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Paper:

An Improved Rumor Routing Protocol Based on Optimized Intersection Angle Theory and Localization Technologies in WSN

Zhuang Liu, Xin Feng†, Jing Zhang, Yan Liu, Jianfei Zhang, and Xin Zhang

School of Computer Science and Technology, Changchun University of Science and Technology
B1601, Science and Tech Building, 7186 Weixing Road, Changchun 130022, China
†Corresponding author, E-mail: lz1227@live.cn

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Routing mechanism is a key issue in Wireless Sensor Networks, and rumor routing protocol can reduce energy consumption and extend the lifecycle of network with unicast mechanism. However, in Rumor Routing protocol, the transmission path of event message is not optimal and random forwarding mechanism will lead to routing loop. In this paper, we investigate Rumor Routing protocol, and propose an improved rumor routing protocol based on optimized intersection angle theory. Localization technology and vector intersection angle mechanism are brought into the new protocol as two metrics of route selection. The new mechanism can reduce the energy consumption of data transmission. We compare Rumor Routing protocol, GPSR protocol, a Rumor Routing-based protocol, and the improved protocol. Results of simulation experiments indicate that the improved routing protocol can reduce the energy consumption of routing path and extend the lifecycle of network.

Keywords: WSN, rumor routing, intersection angle, localization, network lifecycle

1. Introduction

A Wireless Sensor Networks (WSN) is a self-organization multi-hop wireless network, consisting of a large number of sensor nodes deployed in the monitoring area [1]. WSN is widely used in many applications such as environment detection [2, 3], military affairs [4], traffic control [5], target tracking, disaster warning, medical nursing [6] and etc. Because sensor nodes have limited energy without supplement, the routing protocol of WSN should be of low energy consumption. The main WSN routing protocols include energy-centered protocols, data-centered protocols, geography-centered protocols, clustering hierarchy-based protocols and some combinative routing protocols.

In this paper, we introduce the existing state of the art researches of WSN routing protocols, and propose a new routing protocol by an improved mechanism, and compare three congeneric routing protocols with our work.

2. Related Works

In energy-centered protocols, Power Available Routing protocol [1] creates routing table and selects routing path according to the left energy of sensor nodes and the energy requirement of routing path. However, it can only be applied under the condition that sensor nodes know the topology of the whole network. Multi-path Energy Consumption Routing protocol [7] can establish more than one path from the source node to the target node. Path selection depends on the probability obtained from the energy consumption of the path and the left energy of nodes in the path. It can prolong the lifecycle of network, however, the calculation of probability is another overhead of routing protocol because it has to make flooding messages maintain routing table and the value of probability periodically.

In data-centered protocols, Directed Diffusion (DD) [8] routing protocol sends interested inquiry message to monitoring area by flooding method, so sensor nodes can transmit the interested data to sink node. DD protocol has high energy consumption because of flooding method. Rumor Routing (RR) [9] protocol is an improved routing protocol of DD protocol. Sink node of RR protocol queries unicast interested information in network randomly, and sensor node transmits unicast monitoring information to sink node randomly. A routing path can be established when the two messages meet. RR does not use broadcast, however, it may lead to loop circuits and high energy consumption long routing path. Xu's protocol (NM-RRP) [10] is an improved RR protocol which can choose the next hop node through each node and its neighbor nodes from messages recorded by agent messages and inquired messages. Leave information at the neighbor nodes of each node in transmission path, so the random node can be avoided to transmit.

In geography-centered protocols, Geographical and Energy Aware Routing protocol [11] establishes routing path by local geographic information, which can reduce energy consumption, instead of flooding mechanism. However, it causes routing voids without topology information of the network. Greedy Perimeter Stateless Routing protocol (GPSR) [12] establishes routing path by localization information using greedy algorithm to reduce energy consumption. It also causes routing voids because of uneven communications. Graph Embedding Routing protocol [13] presents network topology by virtual polar coordinates and designs network as a tree with ring. Each node selects routing path according to hops and angle distances from the root of the tree. This protocol simplifies the presentation compared with physical coordinate method, however, it need to keep a steady network topology. Geographical Location Information and Minimum Energy Consumption Routing protocol [14] selects routing path according to local topology and minimum energy consumption, however, it requires high node density. Localized Lifetime Maximizing Routing protocol [15] selects routing path according to local geographic information and control on power, however, it still need high node density.

In clustering hierarchy-based protocols, Low Energy Adaptive Clustering Hierarchy protocol (LEACH) [16] selects a portion of sensor nodes as cluster heads (CH) by a probability model. Other normal sensor nodes find the nearest CH and join into its cluster. CH collects, processes, and transfers the data from normal sensor nodes to base station. Normal nodes monitor environment, collect data and send them to CH. Minimal Energy Transmit Routing protocol [17] creates clusters and makes the minimum energy consumption to reduce the whole energy consumption of the network. The path between different clusters is established by the weight of distance power function. However, no geographic information is taken into consideration in those processes which leads to uneven distribution of CHs.

In combinative protocols, Reliable Primary-Backup Routing protocol [18] adopts network topology fault variations and alternative routes with backup path and primary path. It maintains failing route by inquiring the immediate neighbor nodes with alternate routes, so it can fix the topology fault with little extra information. Autoregressive Moving Average Model for Multi-Agent Routing protocol [19] introduces the energy-prediction model into heuristic factor to achieve reliable structure. The energy consumption of each node can be estimated in advance, which can detect the energy status of WSN adaptively. However, these protocols do not process their own energy consumption because of the changing network topology in WSN.

In this paper, we investigate the routing protocols of WSN and propose an improved routing protocol. We adopt random unicast method of RR protocol and localization technology to design the improved routing protocol. An intersection angle theory is introduced to find optimal routing path and avoid routing loop which can reduce energy consumption. We conduct simulation experiments of comparing four protocols including RR, NM-RRP, GPSR, and our improved protocol to find out the performance of our improvements.

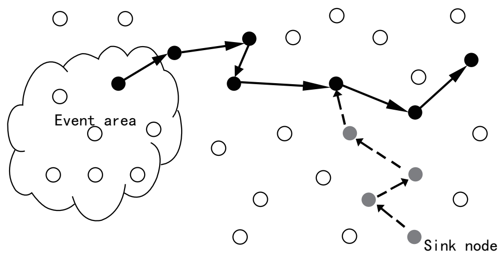

Fig. 1. Rumor routing protocol.

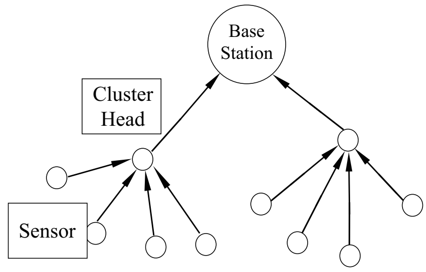

Fig. 2. Topology of LEACH.

According to the above introduction, we use localization technology to locate sensor nodes, and random unicast method to query message, and cluster mechanism to establish network topology.

In RR protocol, an agent sensor node sends unicast event agent message from the event area to the outside randomly, and a sink node sends a unicast query message to the outside randomly. If the two messages meet in one node, i.e. the agent message path crosses the query message path, a routing path between sink node and event area is established. The route mechanism of RR protocol is shown in **Fig. 1**.

In **Fig. 1**, the solid line with arrow represents event agent message path, and the dotted line with arrow represents query message path. The circle node represents normal node and the solid node represents the node in a routing path.

In LEACH protocol, each node can be selected as a CH. The network topology is shown in **Fig. 2**.

In **Fig. 2**, the network is divided into three layers. The first layer is base station which is the super center node with limitless energy in WSN. The second layer is CH layer and the third layer is normal nodes layer.

3. The Improved Protocol

In this paper, we propose an improved rumor routing protocol based on optimized intersection angle theory and localization technologies (OIAT) protocol. OIAT protocol uses cluster topology, localization technologies and intersection angle theory to establish and maintain routing paths of network.

3.1. Cluster and Localization Technologies

We use DV-Hop algorithm [20] to localize sensor nodes. DV-Hop uses the number of hops and hop-size to work out the distance between each unknown sensor node and its referenced beacon sensor node, and then uses trilateration to calculate the locations of unknown sensor nodes. The hop-size calculation is shown in Eq. (1).

$$Hop\text{-}Size_i = \frac{\sum_{j=1}^{n} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j=1}^{n} hop_{ij}}. \quad (1)$$

In Eq. (1), n is the amount of beacon nodes. $Hop\text{-}Size_i$ is the estimated distance of each hop of beacon node. (x_i, y_i) is the coordinate of beacon node i. (x_j, y_j) represents the coordinate of other beacon nodes. hop_{ij} is the number of hops between different beacon nodes.

The two radio energy models [16] are used to calculate energy consumption. One is free space model and the other is multi-path fading channel model [21–23]. The energy consumption of data transmission is shown in Eqs. (2) and (3).

$$E_{TX}(n,d) = \begin{cases} n * E_{elec} + n * \varepsilon_{fs} * d^2 & d < d_0 \\ n * E_{elec} + n * \varepsilon_{mp} * d^4 & d \geq d_0, \end{cases} \quad (2)$$

$$E_{RX}(n) = n * E_{elec}. \quad (3)$$

In Eqs. (2) and (3), $E_{TX}(n,d)$ represents the energy consumption of data sender. n is the amount of data being sent. d is the distance between sender and receiver. $E_{RX}(n)$ represents the energy consumption of the data receiver with n-bit data received. E_{elec} represents the energy consumption of the wireless transceiver circuit. According to the energy consumption of transceiver circuit and power amplification circuit, if the distance between sender and receiver is less than d_0 (distance threshold) the network adopts the free space model (power attenuation proportion to d^2), otherwise the network adopts the multipath attenuation model (power attenuation proportion to d^4).

The improved protocol adopts cluster topology. Network selects CHs from sensor nodes using probability method. Each sensor node works out a random number in a particular scope and compares the number with a threshold to decide if it can turn into a CH. The threshold value calculation is shown in Eq. (4) [16].

$$T(n) = \begin{cases} \dfrac{P}{1 - P \times \left[r \bmod \left(\dfrac{1}{P} \right) \right]} & n \in G \\ 0 & n \notin G. \end{cases} \quad (4)$$

In Eq. (4), $T(n)$ represents the threshold of selecting CH. P is the percentage of the CHs in network. r is the rounds of the clustering hierarchy established. n is the ID of sensor node. G is the collection of sensor nodes that have never been selected as CHs.

3.2. Routing Establishment Algorithm Assumptions and Definitions

The algorithm has the following assumptions:

(1) Isomorphic sensor nodes with limited energy are randomly distributed in monitoring area. Each sensor node is unique.

(2) Sensor nodes have timers and are able to process the data.

(3) Sensor nodes can be localized and are unmovable.

(4) The initial energy of sink node is unlimited.

(5) The end of the network lifecycle is the time when all the sensor nodes in the event area are invalid.

Definition 1: The set of candidate neighbor nodes: comparing the relationship of the positions between the current nodes and its neighbor nodes, the candidate neighbor nodes are those that meet certain position requirement and whose left energy are above certain threshold.
Definition 2: Neighbor list: it records the current state of its neighbor nodes, ID, and so on.
Definition 3: Event list: it records event ID, next hop and other related information.

3.3. Routing Establishment Process

The new algorithm adopts round mechanism. The agent message in event area is a packet of event information including TTL and event properties. The sink node generates an inquiry message for a particular event. When executing the new algorithm, each sensor node will establish a neighbor list as its candidate routing table and will conduct the process of matching inquiry message and event message. There two core processes in the new algorithm, one is the establishment of node's candidate routing table to find out the cross sensor node, and the other is the selection of message routing path for the cross node to find out optimal routing path. The first process is as follows, and the second process is described in Section 3.4.

Step 1: When detecting an event, a sensor node adds an item into its event list. An event message with event ID, location, hops and TTL is sent out.

Step 2: When receiving an event message, a sensor node searches its event list. If there is an item corresponding to the event, the minimum hops will be recorded after comparing. If there is no matched item, the event information will be recorded in the sensor node. The event message will keep transferring randomly till TTL is 0.

Step 3: When receiving an inquiry message with event ID, location and TTL from the sink node, a sensor node checks its event list. If the inquiry fails, the inquiry message will keep transferring randomly till TTL is 0. If the inquiry message is matched, a cross node is found, and TTL is set as 0.

Step 4: Detect candidate neighbor nodes amount. If the amount is not more than 1, the cross node sets its next hop node as this neighbor node, otherwise, the cross node uses OIAT mechanism to optimize the routing path.

Step 5: If there is no reply within a period of time, the sink node will send another inquiry message again.

The algorithm flow of establishment of node's candidate routing table is shown in **Fig. 3**.

3.4. Routing Path Selection Mechanism

The new algorithm divides the network into many areas and uses clustering method to establish network topology. The new algorithm uses localization information to optimize the routing path inside a cluster or between CHs.

A new theory, optimized intersection angle theory, is used to optimize the routing path of RR protocol and avoid routing loop. When the cross node, the sink node and the agent node appearing, network calculates the intersection angle between the out-path vector and the in-path vector. If the angle is less than a threshold the routing path needs to be optimized and the cross node should be changed. Otherwise, including the cross node, all of the nodes in the routing path use intersection mechanism to select their next hops. Furthermore, the routing path is influenced largely by the channel state information (CSI) and the location. Before calculating the angle between sensor nodes, each sensor node produces a set of candidate nodes with signal strength and location information.

The mechanism is shown in **Fig. 4**. The angle between sensor nodes cannot represent the quality of the routing path perfectly.

In **Fig. 4**, the solid line with arrow represents event message path, and the dotted line with arrow represents query message path. The circle node represents normal node and the solid node represents the node in the routing path. Using Rumor Routing protocol, network can establish a routing path as R1= {A, A1, A2, B, C3, C2, C1, C} between the agent node A of event area and the sink node C. Node B is the cross node. Firstly, each sensor node establishes a set of candidate neighbor nodes, and then we link lines between A and B, B and C, and create two vectors: vector AB and vector BC. If $\angle$ABC is less than a threshold, especially an acute angle, the energy consumption of routing path R1 is high. However, if $\angle$ABC is more than a threshold its energy consumption is low. A vector has direction information which can avoid the message being sent towards a wrong direction. Intersection angle can restrict the length of routing path. We calculate $\cos\angle\mathrm{ABC}$ to optimize the routing path and reduce the energy consumption of the routing path. The calculation of $\cos\angle\mathrm{ABC}$ is shown in Eq. (5).

$$\cos\angle\mathrm{ABC} = \frac{|\mathrm{AB}|^2 + |\mathrm{BC}|^2 - |\mathrm{AC}|^2}{2|\mathrm{AB}| * |\mathrm{BC}|} \quad . \;.\;.\;. \quad (5)$$

Equation (5) shows that $\angle$ABC can indicate the rationality of the established routing path. The energy consumption is affected by the quality of routing path. There are three methods to reestablish an optimized routing path including establishing from the agent node, establishing from the event node and establishing from the cross node.

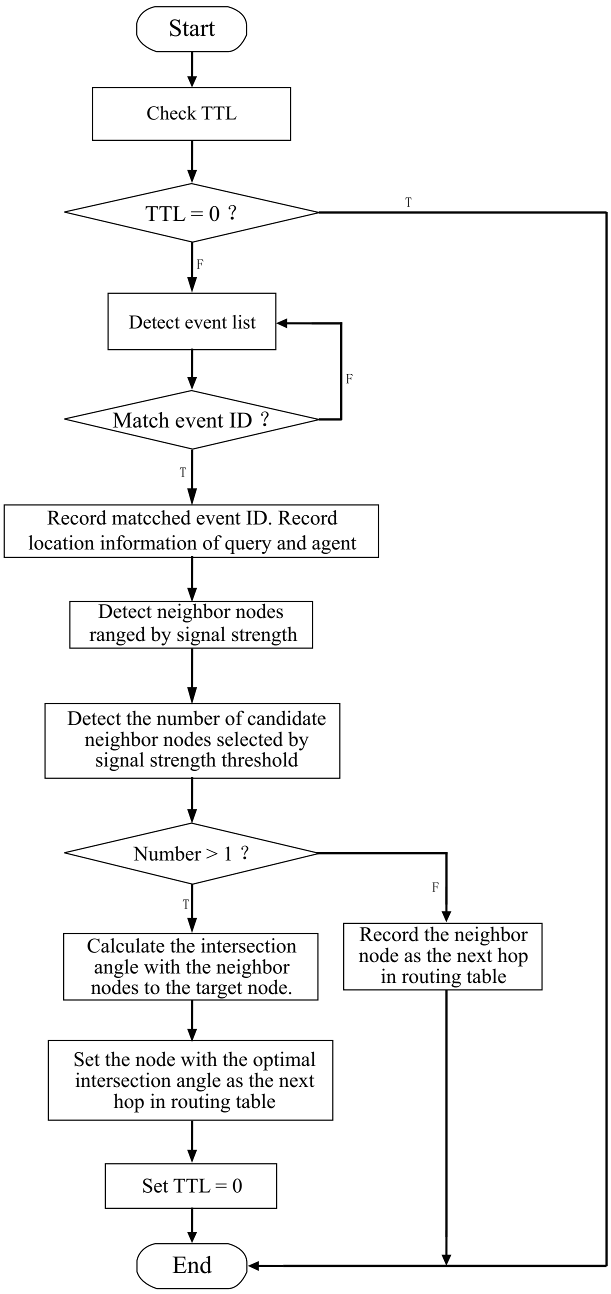

Fig. 3. Establishment of node's candidate routing table.

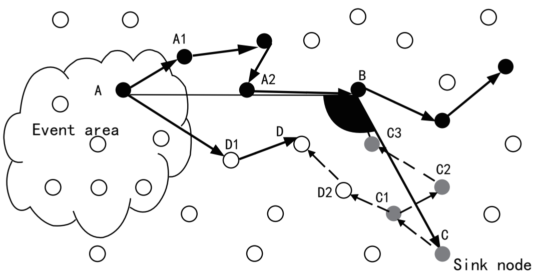

Fig. 4. Mechanism of optimized intersection angle.

In **Fig. 4**, we take event node A for example. R1 is a tortuous path composed of 9 nodes. $\angle$ABC is much less

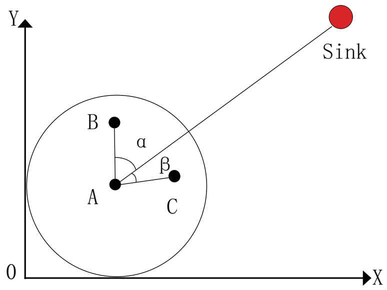

Fig. 5. Path selection mechanism.

than π, therefore, R1 is a high energy consumption path. Network needs to establish a new routing path to reduce energy consumption. Node B sends the location of node C to node A along the adverse path of the agent message path. Then, node A can send event message to node C according to vector AC. According to the location information of node C and vector AC, when selecting the next hop node from its neighbor nodes, node A chooses the node with minimal intersection angle of the new vector and vector AC. In **Fig. 3**, path R2= {A, D1, D, D2, C1, C} is the new routing path found out by OIAT mechanism.

In **Fig. 5**, the black spot represents sensor nodes and the red spot represents sink node. Node A represents the node in charge of establishing routing path. Suppose that the initial energy of nodes is E_{init}, the left energy is E_{left} and the threshold of energy is E_t . The condition is $E_{init} > E_t$. The process of node A selecting the next hop among its neighbor nodes using OIAT theory is as follows:

Step 1: Establish a set of candidate neighbor nodes of node A according to the signal strength threshold and location information.

Step 2: According to the location coordinates of node A and the sink node, the vector A-Sink is constructed. The equation for vector A-Sink is $y = kx + b$, A→Sink.

Step 3: In the candidate neighbor nodes of A, if any node whose X-axis is nearer to Sink than node A, and its E_{left} is less than E_t, it will be put into the candidate neighbor nodes set S_r of node A.

Step 4: According to the formula $\sin\angle\text{BASink} = (1/|\text{AB}|)(|kx + b - y|/\sqrt{k^2+1})$, the intersection angle between each candidate neighbor node with A and vector A-Sink is calculated.

Step 5: The minimum angle $\theta_{\min}$ from vector AX to vector A-Sink is estimated. The neighbor node will be the next hop of A if its intersection angle is equal to $\theta_{\min}$. In **Fig. 4**, node C is the next hop of node A.

4. Simulation Experiments and Analysis

Simulation experiments are executed to verify the effectiveness of OIAT protocol in MatLab R2011b. The

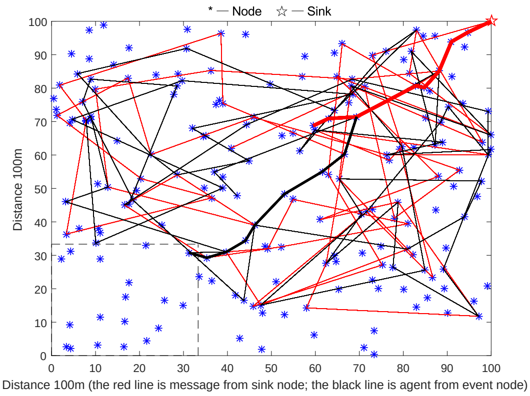

Fig. 6. Routing paths of RR protocol and OIAT protocol.

monitoring area is 100 m∗100 m; the amount of sensor nodes is 200; one-ninth left bottom is set as the event area; node $(100,100)$ is the sink node; the communication radius is 40 m; the initial energy of sensor node is 0.5 J; the amount of experiment rounds is 3000. The two routing paths established by RR protocol and OIAT protocol are shown in **Fig. 6**.

In **Fig. 6**, the event area locates at the left bottom corner, surrounded by the dotted lines; the top right corner node is the agent node of the event area while $(100,100)$ is sink node. The black thin line represents the event agent message path of RR protocol; the red thin line represents the query message path of RR protocol; the black thick line represents the event agent message path of OIAT protocol; the red thick line represents the query message path of OIAT protocol. It can be concluded that the routing path established by OIAT protocol is straighter than that of RR protocol.

Furthermore, we compare energy consumption of four routing protocols, including OIAT protocol, RR protocol, GPSR protocol, and NM-RRP protocol.

In the simulation experiments, the closest node will replace an invalid agent node in event area. The experiment will be terminated when all the sensor nodes in event area are invalid because the energy is exhausted. We investigate the left energy of network by comparing the four protocols. The experimental result is shown in **Fig. 7**. Furthermore, we analyze the amount of valid nodes of network comparing the four protocols. The experiment result is shown in **Fig. 8**.

Figure 7 shows the comparison of the left energy of the entire network. Lateral axis is the rounds of algorithm operation and vertical axis is left energy of the entire network. The red line represents OIAT protocol. The purple line represents GPSR protocol. The green line represents NM-RRP protocol. The black line represents RR protocol. When all the nodes in event area are invalid, the number of the rounds using RR protocol is 2199 and the left energy of the network using RR protocol is 31 J, the number of the rounds using NM-RRP is 2235 and the left energy of the network using NM-RRP protocol is 46 J, the number of the rounds using GPSR protocol is 2285 and the left energy of the network using GPSR protocol

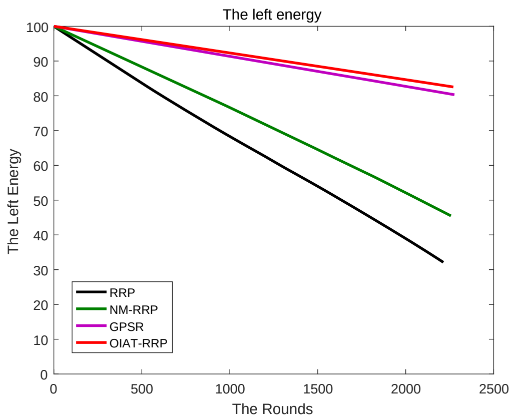

Fig. 7. Comparison of left energy.

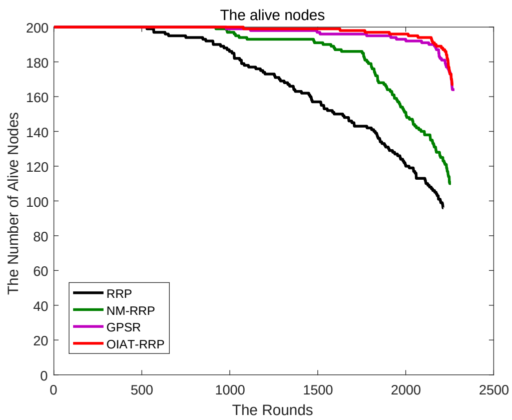

Fig. 8. Comparison of the number of valid nodes.

is 87 J, the number of the rounds using OIAT protocol is 2282 and the left energy of the network using OIAT protocol is 88 J.

Figure 8 shows the comparison of the number of valid nodes. Lateral axis is the rounds of algorithm operation and vertical axis is the number of valid nodes. The red line represents OIAT protocol. The purple line represents GPSR protocol. The green line represents NM-RRP protocol. The black line represents RR protocol. When all the nodes in event area are invalid, there are 95 nodes left in the network using RR protocol, 109 nodes left in the network using NM-RRP protocol, 161 nodes left in the network using GPSR protocol, 164 nodes left in the network using OIAT protocol.

With different initial energy of sensor nodes, we investigate the operation rounds comparing the four protocols. The parameters and results of the comparison experiments are shown in **Table 1**. The experimental result is shown in **Fig. 9**.

In **Fig. 9**, lateral axis is the initial energy of sensor node and vertical axis is the number of rounds of algorithms operation. The red line represents OIAT protocol. The purple line represents GPSR protocol. The green line represents NM-RRP protocol. The black line represents RR protocol.

As illustrated in **Fig. 9**, when all the nodes in event area are invalid, the rounds number becomes larger and larger

Table 1. Operation rounds with different initial energy.

Time	1	2	3	4	5
Initial energy [J]	0.1	0.3	0.5	0.7	0.9
Rounds of RR protocol	463	1356	2063	3040	4047
Rounds of NM-RRP protocol	470	1420	2200	3155	4053
Rounds of GPSR protocol	480	1500	2400	3280	4076
Rounds of OIAT protocol	488	1580	2600	3350	4082

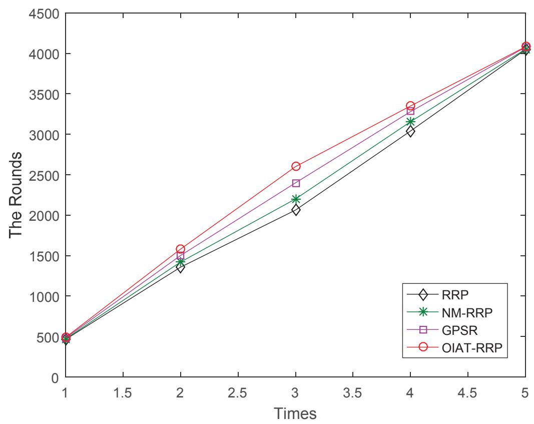

Fig. 9. Operation rounds with different initial energy.

with the increase of the initial energy. With the same initial energy, there are more rounds of OIAT protocol than that of the other three protocols, which shows that OIAT protocol is able to prolong the lifecycle of network effectively.

From the experimental results and the abovementioned analysis, we can draw a conclusion that OIAT protocol is more efficient than the other three protocols in aspect of energy consumption and network lifecycle.

5. Conclusion

In this paper, we investigate the routing protocols of WSN to optimize route establishment mechanism. Considering the problems of high energy consumption of random mechanism and routing loop of rumor routing protocol, this paper proposes an improved rumor routing protocol based on optimized intersection angle theory and localization technologies (OIAT protocol). OIAT protocol can find out more optimized routing path than that of the other three protocols compared. The improved protocol uses localization information and the intersection angle between event path vector and query path vector. Transmitting messages along accurate direction can solve routing loop and optimize routing path. Therefore, message transmission can approach more efficient routing path. Simulation experiments show that the improved protocol can reduce energy consumption and prolong the lifecycle of the network efficiently.

Acknowledgements

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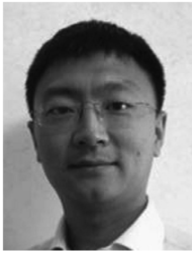

Name:
Zhuang Liu

Affiliation:
Lecturer, School of Computer Science and Technology, Changchun University of Science and Technology

Address:
B1601, Science & Tech Building, 7186 Weixing Road, Changchun 130022, China

Brief Biographical History:

2012 Received Ph.D. from Jilin University
2012 Employed by Changchun University of Science and Technology

Main Works:

• "An Improved GPSR Algorithm Based on Energy Gradient and APIT Grid," J. of Sensors, 2016.
• "A New Rage-Free Localization Algorithm Based on Amendatory Simulation Curve Fitting in WSN," Int. J. of Distributed Sensor Networks, 2015.
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Membership in Academic Societies:

• China Computer Federation (CCF), Member

Name:
Xin Feng

Affiliation:
Associate Professor, School of Computer Science and Technology, Changchun University of Science and Technology

Address:
B1601, Science & Tech Building, 7186 Weixing Road, Changchun 130022, China

Brief Biographical History:

1996 Employed by Changchun University of Science and Technology
2014 Received Ph.D. from University of Changchun University of Science and Technology

Main Works:

• "An Improved Clustering Routing Algorithm Based on Double-CH Clustering and Data Fusion in WSN," J. of Jilin University (Science Edition). Vol.53, No.5, pp. 1013-1017, 2015.
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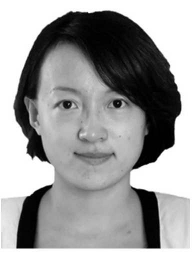
Membership in Academic Societies:

• The Institute of Electrical and Electronics Engineers (IEEE), Member
• China Computer Federation (CCF), Member



Name:
Jing Zhang

Affiliation:
Lecturer, School of Computer Science and Technology, Changchun University of Science and Technology

Address:
7089 Weixing Road, Changchun 130022, China

Brief Biographical History:
2015- School of Computer Science and Technology, Changchun University of Science and Technology

Main Works:
- "Energy-Balanced Strategy for Wireless Sensor Networks by Utilizing Complex Networks Synchronization Theory," Wireless Personal Networks, pp. 1-15, 2017.
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Membership in Academic Societies:
- China Computer Federation (CCF), Member

Name:
Yan Liu

Affiliation:
Lecturer, School of Computer Science and Technology, Changchun University of Science and Technology

Address:
B1601, Science & Tech Building, 7186 Weixing Road, Changchun 130022, China

Brief Biographical History:
2010 Received M.Sc. from Shanghai Jiaotong University
2010 Employed by Center of National Research and Science (CNRS)
2014 Employed by Changchun University of Science and Technology

Main Works:
- "Power interaction in non-hierarchical supply chain network," Int. Conf. on Concurrent Enterprising, pp. 1-8, 2011.

Membership in Academic Societies:
- China Computer Federation (CCF), Member

Name:
Jianfei Zhang

Affiliation:
Lecturer, Changchun University of Science and Technology

Address:
7186 Weixing Road, Changchun 130022, China

Brief Biographical History:
2010-2013 Ph.D. Candidate, Jilin University
2011-2013 Visiting Scholar, University of Texas at Dallas
2014- Changchun University of Science and Technology

Main Works:
- "Switch-Centric Data Center Network Structures Based on Hypergraphs and Combinatorial Block Designs," Parallel & Distributed Systems IEEE Trans., Vol.26, pp. 1154-1164, 2015.

Membership in Academic Societies:
- China Computer Federation (CCF), Member

Name:
Xin Zhang

Affiliation:
Lecturer, School of Computer Science and Technology, Changchun University of Science and Technology

Address:
B1601, Science & Tech Building, 7186 Weixing Road, Changchun 130022, China

Brief Biographical History:
2009 Received M.Sc. from University of Bordeaux 1
2009 Employed by Center of National Research and Science (CNRS)
2014 Employed by Changchun University of Science and Technology

Main Works:
- "A Co-evolution Oriented Change Analysis Framework in Product Development Project," IFAC Proc., Vol.46, Issue 24, pp. 198-205, 2014.

Membership in Academic Societies:
- The Institute of Electrical and Electronics Engineers (IEEE), Member
- China Computer Federation (CCF), Member