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Mobile Agent Dynamic Route Algorithm for WSNs on Balanced Energy Consumption

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Abstract: The computing paradigm on Mobile Agent (MA) for Wireless Sensor Networks (WSNs) to some extent overcomes the problems brought about by the client/server (C/S) model. The MA dynamic route algorithm for WSNs on balanced energy consumption is designed in this study. Because the sensing data of nodes in the same cluster have the characteristic of the temporal and spatial correlation, the selection of the next migration node according to its sensing degree and remaining energy is in favor of balancing the network energy consumption. The collected data are compressed and fused during the migration of MA which reduces the network data transmission traffic and decreases the energy consumption significantly. Theoretical analysis and experimental results show that the proposed route algorithm reduces the energy consumption and transmission delay obviously which is beneficial to keeping the network stability and prolonging the network lifetime.

Key words: Wireless sensor networks, mobile agent, balanced energy consumption, dynamic route

INTRODUCTION

In the last few years, Wireless Sensor Networks (WSNs) have drawn the attention of the research community of theoretical and practical challenges. WSNs can be formed by deploying specialized sensors in the region of interest to perform certain tasks, such as environment monitoring, target tracking, or infra-structure surveillance (Ren *et al.*, 2003; Akyildiz *et al.*, 2002; Dagdeviren *et al.*, 2011).

In WSNs, much redundant sensor nodes are deployed densely to enhance the information sensing accuracy of object (Yang *et al.*, 2007). However, much redundant information posed by the large scale sensor network can lead to network transmission congestion which can consume much energy and cause large transmission delay (Zhou *et al.*, 2007; Bai *et al.*, 2009). Furthermore, the energy of sensor node is scarce, but it is always inconvenient or even impossible to replenish the power. How to delete much redundant, low credible and invalid data to reduce the exorbitant energy consumption? From the angle of prolonging the network lifetime, how to guarantee the balanced energy consumption is vitally important. Since the computing paradigm in collaborative information processing plays an important role in WSNs,

the paradigm must consider the balanced energy consumption of the network. The computing paradigms used in WSNs can be mainly divided into two categories: the client/server (C/S) model and the Mobile Agent (MA) model (Xu and Qi, 2008). Currently, the C/S model is one of the most popular models in WSNs (Choi and Das, 2005), as shown in Fig. 1a. However, the disadvantages of this model are dramatic. Much data gathered by sensor nodes have to be transferred from the clients to the server which consumes much higher energy and reduces the lifetime of WSNs greatly. The MA model can overcome the problems brought about by the C/S model (Qi *et al.*, 2001). The MA is a special kind of software that can execute autonomously which mainly contains identification, itinerary, data space and method (Qi *et al.*, 2003; Chen *et al.*, 2011). As shown in Fig. 1b, after the server dispatches the MA, it migrates among nodes and conducts local data processing using resources available at the sensor node. When MA derives the required information gains, it returns to the server. MA migrates along the sequence of selected valid visiting nodes which decreases the energy consumption and transmission delay and enhances the object tracking efficiency.

As for the mobile agent model, the biggest obstacle is the determination of the dynamic route of MA, i.e., the

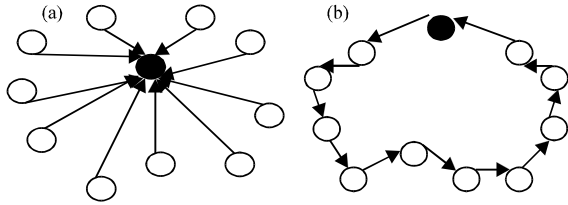


Fig. 1(a-b): Computing paradigms in collaborative information processing in WSNs (a) Client/server computing paradigm and (b) Mobile agent computing paradigm

sequence of valid visiting nodes which affects the level of energy consumption, data fusion accuracy and the overall performance of WSNs (Cai *et al.*, 2012). The MA route is a dynamic optimal route and the algorithm is a NP complete problem (Wu *et al.*, 2004; Hu, 2012). Most MA route planning schemes are based on dynamic optimization of static route. The MA is dispatched after the route is designed and the route is optimized dynamically during the migration of MA (Wang *et al.*, 2011). Since sensor nodes have limited energy and the energy consumption is unbalanced, the sensor node maybe malfunctioning and the connections between nodes can be lost. In the worst case, due to an unexpectedly broken link along its itinerary, an agent can be halted and not reach the target node forever.

The MA dynamic route algorithm for WSNs on balanced energy consumption is designed in this study. Because the sensing data of nodes in the same cluster have the characteristic of the temporal and spatial correlation, the selection of the next migration node is based on the data fusion of node cluster which consider the MA migration cost and the object moving pattern. This algorithm improves the tracking accuracy of the object which is in favor of balancing the network energy consumption. The collected data are compressed and fused during the MA migration which reduces the network data transmission traffic and decrease the energy consumption significantly. Theoretical analysis and experimental results show that the proposed route algorithm reduces the energy consumption and transmission delay comparatively which is beneficial to keeping the network stability and prolonging the network lifetime.

MA DYNAMIC PLANNING ROUTE (MDP)

Different from the static route of MA, the dynamic route of MA do not need to calculate the migration

itinerary before dispatching the MA (Xu and Qi, 2008). The object location and the next migration node are computed according to the local information during the MA migration process (Zhou *et al.*, 2007; Cai *et al.*, 2012). The goal of the MA route calculation is to select a group of sensor nodes in a particular sequence, maximizing the extracted information gains while keeping the resource usage to be minimum.

In order to facilitate the evaluation of different MA migration route algorithms, three metrics are adopted, i.e., energy consumption of the MA migration, information gain and surplus energy of the next migration node. The cost function is as follows (Xu and Qi, 2008):

$$C_{kj}(t) = a \frac{E_{kj}}{E_{max}} + b \left(1 - \frac{I_j}{I_{max}} \right) + (1 - a - b) \left(1 - \frac{e_j(t)}{e_{max}} \right) \quad (1)$$

where, $C_{kj}(t)$ denotes the cost function for MA migration from node k to neighbor node j at time t . The migration cost is composed of three parts. From Eq. 1, the first part denotes the energy consumed by the MA migration to be as little as possible. Where E_{kj} is the energy consumed by the MA migration from node k to node j and E_{max} is the maximum energy consumption and determined by the maximum transmission range between two nodes. The second part denotes the information gains to be as much as possible. Where I_j is the information gains derived on node j and I_{max} is the maximum information gains that can be provided by sensor node. The third part denotes to choose the node with higher surplus energy as the next migration node. Where $e_j(t)$ is the surplus energy on node j at time t and e_{max} is the initial available energy on the node. The cost function takes all three factors into consideration with parameter a and b , where $0 < a, b < 1$ which control the weights of these three factors according to different applications.

If the MA is located at node k and the next migration node is j^* , then they satisfy the following relation:

$$j^* = \arg \min_{j \in N_k} \left\{ a \frac{E_{kj}}{E_{max}} + b \left(1 - \frac{I_j}{I_{max}} \right) + (1 - a - b) \left(1 - \frac{e_j(t)}{e_{max}} \right) \right\} \quad (2)$$

where, N_k is the neighbor node set of node k . When the MA migrates from node k to node j^* , the value of cost function is minimum, that is to say, the energy consumption on the MA migration is relatively small, the information gains is relatively large and node j has much available energy comparatively.

The total migration cost is the sum of each hop and the total information gains is the sum of each I_k . During

the MA migration, once the derived information gains reach the desired value, the MA would return to the server. The derived information accuracy is decided by the value of ΣI_k :

$$\text{Total} = \sum_{k=0}^{\text{Hop}-1} C_{i_k, i_{k+1}} \text{ s.t. Carry} = \sum_{k=0}^{\text{Hop}} I_k > \text{Desire} \quad (3)$$

However, the MDP scheme ignores the special case in which the selected migration node is not in the direction of the moving object. As shown in Fig. 2, the object is located near node C_1 and the MA moves to C_1 at time t . Node A has equal distance with node C_2 and node C_3 . Because node C_2 is closer to the object than node C_3 , the MA on node C_2 would get much stronger signal than that on node C_3 . According to MDP, node C_2 can be selected as the next migration node. From Fig. 2b, we can see that when the MA migrates to node C_2 , the object has move to node C_3 actually. Therefore, in time slot $t+1$, the MA

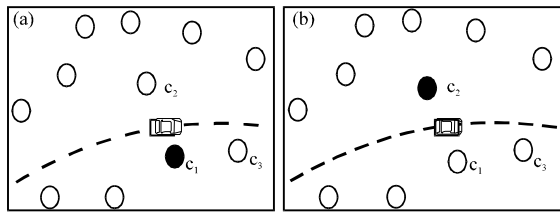


Fig. 2(a-b): Selection of next migration node without considering the MA moving pattern

should migrate to node C_3 which is the optimal choice compared with node C_2 .

Dynamic consideration of the moving pattern of the tracking object can overcome the problem. So we introduce dynamic data fusion method on node cluster to improve the target tracking accuracy. The sensing data of nodes in the same cluster have the characteristic of the temporal and spatial correlation which can be used to predict the moving pattern, such as moving direction and velocity of the object which can enhance the selection accuracy of the next migration node.

MA DYNAMIC PLANNING ROUTE ON DATA FUSION (MDPF)

The MA dynamic route planning algorithm based on data fusion is the scheme that the conception of node clustering is introduced and the data fusion on the cluster is carried out to optimize the selection of MA migration nodes during the dynamic object tracking process. The algorithm can avoid the failed selection of the migration node due to the sudden changes on the moving direction and velocity of the tracking object. Meanwhile, it is in favor of reducing the node energy consumption and improving the balance of network energy consumption.

The diagram of the MA dynamic route algorithm based on data fusion is shown in Fig. 3. When the cluster head node is determined, estimating the distance between the tracking object and the cluster head node, calculating the amount of information gains and updating the value

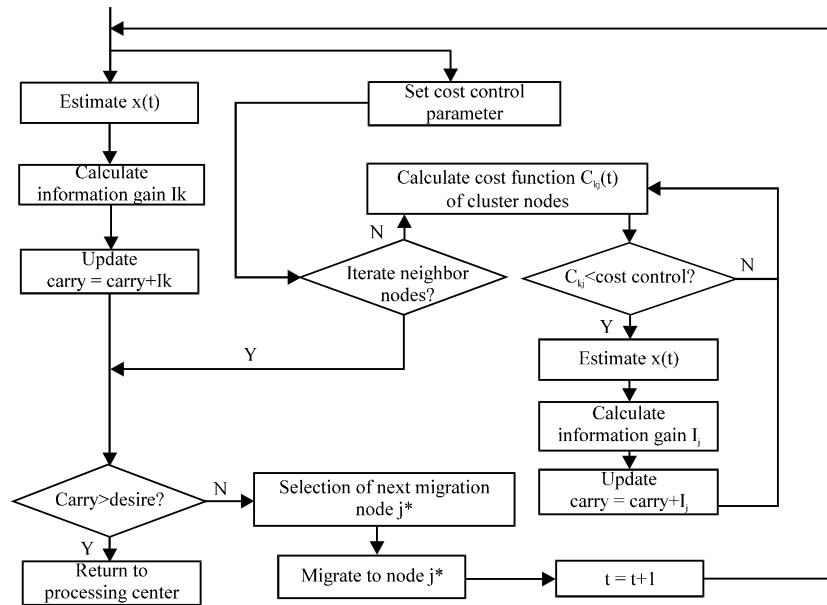


Fig. 3: MA dynamic route planning scheme on data fusion

of Carry. Besides, the selection of cluster member node and relevant calculation should also be conducted at the same time. After the cluster head node is selected, determining one control value of the cost function to select the member nodes, selecting nodes which meet the condition that the cost function value is smaller than the control value into the cluster, calculating the distances between these nodes and the tracking object, calculating the amount of information available and updating the value of Carry until the neighbor nodes are traversed. After that, judging whether the current value of Carry is larger than predetermined value or not. If the current value of Carry is smaller than the value, selecting the next hop cluster head node of the MA through the cost function calculation. Otherwise, the MA begins to return to the processing node. The migration path of MA is mainly along the cluster head node. After the next hop cluster head node is determined, the migration is directly conducted if the cluster head is within the perceived radius. Otherwise, the intermediate node with larger residual energy is selected as the relay node.

While considering three factors of the cost function, setting different values on parameter a and b to increase the degree of concern on the node residual energy and the amount of information gains. Furthermore, the moving pattern of the tracking object should also be considered to predict the moving direction and position of the tracking object so as to select the optimal node to conduct the MA migration. The next hop node within the perceived radius of cluster head is selected which is large in residual energy, much amount of information gains and closer to the cluster head. The selection efficiency of the agent migration node is improved through the overall consideration on the cost function and the motion direction and speed of the tracking object.

ENERGY CONSUMPTION AND DELAY ANALYSIS

Energy consumption analysis: Compared with C/S model, the sensor network based on MA model is to transmit the MA with fused data instead of the original data, so the amount of information transmitted is reduced greatly. Moreover, the MA does not need to visit all sensor nodes. Therefore, the MA model can decrease the energy consumption obviously. As for the MA dynamic route planning algorithm, the network energy consumption consists of not only the consumed energy by the MA migration, but also the energy consumption by the MA route planning. Extra cost can be brought about if the route planning scheme is carried out before MA migration.

In the MA dynamic route planning algorithm based on data fusion, the energy consumption of this algorithm mainly consists of three parts, such as the energy consumption on transmitting MA, receiving MA and data fusion, denoted as E_{itr} , E_{ire} and E_{id_fusion} respectively. The E_{id_fusion} can also be extended as the energy consumption of the MA identity verification by nodes ($E_{id_validate}$), the energy consumption that MA collects the data stored in the nodes ($E_{id_acquire}$) and the energy consumption of data fusion (E_{id_fu}).

The nodes accessed by MA is divided into two categories, one is called relay node, wherein the route node is only responsible for transmitting MA and its energy consumption is $E_{itr}+E_{ire}$ the other one is called fusion node, wherein this kind of node needs to conduct data fusion in addition to transmitting MA. The energy consumption of fusion node can be expressed as $E_{itr}+E_{ire}+E_{id_fusion} = E_{itr}+E_{ire}+E_{id_validate}+E_{id_acquire}+E_{id_fu}$.

On the condition of one order sensing model (Heinzelman *et al.*, 2000), the energy consumption caused by transmitting and receiving k bit data for d distance can be expressed as following equations.

Transmitting energy consumption:

$$E_{tx}(k,d) = E_{tx-elec}(k) + E_{tx-amp}(k,d) = E_{elec} \times k + \epsilon_{amp} \times k \times d^2 \quad (4)$$

Receiving energy consumption:

$$E_{rx}(k) = E_{rx-elec}(k) = E_{elec} \times k \quad (5)$$

where, in $E_{tx-elec}$ means the transmission energy consumption, E_{tx-amp} means channel transmission energy consumption, $\epsilon_{amp} = 100\text{pJ} / (\text{bit} \cdot \text{m}^2)$, $E_{rx-elec}$ means the receiving consumption, $E_{tx-elec} = E_{rx-elec} = E_{elec}$, $E_{elec} = 50 \text{ nJ/bit}$.

Among the MA dynamic route planning algorithm, assuming the number of migration node is v_0 and the total network energy consumption E can be expressed as follows:

$$\begin{aligned} E &= \sum_{i=1}^{v_0} (E_{itr} + E_{ire} + E_{id_fusion}) \\ &= \sum_{i=1}^{v_0} (E_{itr} + E_{ire} + E_{id_validate} + E_{id_acquire} + E_{id_fu}) \\ &= \sum_{i=1}^{v_0} (E_{elec} \times k + \epsilon_{amp} \times k \times d^2 + E_{elec} \times k + E_{id_validate} + E_{id_acquire} + E_{id_fu}) \end{aligned} \quad (6)$$

As for the MA dynamic route planning algorithm on data fusion, Assuming the number of the cluster head nodes that the MA accesses is n_1 and the number of relay

nodes is n_p . The total network energy consumption E can be expressed as follows:

$$\begin{aligned}
 E &= \sum_{i=1}^{n_1} (E_{itr} + E_{ire} + E_{id_fusion}) + \sum_{i=1}^{n_2} (E_{itr} + E_{ire}) \\
 &= \sum_{i=1}^{n_1} (E_{itr} + E_{ire} + E_{id_validate} + E_{id_acquire} + E_{id_fu}) + \sum_{i=1}^{n_2} (E_{itr} + E_{ire}) \\
 &= \sum_{i=1}^{n_1} (E_{elec} \times k + \epsilon_{amp} \times k \times d^2 + E_{elec} \times k + E_{id_validate} + E_{id_acquire} + E_{id_fu}) \\
 &\quad + \sum_{i=1}^{n_2} (E_{elec} \times k + \epsilon_{amp} \times k \times d^2 + E_{elec} \times k)
 \end{aligned} \tag{7}$$

Among the MA dynamic route planning algorithm on data fusion, the energy consumption of MA route planning is avoided and only the message needs to be broadcasted for the neighbor nodes within the regulated interval, wherein the message is small in data size and short in transmission distance, therefore it can be ignored for the convenience of calculation. Data fusion reduces the dynamic fluctuant change of the migration itinerary which would decrease the MA migration hop and the energy consumption.

Network delay analysis: The network delay denotes the time needed from the server dispatching MA to MA returning to the server. The delay generally consists of three parts, i.e., the delay of sensor node transmitting MA, the delay of MA transmitted from one node to another and the delay of data fusion on MA. Compared with the MA curve dynamic route algorithm mentioned in the delay of collecting the total network information in advance can be saved by the proposed algorithm in this study. The information can be gathered on the cluster head node by member nodes during the process of MA migration which reduces the network delay greatly. The nodes that MA passes through during the migration are reduced remarkably. Therefore, the network delay of MA dynamic route algorithm based on data fusion is decreased obviously.

PERFORMANCE EVALUATION

Experimental environment and parameter setting: We developed the Matlab-based simulation scenarios to evaluate the performance of the proposed algorithm. The network is arranged in a 20×20 m rectangular area, wherein 500 sensor nodes are scattered randomly, the sensing radius of the node is 5 m and the node density is 1.25 m⁻². The initial energy of the sensor node is 36 J and the node message are broadcasted to neighbor nodes every 0.1 sec. The moving speed of the tracking object is 5 m sec⁻¹.

Table 1: Basic parameter setting of the wireless sensor network

Parameters	Values
Network area (m ²)	20×20
The number of nodes	500
Initial energy of nodes (j)	36
Distribution form of nodes	Random distribution
Sensing radius of nodes (m)	5
Motion speed of object (sec ⁻¹)	5
Interval of node broadcasting data message (sec)	0.1
Size of MA (bits)	100+400 = 500

Assume the length of MA code is 100 bits, the size of carried data is 400 bits, wherein the size of the data carried by MA is fixed. The basic parameter of the WSN is setted as shown in Table 1.

The parameter setting mainly involves the selection of weighted coefficient a, b in the cost function which relate to energy consumption on migration, the amount of collected information and node residual energy after migration. In MA dynamic route planning algorithm, three parameters should be considered in a balanced way. For the MA dynamic planning route algorithm based on data fusion, the cost function for the selection of the cluster head node should be considered separately with the cost function for the selection of the non-cluster head node. In the selection process of the former one, the amount of collected information should be considered firstly and then the residual energy should be focused on. Given those reasons mentioned above, a and b are set as 0.1 and 0.3, respectively. During the process of MA migration from one cluster head node to the next cluster head node, the process can be conducted by a relay node if it exceeds the sensing radius. In the selection process of the latter one, the weight parameter for the residual energy of the nodes can be reduced because no data fusion is carried out on the relay node, wherein a and b are set as 0.5 and 0.3, respectively. By the joint programming of two cost functions, the optimal migration path of MA is determined.

Energy consumption and network delay are adopted to evaluate the network performance. During the evaluation process, the number of nodes in WSNs is increased gradually in order to compare the network performance of LCF, MDP and MDPF algorithm.

Experiment result and analysis

MA migration itinerary simulation: Figure 4 and 5 are the MA migration itinerary simulation of MDP and MDPF algorithm, respectively. The MA firstly migrates along the blue itinerary to conduct the object tracking and then returns to the processing node along the green itinerary which is the shortest path with larger residual energy. As can be seen in two figures, the selection of next hop node

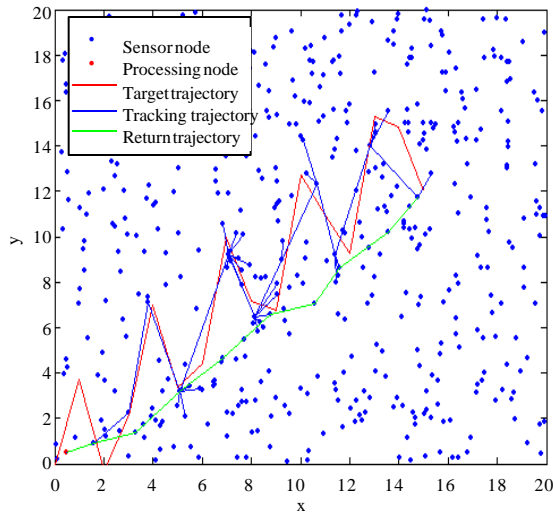


Fig. 4: MA itinerary simulation on MDP algorithm

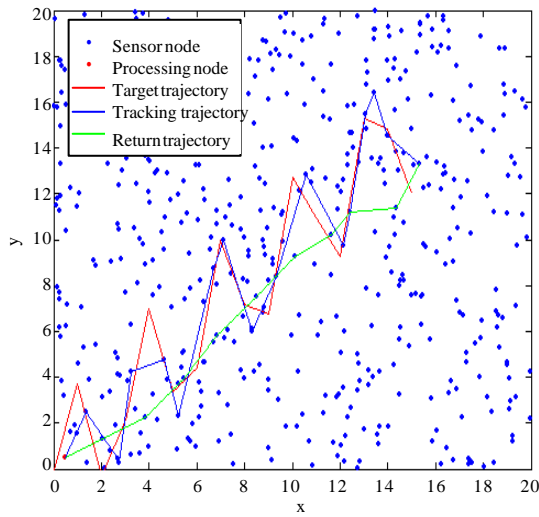


Fig. 5: MA itinerary simulation on MDPF algorithm

in our algorithm is more accurate and the tracking of object is more efficient.

Network performance analysis: As shown in Fig. 6, when the number of nodes is increased from 100 to 800, namely during the process that the scale of WSN is gradually expanded, the energy consumption of MDP and MDPF algorithm are both smaller than that of the traditional LCF algorithm obviously. Besides, MDPF algorithm is better than the MDP algorithm, because MA migrates to the next hop cluster head node after data fusion is realized on each cluster head node which reduces the back and forth migration of MA to some node and

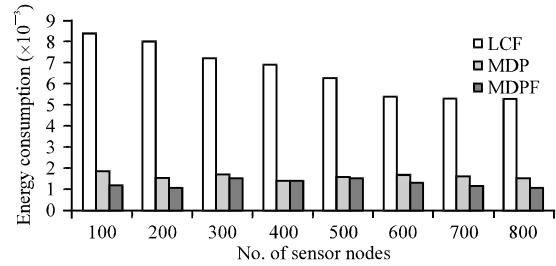


Fig. 6: Comparison of network energy consumption of three algorithms

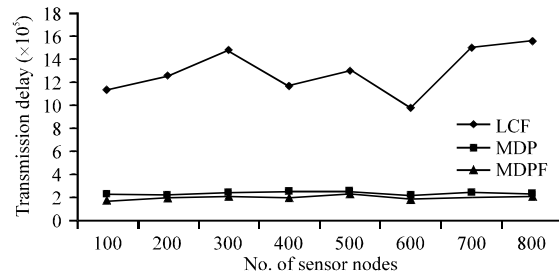


Fig. 7: Comparison of network delay of three algorithms

decreases the integral hop number, therefore the energy consumption is reduced.

As shown in Fig. 7, with the increase of the network scale, the delay of LCF algorithm occurs fluctuating changes. Because sensor nodes are distributed randomly in the network, some nodes may be close to the object and the MA migration hop number is reduced. The total hop number of both MDP and MDPF algorithm are slightly decreased and stable relatively, because the search of object nodes and the return to the processing node are along the optimal path purposefully. The reason why the delay of MDPF algorithm is better than that of MDP algorithm is that the data fusion process reduces the MA migration on member node of the cluster which can decrease the network delay effectively.

CONCLUSION

A mobile Agent dynamic route planning algorithm on data fusion is presented in this study. With the idea of node clustering, the object tracking efficiency of WSNs is improved and the energy consumption for the MA migration is balanced. Theoretical analysis and experimental results show that the proposed route algorithm reduces the energy consumption and transmission delay comparatively which is beneficial to keeping the network stability and prolonging the network lifetime.

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