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Energy balance LEACH networking protocol based on mobile node adaptive cluster head strategy

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Abstract. How to evenly use network node energy and to generate high-reliability route is a difficulty for WirelessHART network research. A kind of GRAEB (Graph Routing Algorithm based on Energy Balancing) graph algorithm has been put forward. Firstly, network is initialized as linked graph structure, which can improve abundant redundant routs. Network manager generates node robust factor matrix according to factors of whole-network and node surplus energy, communication period and link distribution, etc. node selects optimal route by comparing nearby robust coefficient. In addition, limit valve value of nearby node has been specified and only neighborhood with optimal robust coefficient is reserved for each route update. It is shown by simulation result that GRAEB not only has improved network liability, but also has extended network life.

Key words. Graph route, LEACH protocol, Energy balance, Node movement, Adaptive cluster head strategy.

1. Introduction

WirelessHART is wireless Mesh network communication protocol [1, 2] which is promoted by HART Foundation in 2007 and is applied to industrial process control, equipment health supervision and asset maintenance, etc. High transmission reliability and energy finiteness are major difficulties for WirelessHART network and reasonable and balanced application of whole-network energy is necessary measure for its industrialization. Existing route selection algorithm cannot have reliability and long lifecycle, which is very difficult to be applied to Wireless HART network directly. Therefore, it is necessary to design simple route algorithm aiming at unique graph design of WirelessHART network, which not only guarantees simple route

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algorithm, but also greatly extends network life.

Up to now, researchers have put forward successively many energy-saving route protocols. Literature [4] transmits data by seeking for route with minimal energy lost of single route, while, the route energy can exhaust energy with increase of communication frequency. Network is decomposed as several disconnected sub-networks. Method in literature [5] is also to select a fixed route to transmit, which is inapplicable to WirelessHART industrial wireless networking requirement. Literature [6] has put forward a kind of distributed processing route algorithm, which can only ensure local energy balance. In MCP-PS algorithm in literature [6], node can select next hop dynamically and automatically without adopting fixed route and algorithm cannot ensure high reliability. Literature [8] has put forward a kind of graph route algorithm ELHFR of shortest route surplus energy, while energy balance of network is not considered. Literature [9] has obviously ignored communication load of nodes by taking shortest route surplus energy as node to select measurement of next hop. Energy balance route algorithm MEBRS put forward by literature [10] can ensure energy balance of network, route structure attached by the algorithm cannot ensure shortest route and complexity of the algorithm is relatively large. Therefore, how to ensure robustness and optimal energy balance of network is the maximal difficulty for WirelessHART research.

Aiming at foresaid condition, this paper puts forward a kind of Graph Routing Algorithm based on Energy Balancing (Graph Routing Algorithm based on Energy Balancing, GRAEB) and the algorithm takes node communication load, link connection and surplus energy into consideration, which makes energy of network node to the best balance and extends network life.

Content arrangement of this Paper is as follows: Chapter I provides whole realization process of GRAEB algorithm from the third aspect; Chapter II carries out performance assessment and Chapter III executes performance simulation to algorithm and Chapter IV concludes the whole paper.

2. GRAEB algorithm process

Whole process of GRAEB route algorithm is detailed from three aspects of topology establishment, robust coefficient solution and route selection update.

2.1. Topology establishment algorithm

Initialize network administrator, establish initialization gateway GW (Gateway) and set degree of GW as 0. It is supposed that communication radius of all nodes is r, so, all nodes in GW circumference r will request to join in network. Next, network administrator will distribute only address for these new nodes and record degree as 1 in node attributes; similarly, nodes with degree 1 will approve child node with acceptance 2 to join in network. In addition, child node with degree 2 will write father node with degree 1 into neighbor route list. By that analogy, initialized graph route structure will form until all nodes go through. Topology establishment process is shown as Fig.1.

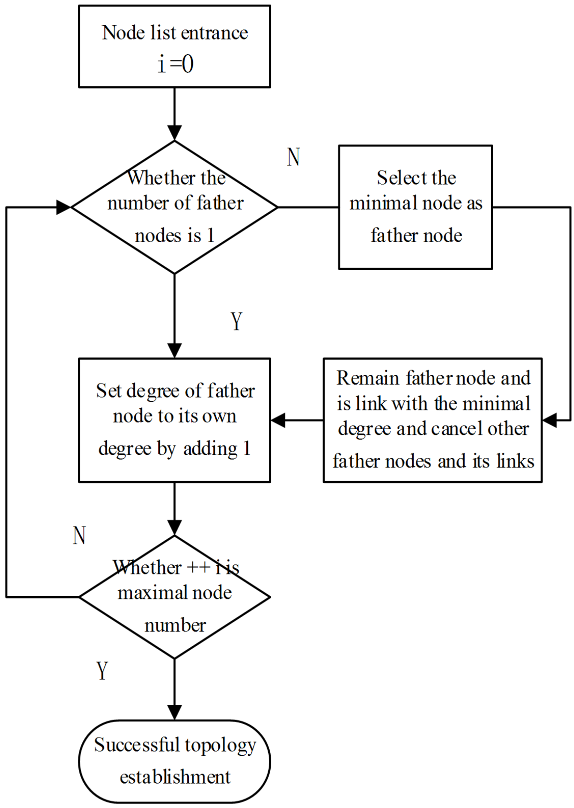

Fig. 1. Topology establishment algorithm

Initial topological structure generation observes the following important principles:

(1) Nodes with the same degree are called as brother nodes and link connection is not established between them, which is because shortest route [11].

(2) Initialization process of each node shall have link connection and initial neighbor number of each node is not limited.

(3) In initial communication, nodes will send surplus energy, communication period and neighbor table per hop. At the same time, selection of route is judged according to surplus energy of nodes.

Supposed that WirelessHART network with 8 nodes, initial network topology structure is shown as Fig.2 according to foresaid topology establishment process and degree is 0 for gateway node with node 0. Node 1, node 2 and node 3 are located in communication radius, so, they will connect with gateway and address and degree will be distributed by network administrator and their degree is set as 1. Node 4 and node 5 will connect respectively with node 1, node 2 and node 3, so, their degree is 3; by this analogy, network topology generation process will be completed until link connection is established for all nodes.

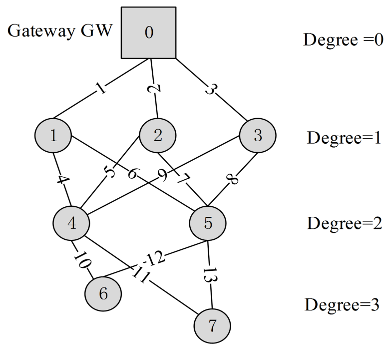

Fig. 2. Initialized network topology structure chart

2.2. Node robust coefficient calculation

(1) Specification and analysis of relevant parameters

1) Node link matrix $SN \times L$: $SN \times L$ is matrix expression form of all node links. Where, N represents sum of nodes and column vector represents each node that is marked strictly; L represents all link number and row vector has represented each link that is marked strictly; otherwise, there is no link [10].

2)Surplus energy matrix of nodes $WN \times 1$: $WN \times 1$ is set of all node surplus energy.

3)Node communication period matrix $PN\times 1$: node transmits communication period to network administrator regularly and $PN\times 1$ is set of all nodes communication periods.

4)Node communication frequency matrix $FN\times 1$: node communication frequency has reflected load of nodes. Any element in $FN\times 1$, $Fi1$ $(i < N)$ refers to communication times for each node per second. $FN\times 1$ can be obtained according to node communication period matrix, $PN\times 1$, where:

$$F_{i1} = \frac{1}{P_{i1}} . \tag{1}$$

5)Link communication frequency index matrix $TL\times$: $TL\times$ has reflected use frequency of each link. The high frequency is, the larger load and the faster energy consumption are; the lower frequency is, the smaller load and slower energy consumption are. Because link communication frequency is related to link ends nodes and is closely related to nodes selection, it is extremely important to establish link communication frequency reasonably. Here, geometrical distance method is adopted: it is supposed that nodes on both sides of link l are respectively p and q, so their communication frequencies are $Fp\times 1$ and $Fq\times 1$ and communication frequency index of link l, $TL\times 1 (l < L)$ is estimated as follows:

$$T_{l1} = \sqrt{F_{p1}^2 + F_{q1}^2} . \tag{2}$$

6)Node energy consumption factor matrix *BN×1*: *BN×1* is estimation for relative energy consumption in node unit time. Where, any element *Bl1(l<N)* represents energy consumption efficiency of node i.

7)Node robust coefficient matrix *RN×1*: *RN×1* takes energy consumption efficiency and surplus energy value into consideration simultaneously, which is comprehensive representation of node robust.

(2) Robust coefficient matrix *RN×1* algorithm

By collecting information of surplus energy, communication period and neighbor information in routing list, etc., network administrator can calculate node robust coefficient of each node and can broadcast to all sub-nodes. Steps that network administrators analyze and calculate *RN×1* are as follows:

1)Node communication frequency matrix *FN×1* is calculated by formula (1).

2)Link communication frequency matrix *TL×1* is obtained by formula (2).

3)Multiplying node link matrix *SN × L* with *TL×1* obtained from formula (2), node energy consumption factor matrix, *BN×1* is obtained and calculation method is as follows:

$$B_{N\times 1} = S_{N\times L} \bullet T_{L\times 1} \tag{3}$$

4)Any element in node robust coefficient matrix *RN×1* can be obtained from the following equation:

$$R_{i1} = \frac{W_{i1}}{B_{i1}} \tag{4}$$

2.3. Topology update and route selection algorithm

To ensure network performance stability, network administrator shall update route and topological structure periodically. Middle node by comparing with robust coefficient of neighbor nodes, eliminates neighbors with relatively poor performance, remains or increases relatively excellent nodes as new neighbor nodes (maximal valve value *Nmax* is set for neighbor nodes number).

Node number in network is downward successively; firstly, it starts from node with the maximal node; if the number of node neighbors is larger than valve value, neighbors with the number of *Nmax* are selected preferentially by comparing with robust coefficient of neighbors and rest nodes are eliminated; otherwise, it transfers to next node and continues foresaid process. Flow diagram of algorithm is shown as Fig. 3.

Network in Fig. 2 is selected for research and *Nmax = 2* is selected and network topology structure update is shown as Fig.4. Specific process is as follows and neighbor nodes of node 4 are respectively 1, 2 and 3 and robust coefficients of these neighbor nodes are compared by foresaid algorithms; it is assumed that robust coefficients of 1 and 2 are relatively superior, so, node 4 will eliminate node 3 from its neighbor table. Similarly, node 5 will be eliminated from node 1 from its neighbor table, which has completed topology update from the whole network.

After completion of topology update, it is assumed that optimal route of node j to gateway shall be found out. The node shall inspect robust coefficient information of its neighbor node in its own routing list and compares and selects optimal node

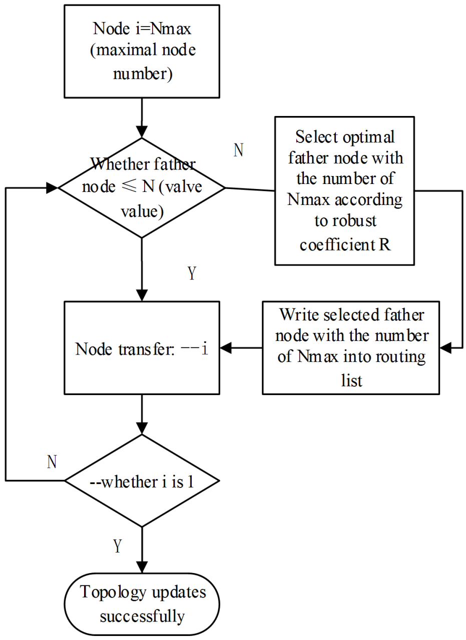

Fig. 3. GRAEB algorithm updates network topology structure

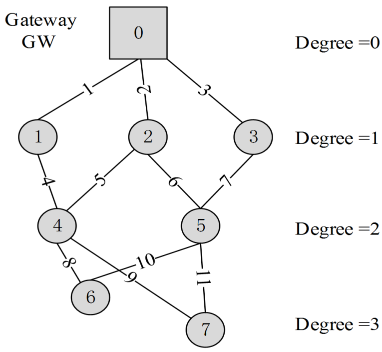

Fig. 4. Initialized network topology structure chart

of robust coefficient as next hop address by this analogy until reaching gateway. Selective process of route is shown as the followings:

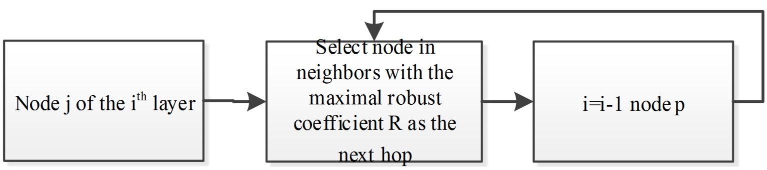

Fig. 5. Routing selection algorithm

3. GRAEB algorithm performance analysis

GRAEB graph route provides hopscotch redundancy and ensures high reliability by adopting improved BFS (breadth-first searching) algorithm. Graph topology establishment mechanism in this paper has cancelled link connection between brother nodes and can ensure that hop count of each node reaching gateway is the shortest, which shortens delay and is one of the reasons. Algorithm in this paper can not only realizes minimal hop count, but also realizes selection of quality.

Traditional topology establishment algorithm is divided by degree, which only considers network topology generation to the maximum, but ignores reliability of neighbor nodes and brings dilemma of route selection [11]. GRAEB graph route limits the number of neighbor nodes and source node eliminates neighbor node with relatively poor performance and remains or increases relatively excellent nodes as neighbor nodes and sets upper limit for neighbor node by comparing robust coefficient of the next hop node. The mechanism not only simplifies size of routing list, but also ensures whole network energy balance to the maximum.

For improvement of energy balance, compared with surplus energy selection algorithm ELHFR [8], the route selection mechanism gives consideration to both whole-network surplus energy and node communication load. According to the mechanism, nodes with relatively excellent robustness are selected by priority, which prevents the most excellent node from being selected frequently, ensures balance of the whole network energy and extends network life and has outstanding significance for WirelessHART industrial wireless sensor network.

Besides, WirelessHART network also can obtain better effect during execution of high-reliability task. To prove high reliability of graph route algorithm in this paper, we define several parameters firstly: Pe refers to probability of false reception of normal signal for introduction of noise (mainly refers to Gaussian white noise) and reception failure caused by media interference conflict or various decays; Pd refers to probability of node invalidation caused by too low energy, cache overflow or other external interference; m is the number of neighbor nodes of each node; n refers minimal hop count of node from source node to gateway (shortest hop count has been realized in algorithm); refers to successful transmission probability of the graph route from source route to uplink process of gateway.

After n hop, probability of correct information transmission is:

$$P_{graph} = \left\{1 - \left[1 - (1 - P_e)^2 (1 - P_d)\right]^m\right\}^n . \tag{5}$$

However, several uncrossed redundant routes shall be provided by AOMDV multipath routes in current stage [12]. It is supposed that system performance parameter can be the same with GRAEB graph route and probability $PAOMDV$ that information can be transmitted correctly after n hops of AOMDV route is defined hereinafter.

Obviously, according to serial link probability algorithm, it can be obtained that [8]:

$$P_{\mathrm{AOMDV}} = (1 - P_d)^2 \left\{1 - \left[1 - (1 - P_e)^n (1 - P_d)^{n-1}\right]^m\right\} . \tag{6}$$

4. GRAEB algorithm performance simulation

4.1. Network life simulation

Not considering repeated transmission and error code caused by non-noise factor, MATLAB comparison simulation shall be carried out to GBAEB algorithm and maximal surplus energy selection algorithm and calculation of energy consumption for each wireless communication can be obtained from literature [13] and rest relevant parameters are shown in Table 1.

Table 1. Simulation parameters setting

Parameter type	value	Parameter type	value
smulation area	200 × 200	initialized energy E0	1
the number of topology	10	FN*1	0
gateway position	(0, 0)	transmission bit rate R0	2B/S/HZ
noise power	-70DBM	cargo handling capacity $\eta 0$	1.9B/S/HZ

Simulation is carried out in the 10 kinds of different graph topologies and optimal route to gateway shall be sought out by selecting source node by random selection according to two kinds of algorithms until all energy of nodes is consumed. Then, average transmission time of the 10 topology structures is taken as average network lifecycle of the two kinds of algorithms. Simulation results are shown as Fig.6.

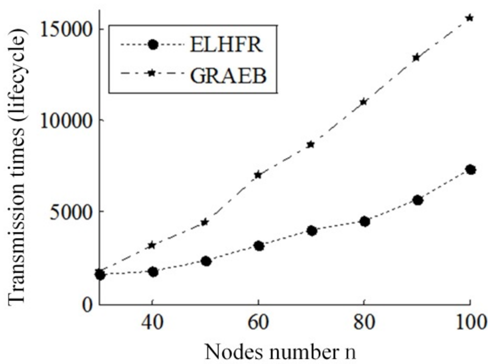

Fig. 6. Network lifecycle comparison

Fig. 6 specifies that with the increase of network node number, network lives under the two kinds of algorithms are both improved significantly and network life of the algorithm is about 2 times of ELHFR algorithm. According to the trend, with further increase of network nodes, advantages of the algorithm are more outstanding. It is because that ELHFR algorithm always selects node with the most surplus energy as the next hop, which will cause that these nodes will be selected frequently, while other nodes are in idle state; the algorithm considers surplus energy and communication load and nodes with relatively more surplus node energy and few communication frequency will be selected in priority and the mechanism effectively has balanced energy of all nodes and has extended network life.

4.2. Reliability simulation

Compared with multi-path route AOMDV, according to formulas (5) and (6), relevant parameters are selected as: $Pe = 0.03$; $Pd = 0.03$; $m = 3$ and transmission reliability of the two kinds of algorithms can be obtained and influence of different m values on communication reliability of GRAEB graph route can be obtained simultaneously. Simulation result is shown as Fig. 7-8:

Fig.7 specifies that GRAEB graph route has relatively high reliabiilty compared with AOMDV multi-path route and advantges of GRAEB graph route will be more obvious with the increase of hop count of route. When n = 20, probability for accurate information reception of GRAEB is 0.9868 and undistorted transmission can be reached almost;

Packet loss probability condition under different neighbor nodes number is described in figure 8. It can be seen from graph that reliability of communication can be promoted further with increase of neighbor node m and undistorted transmission can be reached almost when m = 4. This experiment has solved a practical industrial problem, namely, when packet loss probability of path is relatively large and network communication quality is relatively poor, high reliability transmission of data can be realized by increasig neighbor node number in topology structure. However, increase of m will bring forward routing list expense and complexity if robut coefficient calculation and will lead to faster energy consumption simultanuously. Balance between m value and energy optimality shall be determined as the case may be and more excellent algorithm is to be researched.

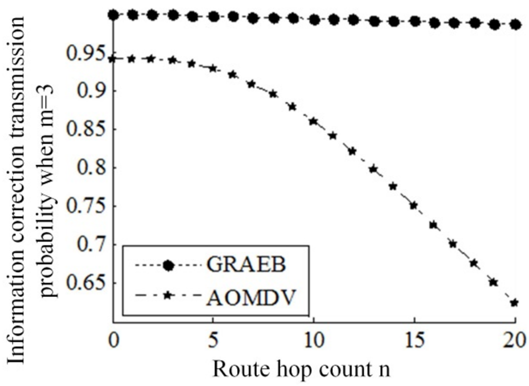

Fig. 7. Reliability comparison of BRAEB graph route and AOMDV route When m = 3

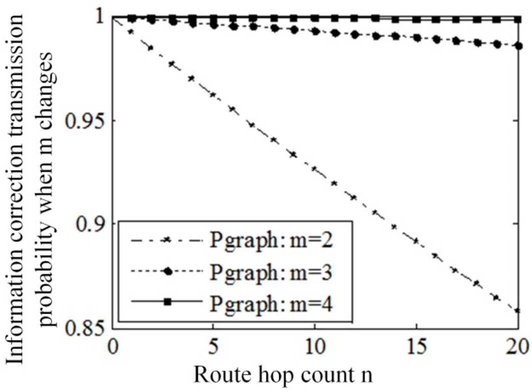

Fig. 8. Reliability comparison of BRAEB graph route and AOMDV route When m changes

5. Conclusion

Aiming at application requirement in WirelessHART industrial networking, this paper has put forward a kind of energy balance graph route algorithm GRAEB. Firstly, network generates the shortest route topology structure according to graph algorithm and then, nodes selects route and update topology according to robust coefficient matrix. At the same time, algorithm has also limited the number of each node and neighbors with relatively poor performance shall be eliminated periodically to ensure transmission reliability. GRAEB algorithm has solved energy balance and high reliability in WirelessHART practical application; has sufficiently guaranteed load balance of network; has extended network life and has improved communication reliability at the same time.

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