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RESEARCH

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Research on the energy balance algorithm of WSN based on topology control

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Abstract

Topology control is a key energy-saving technology in the wireless-sensor networking. In this paper, networking-associated algorithm named local minimum spanning tree (LMST) employed while compromising on energy balance issues, leading to the short lifetime of the network, and proposes an energy balance algorithm. The algorithm fully investigates the energy utilization to link the data communication and the remaining energy of the communication node, to achieve the balanced energy, and to avoid the complexities associated with excessive consumption of energy when the intermediate node acts as a data forwarding task, thus extending the network life cycle. The simulated experimental outcomes showed a great potential of the proposed algorithm that can efficiently prolong the network lifetime and guarantee the long-term reliable operation of the network while ensuring other network performance indicators, such as throughput and delivery rate.

Keywords: Energy balance, Topology control, Wireless sensor network, CLC: TP918.91

1 Introduction

As a new type of network information acquisition system, wireless sensor networks have extremely broad application prospects in civilian and military fields. It has the characteristics of huge scale self-organized, random distribution, and multifaceted circumstances with just few sensor node resources and frequent network topology changes [1]. This depicts the significance of controlling topology in the field of wireless sensor network. The research of controlling topology is to improve the life of the network life as the main target and with the foundation of ensuring the communication degree and coverage of the network, taking into account the communication interference, network delay, load balancing, simplicity, reliability, scalability, and so on, thus forming an optimized network topology [2]. Currently, several classification methods to control the topology algorithms, which are sub-divided into two algorithms such as "global topology control" algorithms and "distributed topology control" according to whether the algorithm needs global network information or local network information.

The "global topology control" is an algorithm that performs topology modification according to the worldwide topology statistics, performs network topology structure work on a particular node, and serves as algorithms named "relative neighborhood graph" (RNG) [3], "minimum spanning tree" (MST), connect algorithm [4], and so on. While the other algorithm called "distributed topology control" links the local statistics to maintain the association of the network, such as "local information no topology (LINT) algorithm [4] distributed relative neighborhood graph (dist-RNG) algorithm [5], LMST-type algorithm [6], and mobile grid algorithm [7].

Because the wireless sensor network belongs to a distributed network, there is no central node in the network, and it is not suitable to use a global topology control algorithm. In document [6], a popular control topology-based "local minimum spanning tree" (LMST) has been proposed. It has a common purpose which is to control power on adjacent graph. This algorithm mainly contains each node that computes by the minimum spanning tree method according to the locally associated topology, which can successfully reduce the global communication energy utilization. However, the network topology constructed by local spanning tree algorithm has little connectivity and very less noisy link. Moreover, the algorithm does not include the issues of

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balance energy. The middle node of the whole network communication link beside the sink-node controlling the task of accelerating a large amount of information. While the larger load increases the energy losses greater than the leaf node, and any middle-node is invalid, that will ultimately lead to network topology interruption. As a result, network connectivity is affected and network lifetime is shortened. Therefore, concerning the solution of energy balance complications, this research work aims to propose an LMST algorithm grounded on energy stability. In the construction of the topology, the energy utilization because of nodes communications and the remaining energy for communication nodes are comprehensively considered. Because the middle-node consumes more energy for sending information packets. The other leaf nodes are not accountable for information packets forwarding by minimizing energy utilization. As the service time increases, it leads to gradual increase of link weight among the middle node and supplementary nodes, and the intermediate node may become a leaf node, and it is no longer responsible for the data forwarding work and saves energy.

2 Energy-balanced network topology control algorithm

2.1 LMST algorithm

LMST algorithm [8–10] is a typical control algorithm grounded on neighborhood graph. Such type of graph control algorithm sets the topology graph G formed when all the nodes transmit using the maximum transmit power. According to a certain neighbor judgment condition q, the neighboring graph G' of the graph is obtained. Finally, each node in G' determines the transmit power by its nearest communication node. The main algorithms include RNG, MST, LMST, and so on. The LMST algorithm [11–14] is to send Hello packets to any node in the plane with the maximum statement radius $d_{\max}$, accumulate all the info from closer nodes, and starts greedy algorithm to construct the local minimum spanning tree which takes itself as the root node.

The communication power of the node is set, and the communication radius is adjusted to reach all the one-hop neighbors on its LMST to attain the goal of evaluating the total energy consumption by local minimum communication. The system is in fact a distributed approximate optimal implementation of the global minimum spanning tree algorithm. By adjusting the locally independent minimum spanning tree, the local minimum spanning tree algorithm can recognize the double connectivity of the topology, and it successfully lessen the transmit power of maintaining the comprehensive global connection and improve the collision of the MAC-layer. Furthermore, this algorithm constructs the local accumulated information-based topology to minimize the number of interactive packets and the time delay required. This local topology repair can be carried out in a definite direction to the node movement problem. Compared with other neighbor graph methods (such as UDG), it reduces energy consumption, contains fewer links, reduces interference in the network, and improves performance provided in Fig. 1.

Although the LMST type algorithm constructs a network topology efficiently by locally minimum total energy consumption, ignoring the problem of energy balance. The middle node bears too much load in the network, which consumes a lot of energy and easily leads to poor network connectivity.

2.2 Network model

There are some assumptions included in this article such as (1) every node has uniform maximum transmit power capability, that includes a section having a radius of $d_{\max}$, and can modify that radius by regulating the transmit power. (2) Each node has the same preliminary energy, and the position info can be acquired through localization algorithm. (3) A relationship between energy utilization and communication gap in wireless communication is [15, 16]:

$$E = kd^n + C \tag{1}$$

Where E = consumed energy, k = a constant associated with the working system, d = communication gap, and C = working system constant and its value is taken as "0." Here, n has a value of 3. That is, energy consumption for communication is related to the third power of communication space.

Furthermore, LMST algorithm based on energy balance considers the remaining energy of the communication node while taking into account the node communication energy consumption. Therefore, the algorithm link weight [17, 18] is

$$R = k_1 d(r,t) + k_2(2E_0/(E_r + E_t)) \tag{2}$$

Where $k_1 + k_2 = 1$, and $d\ (r,\ t)$ = space between the transferring node and accepting nodes, E_0 = the node's initial energy, E_{t} = remaining energy of the transferring node. E_{r} = remaining energy of the accepting node; k_1 and k_2 are variable parameters. However, if the remaining energy of two nodes after transferring or accepting is high, the weight of link parameter (R) becomes lower. While if the remaining energy of nodes is lower, the weight (R) value becomes relatively high and the intermediate node is less likely to be responsible for the task of data forwarding, which saves its own energy and prolongs the life of the node. The whole network gradually reaches the state of energy balance during operation.

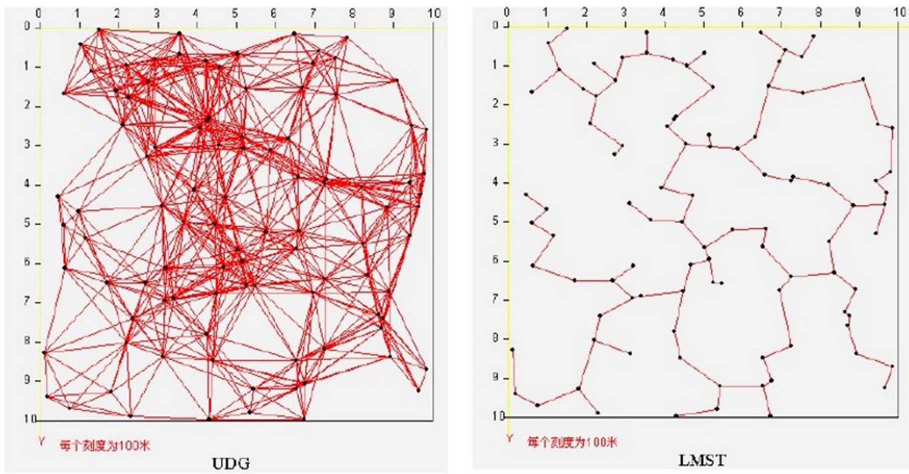

Fig. 1 Topology diagram generated by UDG algorithm and LMST algorithm

2.3 Description of network topology control algorithm based on energy balance

This algorithm takes balancing energy consumption as the goal. When the topology is constructed, the energy utilization and the remaining energy of the nodes for communication are considered, and the effect of energy balance is achieved [19, 20].

(1) Collect node information. The node "u" periodically transmits a Hello packet to other node in the valid range at the d_{max}, and the subsequent acceptor node feeds back the response packet to the sender node u, so that the node u can acquire the response of all the nodes in its visible neighboring area NVu(G).
(2) Constructing topology graph. The node u works on the basis of the greedy algorithm to obtain the LMST in perspective of the visible neighbor node information and calculates the link weight coefficient R according to the formula (2). With the increase of service time, the gradual increase of weight between the intermediate node and other neighbor nodes has been observed, and there is a greater probability in topology construction from intermediate node to leaf node, which is no longer responsible for data forwarding and saves energy.
(3) Determine the transmit power. Based on the determined structure of the LMST, the node u determines its own transmit power and regulates the communication radius d_{max} to grasp all one-hop neighbors.
(4) Bidirectional processing. The node u directs a check packet for whole one-hop neighbors in the tree and waits for receiving the response packet from the neighbor node. After the time-lag, the received response packet defines a link between the node u and neighbor node is bidirectional. If not, the edge is deleted.
(5) Broadcast topology. The node u broadcasts its own reasonable neighbor node, and the advised node stores information into the data construction Info_Root Node, marking the considered node as the reasonable neighbor node of the node u and receiving the information packet from the u. After accepting a data packet by each node, it requires to examine the Info_Root Node to determine the receiving of the data packet. If it cannot be received, it is discarded.
(6) Reconstruct the topology. Due to energy consumed by the node or may be dead node, every network node needs to operate the algorithm periodically, to perform topology reconstruction based on the existing visible information by the neighbor node, to obtain a new LMST, and to determine the transmit power.

3 Simulation experiment

This paper uses software "Atarrays" to simulate the LMST algorithm to evaluate the performance of the employed algorithm from the network lifetime, throughput, delivery rate, and other related performance indicators. The network lifetime is less than 60% of the duration until the dead node, and the throughput is the ratio of the amount of data received by the end node to the time used. While the delivery rate refers to the percentage of the packets received and sent by the end node. Table 1 shows the setting of relevant input parameters used for simulation experiments.

4 Simulation analysis

Experiment 1 compares the network lifetime of wireless sensor networks under the two algorithms. In Fig. 2, the

Table 1 Parameter setting of simulation experiment

Parameter setting	Value
Area size	100 m × 100 m
Static sensor node	60
Static sink node	1
Maximum power radius of the node	300 m
Adjustable power radius	0~300 m
Node topology reconstruction time	25 s
Node packet interval time	Based on 1.0
The size of the packet	1024
Start time of node contract	10.0 s

node failure under the LMST algorithm is fast, and the node failure starts at about 123 s. The effective node number decreases to less than 60% at about 220 s. In this algorithm, the node can work for a long time, the node failure occurs at about 180 s, and the effective number of nodes decreases to less than 60% at about 280 s. In this thorough network lifetime, the effective nodes used in this algorithm are more than the number of effective nodes under the LMST algorithm.

Experiment 2 compares the throughput under the two algorithms. Because the number of packets sent is evaluated by the number of effective nodes, it can be perceived from Fig. 3 that when the time is 120 s, the number of packets under the LMST algorithm has a significant decline, and the drop speed of the number of packets is faster than that of the algorithm in this paper. There are more effective node points in this algorithm than in the LMST algorithm in the lifetime of whole network.

Experiment 3 compares the delivery rate of network nodes under the two algorithms. As shown in Fig. 4, the delivery rate curve under the two algorithms is basically similar, but after 80 s, the drop speed of delivery rate curve based on LMST algorithm is much faster than that of original algorithm. The smaller the delivery rate of network nodes is, the more data packets are lost. In the later stage of the operation, the delivery rate under both algorithms decreased significantly because the number of effective nodes decreased.

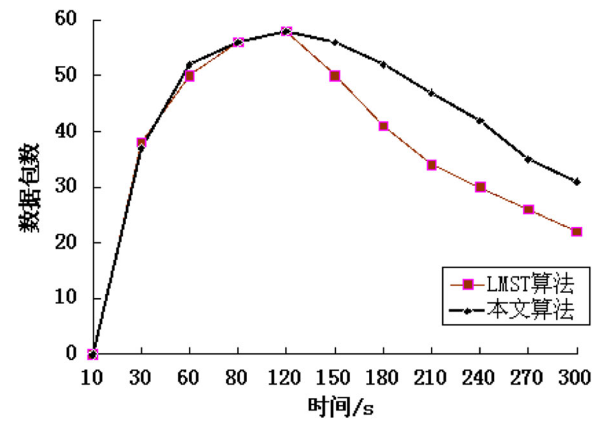

Fig. 3 Comparison of throughput curve between LMST algorithm and this algorithm

5 Conclusion

The LMST algorithm can excellently construct a network topology employing local minimum total energy consumption, but the algorithm ignores the problematic energy balance. The intermediate node bears too much load in the network, which consumes a lot of energy and easily leads to poor network connectivity. This algorithm fully ponders the energy consumed by the communication link of the provided data and the remaining energy of the communication node to attain the outcome of energy balance, avoiding the complexities of excessive energy consumed, while the intermediate node acts as a data forwarding task, thereby extending the life cycle of

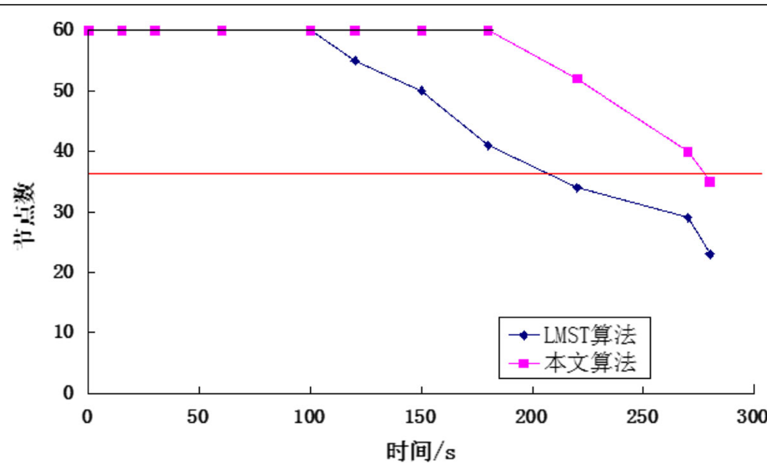

Fig. 2 Comparison of network lifetime curves under this algorithm and LMST algorithm

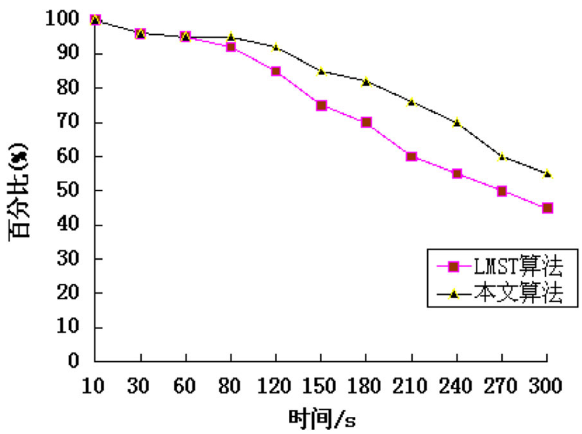

Fig. 4 Comparison of network node delivery rate curves between this algorithm and LMST algorithm

the whole network. The simulation experiment illustrated that the proposed algorithm will effectively elongate the life span of the network and guarantee the long-term reliable operation of the network while ensuring other network performance indicators, such as throughput and delivery rate.

Abbreviations

LINT: Local Information No Topology; LMTS: Local minimum spanning tree algorithm; MAC: Media access control; MST: Minimum spanning tree; RNG: Relative neighborhood graph algorithm; UDG: Unit disk graph

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Availability of data and materials

The materials and data are true and reliable in this paper.

Authors' contributions

TQ (550533905@qq.com) is the corresponding author. WZ and YH conceived the proposed scheme. WZ and MW conducted the detailed derivation of the proposed algorithm and carried out most of the experiments and data analysis. MK carried out some parts of the experiments and data analysis. MW helped to improve the experimental simulation. All authors have read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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