ &= kE_{elec} + k\varepsilon_{fs}d^r \end{aligned} \quad (1)$$

where E_{elec} is the energy consumption of the wireless transceiver circuit, ε_{fs} and ε_{mp} are the energy consumption of the power amplifier in the free-space model and the multipath fading model respectively, r is a constant of wireless channel decided by the transmission distance of signal d ($r = 2$ if $d < d_o$, otherwise, $r = 4$), and d_o is the transmission distance threshold which is defined as:

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{2}$$

The energy consumption of the receiving side can be calculated as follows:

$$E_{Rx}(k) = E_{Rx_{elec}}(k) = kE_{elec} \tag{3}$$

IV. Multi-Mode Clusters Maintenance (M²CM) Model

Similar to the classic LEACH algorithm, M²CM proposed in this paper still divides the network into several clusters, CM of each cluster forwards the collected information to the base station (BS) through CH. The difference is, M²CM algorithm is divided into three stages: cluster building, cluster communication and cluster maintenance, without concept of "round" no longer, the network will maintain the current cluster topology if the triggering event or condition does not appear on cluster maintenance. Once the event that requires cluster maintenance appears, maintenance only occurs in the local scope of the damaged cluster, without affecting the normal work and communication with other clusters. In order to describe the cluster maintenance process of M²CM algorithm clearly, the following events are defined as follows:

Definition 1 Maximum cluster or Minimum cluster: the number of CH exceeds the upper limit $N_{\max} = \theta \cdot N/K_{opt}$ which is the maximum cluster, the CH number below the lower limit $N_{\min} = \beta \cdot N/K_{opt}$ which is the minimal cluster. where N is the total number of active nodes in the monitoring area, K_{opt} is the optimal number of CH[18], θ and β are the adjustable parameters and $\theta > 1$, $0 < \beta < 1$.

4.1 Algorithm description

Based on the thought of above-mentioned M²CM algorithm, the working steps of M²CM algorithm is as follows:

Step 1 Clusters generating phase. Clustering is a well-known approach to cope with large nodes density and efficiently conserving energy in wireless sensor networks, therefore, the first step of M²CM algorithm is still generation of clusters based on the well-known LEACH algorithm.

Step 2 Clusters communication phase. Secondly, on completing clusters' establishment, the network enters into the normal communication phase. CM sends its residual energy, the collected data packets information to CH in a scheduled TDMA time slot, and then CH makes the received information fusion and transmits them to BS.

Step 3 Clusters maintenance phase. After a period of data communication, the cluster will start single cluster maintenance program in the cluster when the following events occur: CH failures or residual energy below the set threshold, CH load imbalance, new nodes join the cluster or CM fails to exit. If multiple adjacent clusters achieve the conditions which start single cluster maintenance simultaneously, start multi-cluster maintenance program to jointly safeguard these multiple clusters.

Step 4 Clusters re-communication-maintenance loop phase. After the clusters maintenance, restore the cluster back to the cluster communication phase, begin to enter the cluster communication once again i.e. cluster maintenance cycle until energy depletion, or if too many nodes die or unable to form a complete cluster structure, the network is no longer able to communicate properly. It means that the lifetime of whole network is over.

The flowchart of energy-efficient multi-mode clusters maintenance mechanism is shown in Fig. 2.

4.2 Single cluster maintenance modes

Single cluster maintenance program is the cluster maintenance performed only within a single cluster, which does not involve other clusters, mainly in the following situations.

Mode 1 (Time slot reallocation) If there are new nodes applied to join a cluster and the number of CMs within the cluster does not exceed N_{max}, or CMs fail to exit, results in the number of CMs within the cluster not being less than N_{min}, with just time slot reallocation.

The CH re-creates a new TDMA slot according to the received number of join requests or the number of failure nodes that are discovered, and broadcasts in the cluster, CMs send message in the new slot.

Mode 2 (CH re-election) When the energy of CH is below 0.618 times the average residual energy of CM, in order to better balance the network energy consumption, start CH re-election.

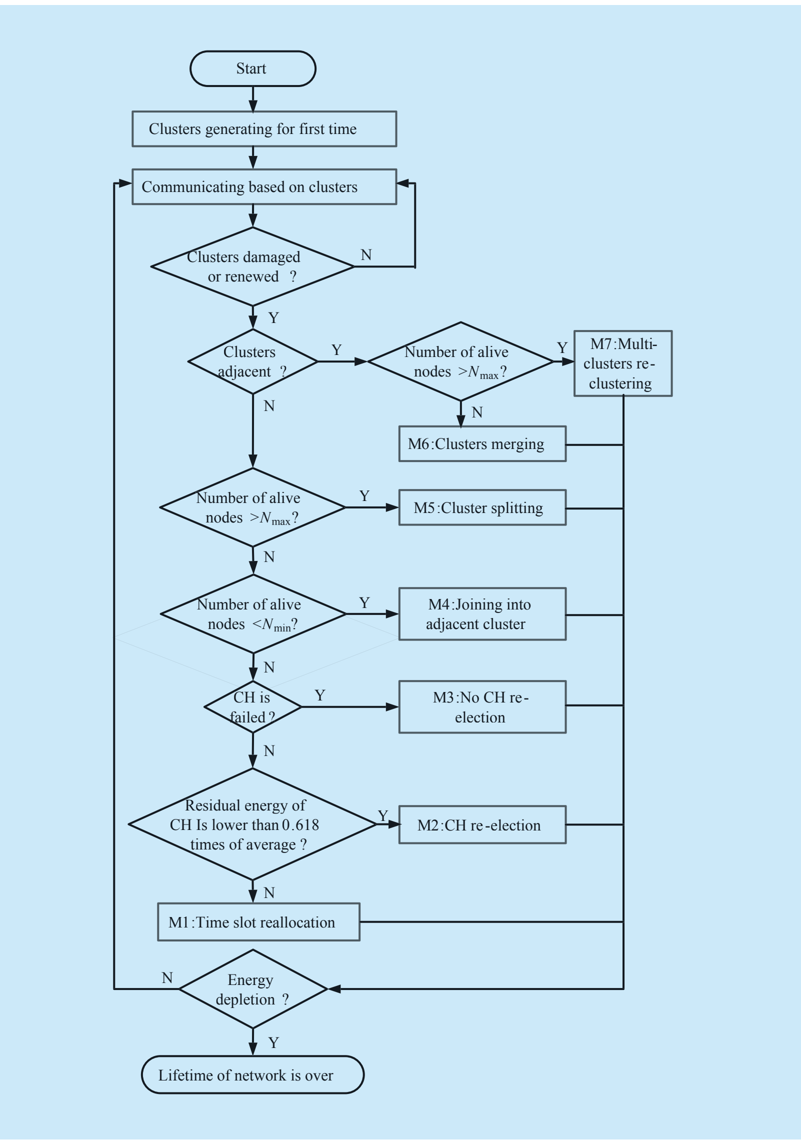


Fig. 2 *Flowchart of energy-efficient multi-mode clusters maintenance*

The cluster rebuild message is broadcast by the CH in the cluster, CM sends its residual energy to CH after receiving the message, and marks itself as an unclustered state. After the CH receives all the messages, CM within maximum energy will be elected as the new CH, and broadcasts the CH replacement message to the other CMs in the cluster and the adjacent CH.

Mode 3 (No CH re-election) When the CH energy is depleted or fails, the cluster is unable to continue to work, no CH re-election is performed.

Firstly, head failure message is broadcasted by the CM which finds the faulty CH. Other CM sends its own residual energy $E_{Residual}$ and ID to the CM after receiving the message, then the CM puts forward the node of maximum energy as CH according to the message received, and broadcasts the ID number of new CH in the cluster. After receiving the new CH message, CMs first match their ID, if they do not match the ID they send join request to the new CH, otherwise the nodes wait to receive the join request. After receiving the join requests, the new CH creates a new TDMA slot and broadcasts in the cluster.

Mode 4 (Joining into the adjacent cluster) When the damaged nodes within a cluster reach a certain number, the number of CM is less than N_{min} and the number of adjacent cluster nodes are between N_{min} and N_{max}, joining into the adjacent cluster maintenance strategy will be started.

The CH broadcasts JOIN_REQ message to join adjacent clusters in the cluster, and sets itself as unclustered, CMs choose to join adjacent clusters with CH after receiving the message. After the adjacent CH receives the JOIN_REQ message, if the number of CM in its cluster does not exceed N_{max}, then the CM is added to the cluster, otherwise it gives a reject message to the CM, the CM will send JOIN_REQ to other adjacent CHs.

Mode 5 (Cluster splitting) When the number of CM within a cluster is larger than N_{max} and the number of CM in the adjacent clusters is between N_{min} and N_{max}, start cluster split maintenance strategy.

The CH determines the number n of clusters that will be split according to $avg = mem/n$, where mem is the number of CMs, n is the number of CHs in the current cluster, with the initial value of 1, the algorithm makes $avg < N_{max}$ through n plus 1 to determine n. Then the cluster splitting algorithm is performed, CH specifies the former n nodes have the maximum energy in the cluster to the new CHs. The new CHs broadcast the CH message ADV_CH, CMs decided to join the strongest signals corresponding to the cluster where the CH located. In order to avoid the number of nodes in new cluster being greater than N_{max}, the new CH will no longer accept JOIN_REQ from the CMs when the number of JOIN_REQ messages equals to N_{max}.

4.3 Multi-cluster maintenance modes

When the damaged area of clusters within network is larger, and the damaged clusters (at least two) are adjacent, in order to conduct a comprehensive assessment and overall coordination, to achieve load balancing between clusters, a more rational use of network resources, setting the multi-cluster maintenance mode.

Mode 6 (Cluster merging) When multiple adjacent clusters are damaged, and the number of nodes does not exceed N_{max} after the merging of these clusters within a cluster, then start the cluster merge maintenance strategy.

In the clusters merge process, setting the CH which first sends the merge message as the associated CH generally, responsible for inter-cluster notice. Other CHs of the adjacent clusters broadcast merge message in its respective cluster, and join the cluster where the associated CH located. Meanwhile the associated CH chooses the node of the largest energy as the new CH in the correlation clusters.

Mode 7 (Multi-cluster re-clustering) When multiple adjacent clusters are damaged, and the number of nodes exceeds N_{max} after the merging of these adjacent clusters within a cluster, then start multi-cluster re-clustering strategy in the multiple adjacent clusters within the scope of the damage.

Suppose there are n clusters damaged, set the CH which first sends the merge message as the associated CH generally, responsible for inter-cluster notice. Other CH of the adjacent clusters broadcasts in its respective cluster, and sends the number of CM to the associated with the CH. Then the associated CH determines the number of nodes in the consolidated clusters according to the received information, then calculates the average number of all the damaged adjacent clusters (including this cluster), denoted by avg as follows:

$$avg = \frac{\sum_{i=1}^{n} mem_i}{n} \tag{4}$$

where mem_i is the number of nodes within the i -th adjacent cluster. By adjusting the value of n making avg not greater than N_{max} and not less than N_{min}, writes down the number of new CHs n at this time. Then the adjacent CH broadcasts the re-clustering message, starts the re-clustering based on LEACH algorithm within the scope of the damaged adjacent clusters to ensure the number of CHs is n.

V. Simulation Results and Analysis

5.1 Simulation environment

In order to realize a comprehensive estimation of the performance of the M^2CM algorithm, this paper tests LEACH and M^2CM algorithm under NS2 network simulation platform. Simulation involves two scenarios, where 100 nodes and 200 nodes randomly distributed in 100 m×100 m area. All sensor nodes have the same initial energy 2J, data packet size is 500 Bytes, head size of packet is 25 Bytes, and BS is located in (50,175). Typically, the power consumption of receiving and transmitting circuit to deal with 1bit data is $E_{elec} = 50$ nJ/bit, the power consumption of amplifier to deal with each bit data transmission is $\varepsilon_{fs} = 10$ pJ/bit/m^2. Here the chosen simulation parameters are typical and same as papers of kind in order to conveniently compare each other in performances.

5.2 Selection of the parameter threshold

This paper involves two parameters: and β, which decide when to start cluster maintenance, affect the energy consumption and maintenance directly. If θ and β are small, cluster split times are more frequent, otherwise CH re-election, clusters merge times are more frequent, therefore, improper values of θ and β will result in unnecessary energy waste by nodes, thereby shortening the network lifetime.

In order to optimize the values of θ and β, from the standard deviation of the cluster density, this paper introduces network load balancing index S defined as:

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{5}$$

where x_i is number of nodes in the i -th cluster, is the expected node number in each cluster, and n is the current number of clusters.

Formula (5) shows that S is the standard deviation of the cluster density which will mainly effect on the balance of energy consumption between nodes and the lifetime of network, in essence, indicates the degree of deviation from the mean value of the cluster density expected. The experiment results show that a steady and moderate S is helpful to prolong the lifetime of the network.

To select the optimal values of θ and β through simulation and eliminate the randomness of the simulation, we execute the simulation 100 times for each (θ, β) in various network structures, to get the average value of S. From the simulation results shown in Fig. 3, it is clearly understood that, when =1.5 and β=0.5, the load balance index achieves the minimum, that is the most balanced load in the network at this time. These parameters will be used in the following simulation.

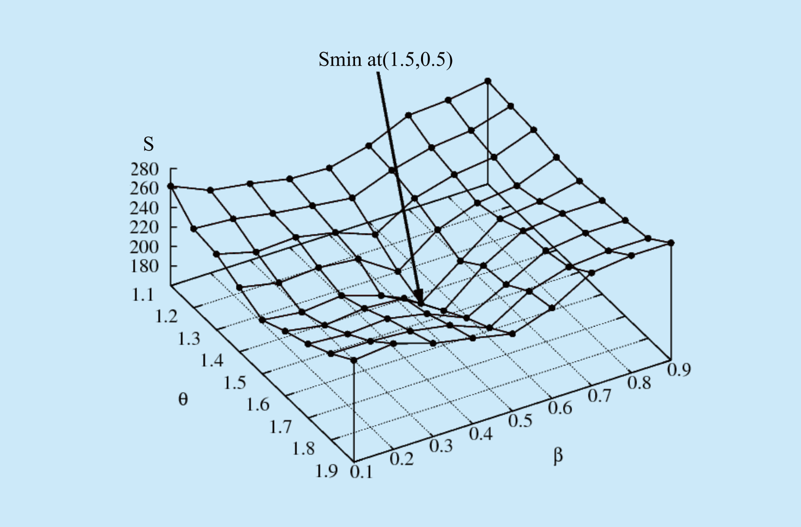


Fig. 3 *θ and β impact on balance of load*

5.3 Performance simulation and result analysis of M²CM

5.3.1 Single cluster and multi-cluster maintenance energy consumption comparison

In order to better reflect the necessity of the multi-cluster maintenance mode, in this paper, comparing energy consumption by taking single cluster and multi-cluster maintenance in the adjacent multiple clusters damaged, as shown in Fig. 4. As can be seen from the figure, multi-cluster maintenance relative to single cluster maintenance is more energy-efficient, and maintenance times are less than for the single cluster, thus it is more conducive to a stable cluster structure. This is because when adjacent multiple clusters are damaged, multi-cluster maintenance is no longer con-

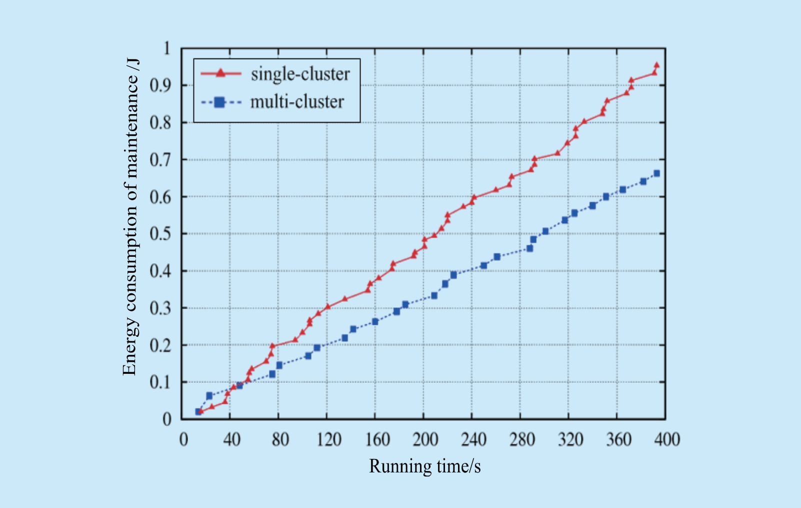


Fig. 4 *Energy consumption comparison*

fined to single cluster conducted. These damaged clusters are subject to joint maintenance from the point of view of the overall network, so as to achieve a more balanced load between clusters, more rational allocation of network resources. This also avoids the irrationality of single cluster maintenance program carried out and the energy consumption.

5.3.2 Multi-mode clustering mechanism test

In order to visually see seven kinds of cluster maintenance modes in M^2CM which have advantages in terms of network load balancing, in-time response, the experiment uses data generated during the NS2 running to NAM graphic. The test results are shown from Fig. 5 to Fig. 9, where the block diagram node identified as CH, circle node is CM.

Fig. 5 is a response of M^2CM on failure of CH, where triangle identifies the failed CH. Figure a is the cluster structure before the CH is not damaged, figure b is the structure in the 21 seconds, in which case CH of cluster #3-1 suddenly is damaged caused by failure, figure c is the time in 21.1 seconds, CMs gets on no CH re-election after finding the failure of CH, cluster #3-1 becomes cluster #3-2 to complete the maintenance of CH failure.

Fig. 6 is a response of M^2CM on CH energy below the set threshold and new nodes join. Figure a is the cluster structure after the first clustering, figure b is the network topology at 60 seconds, the CH remaining energy of cluster #4-1 is below the threshold and at the same time, new nodes are added to cluster #2-1 and cluster #5-1. M^2CM adopts CH re-election in cluster #4-1 and time slot redistribution in cluster #2-1 and cluster #5-1, resulting in generation of new clusters #4-2, cluster #2-2, and cluster #5-2. Network running can be seen from the NAM shown, and M^2CM resolves the network function disruptions caused by the whole network maintenance effectively, avoiding excessive maintenance and unnecessary energy wastage caused by re-clustering in undamaged area.

Fig. 7 is a response of M^2CM on non-adjacent damaged clusters. Fig. 7(a) is the network topology in 100 seconds. As can be seen from the figure, clustering is not balanced obviously in the network, the number of CMs in cluster #1-1 is greater than N_{max}, the number of CMs

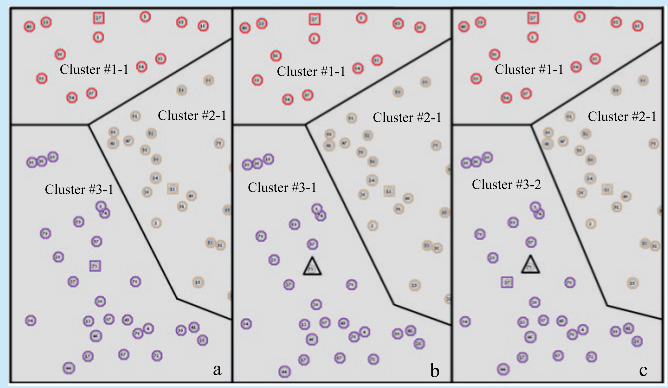


Fig. 5 *No CH re-election*

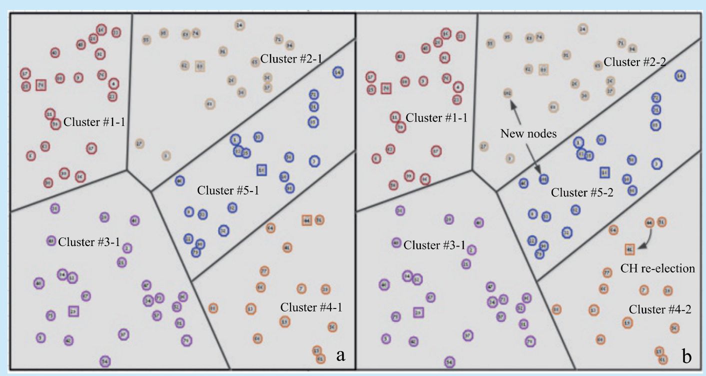


Fig. 6 *CH re-election and time slot redistribution*

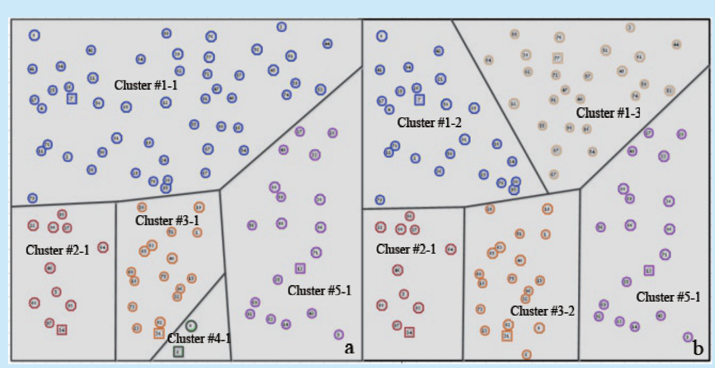


Fig. 7 *Response of M^2CM on non-adjacent clusters*

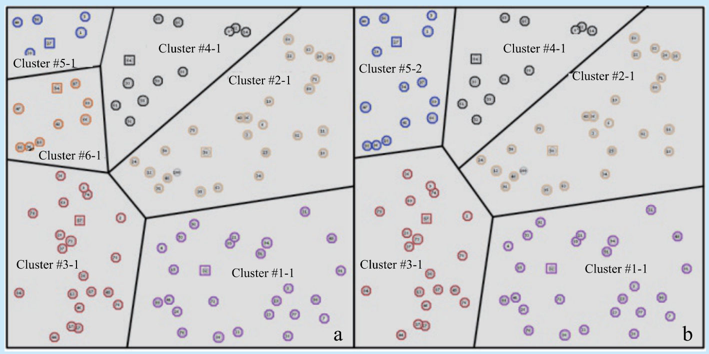


Fig. 8 *Clusters consolidation*

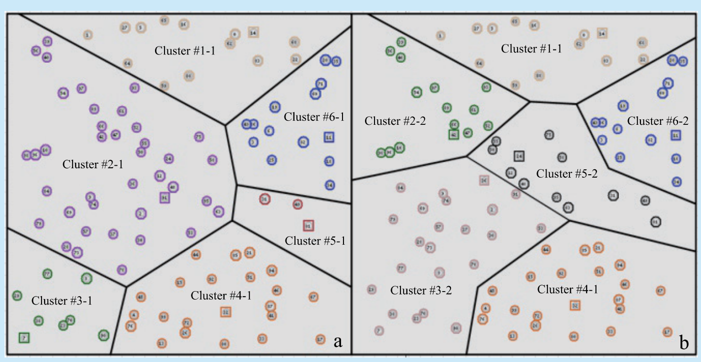


Fig. 9 *Re-clustering based on multi clusters*

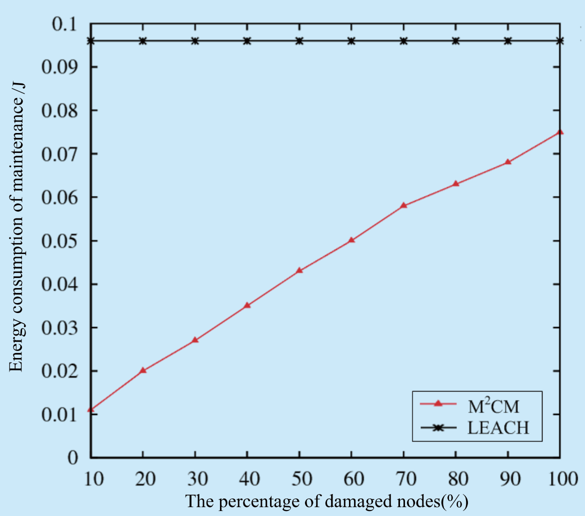


Fig. 10 *Energy consumption of maintenance versus different percentage of damaged nodes*

in cluster #4-1 is less than N_{min}, and they are non-adjacent. In Fig. 7(b), M^{2}CM starts single cluster maintenance program, cluster #1-1 splits into clusters #1-2 and cluster #1-3, cluster #4-1 joins into the neighbor cluster #3-1, the network load becomes balanced as can be seen at this time.

Figs. 8 and 9 show responses of M^{2}CM on adjacent clusters, according to 5.3.1. In this case, multi-cluster maintenance is better than single cluster maintenance. Fig. 8a is the structure of cluster at 161 seconds, clusters #5-1 and cluster #6-1 are damaged adjacent clusters, and the number of nodes in cluster does not exceed N_{max} after merging. At this time, M^{2}CM adopt clusters merge strategy, in Fig. 8b, cluster #5-1 and cluster #6-1 clusters merge into cluster #5-2, without affecting the working of the rest of the clusters.

Fig. 9a is the cluster structure in 200 seconds, cluster #2-1, cluster #3-1 and cluster #5-1 are damaged adjacent clusters, and the number of nodes exceeds N_{max} after merging. M^{2}CM adopts multi-cluster re-clustering, as seen in Fig. 9b after maintenance, the rebuilt cluster becomes cluster #2-2, cluster #3-2 and cluster #5-2. From Fig. 9b it is clearly understood that the network load becomes more balanced after maintenance, and the maintenance carried out only in the damaged clusters.

5.3.3 Recovery energy comparison for different percentage of damaged nodes

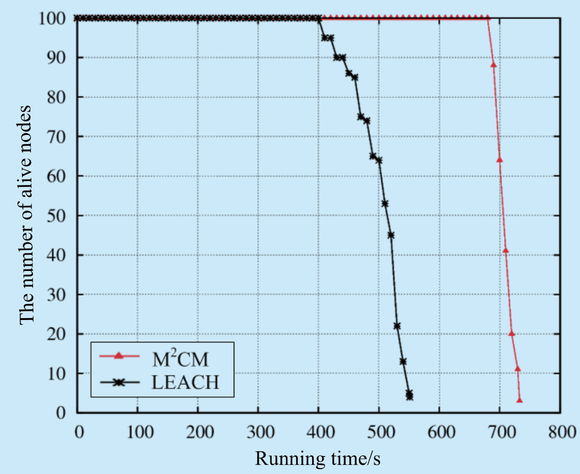
Fig. 10 is the maintenance energy consumption corresponding to the percentage of damaged nodes of M^{2}CM and LEACH, as can be seen from the figure. No matter how much is the ratio of damaged nodes, LEACH uses periodic maintenance of the whole network and energy consumption is constant: 0.096 J. Different from the LEACH, energy consumption of M^{2}CM increases with proportional to number of damaged nodes. When fewer nodes are damaged, only a few damaged clusters are allotted for maintenance, so energy consumption is lower relatively. When there is a higher proportion of the scenario of damaged nodes (even damaged nodes reached 100%), although the maintenance workload closes to the whole network, energy consumption of M^{2}CM maintenance is still less than LEACH. This is because this paper uses the free-space transmission and multipath fading transmission model, as per formula (1) which shows that communication energy consumption of the nodes is related with distance. In M^{2}CM the damaged nodes communicate in the damaged region, only broadcast in the damaged area, with no network-wide broadcast. When CH re-election is needed, the new CH election is designated by the previous CH, or when time slot redistribution is needed, CH only allocates time slot for the new entrant, so energy saved compares with LEACH.

It is noted that we choose LEACH as the comparison object in performance estimation of algorithm because it is widely accepted and easily understood.

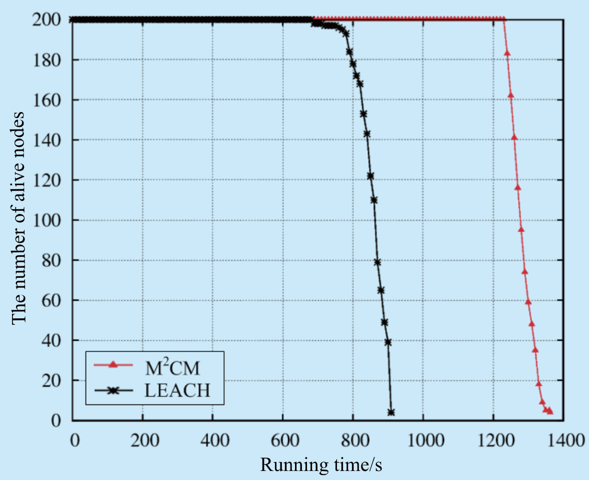
5.3.4 Comparison of network survival time

Fig. 11(a), 11(b) are the comparisons of network of survival time of M^{2}CM and LEACH in 100 nodes (scenario 1) and 200 nodes (scenario 2) environment. From the figure we can get Table 1 as follows:

Where FND is the time of "first node death", END is the time at which all nodes are damaged, AND is the "average time of node death". Table 1 shows that END of M^{2}CM extends 33.0% compared with LEACH in scenario 1 environment, and FND is nearly close to 1.7 times of LEACH. In scenario 2 environment, the advantage of M^{2}CM is further reflected, END prolonged 49.8% compared with LEACH, and FND is close to nearly 1.8 times of LEACH. Thanks to M^{2}CM considering the different scenarios of damaged clusters, there is effective maintenance of the cluster (inter-cluster) topology only through the local information, improving the utilization of energy. This extends the network lifetime compared with LEACH. In addition, M^{2}CM algorithm distributed the energy consumption into each node evenly, as can be seen from the figure. The death time of the nodes is very close, and the accuracy of data collection is improved.



(a) Network survival time of 100 nodes



(b) Network survival time of 200 nodes

Fig. 11 *Comparison of network survival time*

Table I *Comparison of the network survival time(s)*

	M^{2}CM (scenario 1/ scenario 2)	LEACH (scenario 1/ scenario 2)
FND	685/1240	400/690
END	733/1362	551/909
AND	714/1282	497/856

5.3.5 Comparison of the data packets received

Fig. 12(a) shows the amount of data packet received by BS from 100 nodes. From the figure it is clear that the new algorithm can improve the amount of data received effectively compared with LEACH (improved 34.4%); this is because M^{2}CM is able to extend the network

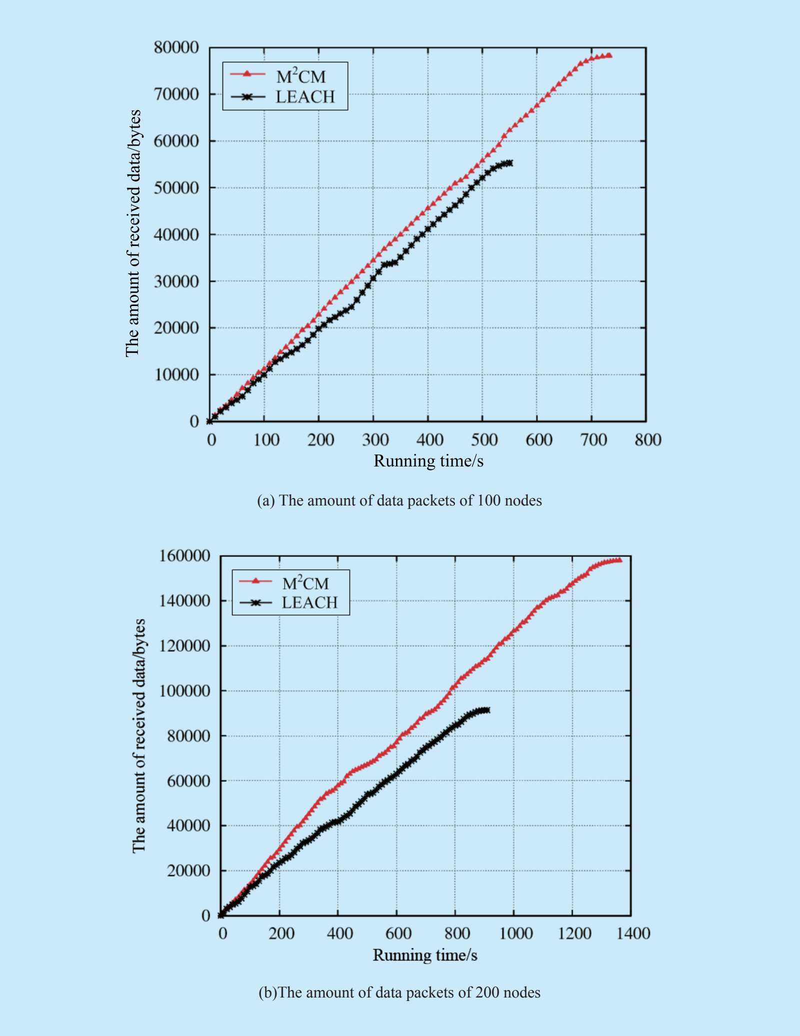


Fig. 12 *Comparison of received data packets*

lifetime. In addition, with more nodes, this advantage is more obvious. Fig. 12(b) shows the amount of data packet received from 200 nodes. The amount of data received by M^2CM improved 74.6% compared with LEACH.

In addition, due to the M^2CM algorithm working under local-area and event-driven, therefore, the computation complexity of the solutions is low, in fact, it is validated by the above results of experiment in energy consumption, network survival time and transmitted data packets.

VI. CONCLUSION

The traditional clusters maintenance scheme adopts network function interrupt and energy wastage problems are followed by periodic time-driven processes and the whole network is re-clustered in hierarchical wireless sensor networks. In order to improve energy utilization rate, prolong the network survival time and improve the network service performance, this paper presents an energy-efficient M^2CM algorithm for clusters maintenance based on event-driven and local mechanism in hierarchical WSNs. The M^2CM adapts to different cluster maintenance modes, through different trigger types and adaptive adjacent relationship with the damaged clusters. It does targeted maintenance and local cluster structural adjustment. The simulation results based on NS2 show that the new model has characteristics of low maintenance cost, load balancing, can prolong the network lifetime and increase the amount of transmitted data compared with LEACH. The algorithm also has good adaptability and robustness and can adapt to the application of large-scale WSNs.

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