A New Clustering Routing Protocol Based on Optimized Intersection Angle Rumor Routing and Localization Technology in WSN

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ABSTRACT: *Routing is a key issue in Wireless Sensor Networks due to the network consisting of a large number of self-organization sensor nodes with limited energy, processing capability and storage. Lifecycle of network is one of the crucial issues which are influenced by routing protocol greatly in WSN. Therefore many researchers focus on the routing protocol and how to improve it. Rumor Routing Protocol is one of the classical routing protocol based on query, which is developed from Directed Diffusion Routing Protocol. In this paper, we investigate routing protocol based on query and propose a new routing protocol, in which we use clustering idea to control the data volume to transmit, and localization technology and rumor routing protocol optimized by intersection angle theory to reduce the energy consumption of data transmission. Results of simulation experiments indicate that the new routing protocol can reduce the energy consumption of the network and extend the lifecycle of the network.*

Keywords: WSN, Cluster routing, Rumor routing, Energy consumption, Network lifecycle

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1. Introduction

Wireless Sensor Networks (WSN) is widely used in many applications such as environment detection, military affairs, target tracking, disaster warning and etc. By definition, WSN consists of a large number of sensor nodes, which is self-organization, and communicate through wireless and multi-hops way. With limited energy to process and store data, the sensor nodes cannot be maintained in time, so that the sensor nodes should be of low energy consumption in processing routing protocol which is one of the key issues in WSN. The main routing protocols include energy-centered protocol, data-centered protocol, geography-centered protocol, clustering hierarchy-based protocol and some combinative protocol.

In energy-centered protocols [1]-[3], power available routing protocol (PA) creates routing table and selects routing path according to the left energy of the nodes and the energy requirement of the path, however, it can only be applied under the condition that the nodes know the topology of the whole network, and the nodes can only obtain the local topology of the network around it. Multi-path energy consumption routing protocol can calculate more than one path from the source node to the target node, and the path selection depends on the probability obtained from the energy consumption of the path and the left energy of the nodes in the path. It can prolong lifecycle of network, but the calculation of the probability is another overhead of the routing because it has to make flooding messages to maintain the routing table and the value of probability periodically.

In data-centered protocols [4] [5], Directed diffusion (DD) routing protocol sends interested information to the network by flooding method, so that the monitoring nodes will transmit the interested data to the sink nodes. DD is a classical data-centered protocol, but the main disadvantage is its high energy consumption. Rumor Routing (RR) protocol is an improved routing protocol of DD, in which sink node queries interested information by unicast randomly in network, while simultaneously, sensor node transmits monitoring information to sink node by unicast randomly, and the routing path is established when the two messages meet. This protocol does not use broadcast, but may lead to loop circuits and long routing path which causes extra energy consumption.

In geography-centered protocols [6]-[9], GEAR routing protocol selects routing path by local geographic information of event instead of by flooding, and it can reduce energy consumption, however, it causes routing cavity because of its lacking information of topology of the network. GEM routing protocol presents network topology by virtual polar coordinates and design it as a tree with ring, and each node selects path according to hops and angle distances from the root of the tree. This protocol simplifies the presentation compared with the physical coordinate method, however, it is difficult to keep a steady network topology. Therefore the tree needs to be adjusted frequently. GLB-DMECR routing protocol is a distributed algorithm selecting path according to the local topology and the minimum energy consumption, but it requires high node density. LL TMR routing protocol selects routing path according to the local geographic information and the control on power, but it also has high requirement on node density.

In clustering hierarchy-based protocols [10]-[11], Low Energy Adaptive Clustering Hierarchy protocol (LEACH) is a hierarchy clustering routing protocol. In LEACH, the network selects a portion of the sensor nodes as cluster heads (CH) by a probability model, and other sensor nodes work as normal nodes which find the nearest CH and join in the cluster serviced by this CH. And then the network has a clustering hierarchical topology. CH collects, processes, and transfers the data from the sensor nodes in the network and communicates with the base station. All the other sensor nodes monitor the environment, collect data and send the data to the CH. MEP routing protocol creates, clusters and makes the minimum energy consumption to reduce the whole energy consumption of network. The path between different clusters is established by the weight of distance's power function, however, no geographic information is taken into consideration in the process, and hence distribution of cluster heads are not distributed well.

In combinative protocols [12]-[13], RPBLR routing protocol adapts network topology fault variations, utilizes the alternative routes which include the backup and the primary route, and maintains the failing route by inquiring the immediate neighbor nodes that have alternate routes. So it can fix the fault topology fault without too much extra information and data transmission, but it does not keep QoS and can not guarantee the service. PRACO routing protocol achieves both energy consumption and reliable structure via introducing the energy-prediction model into heuristic factor, and the future energy consumption of each node can be estimated in advance, which can endow the ability to adaptively detect the energy status of WSN. However, it does not take energy consumption of the protocol itself while the size of the energy factor is too large which can arouse frequent change of network topology.

In this paper, we investigate the routing protocols of WSN and propose a new routing protocol which is improved from the aspect of clustering process, agent selecting and path selecting. We adopt clustering hierarchy theory of LEACH to cluster network, take energy factor into account to select information agent in cluster and use localization technology and intersection angle theory to improve the routing path of Rumor Routing protocol between different agents, in order to reduce energy consumption of network and extend network lifecycle.

2. Related Work

To avoid the high energy consumption of flooding method, Rumor Routing (RR) protocol [5] uses unicast method to transmit query massage. The basic idea of RR protocol is that an agent sensor node sends message from the event area to outside by random unicast method, and the sink node also sends a query message to outside by random unicast method. In the case that the two messages reach one same node, in other words, the agent message path crosses with the query message path, then the routing path between sink node and event area is established. The Rumor Routing protocol is shown in figure 1.

In figure 1, solid line with arrow represents event message path, and dotted line with arrow represents query message path. Circle

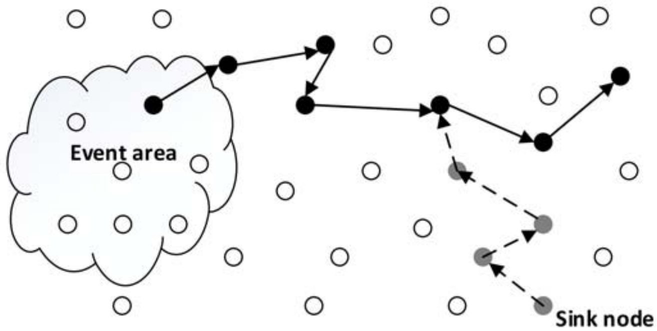

Figure 1. Rumor Routing protocol

nodes represent normal nodes and solid nodes represent the nodes in the routing path.

In LEACH [10], each node has a chance to be selected as the cluster head, and there are two stages in each establishing period. The first stage is clusters construction and the second stage is data transferring. The topology of the LEACH is shown in Figure 2.

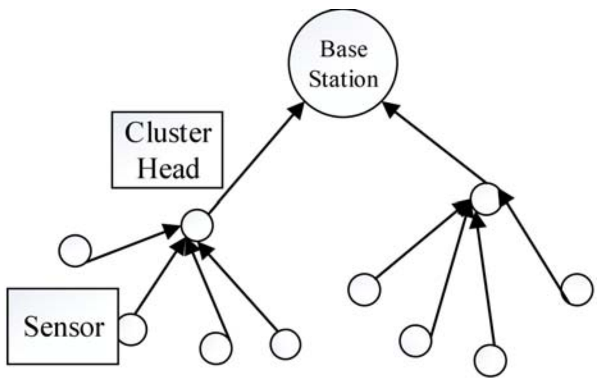

Figure 2. Topology of LEACH

In figure 2, the network is divided to three layers. The first layer is base station, the second layer is cluster head layer and the third layer is normal nodes layer.

Improved Protocol

Firstly, we use DV-Hop algorithm [14] to carry on nodes localization. DV-Hop uses trilateration to calculate the location of unknown nodes, and uses the number of hops multiplying by hop-size to work out the distance between each unknown node and its referenced beacon node. The hop-size is show in equation 1.

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

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

We use the two radio energy model of LEACH [10]. One is free space model and the other is multi-path fading channel model [15] [16] [17]. The energy consumption of data transmission is shown in equation 2 and equation 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 equation 1 and equation 2, 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 to be received. E_{elec} represents the energy consumption of the wireless transceiver circuit. Taking the energy consumption of the transceiver circuit and power amplification circuit into account in the model, if the distance between the sending node and receiving node is less than d_0, the threshold of distance, the network adopts the free space model (power attenuation proportion to d^2). Otherwise the network adopts the multi-path attenuation model (power attenuation proportion to d^4).

Next, we use hierarchy clustering method of LEACH. Network selects CH from sensor nodes in a random way, and each sensor node works out a random number in a particular scope and compares the number with a threshold value to decide if it can turn into a CH. The threshold value is shown in equation 4.

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

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

At last, we divide the network into areas and use the result of clustering step to avoid the disadvantage of limited node amount in LEACH. We use the localization information to improve the routing path inside a cluster and the routing path between CH. We locate the cross node of Rumor Routing protocol, sink node and the agent node of event area And then, we calculate the intersection angle between the line drawn by agent node with cross node and sink node with cross node. If the intersection angle is less than a threshold the routing path needs to be optimized and if the angle is more than the threshold the routing path can be established right now. The idea of the improved protocol is shown in figure 3.

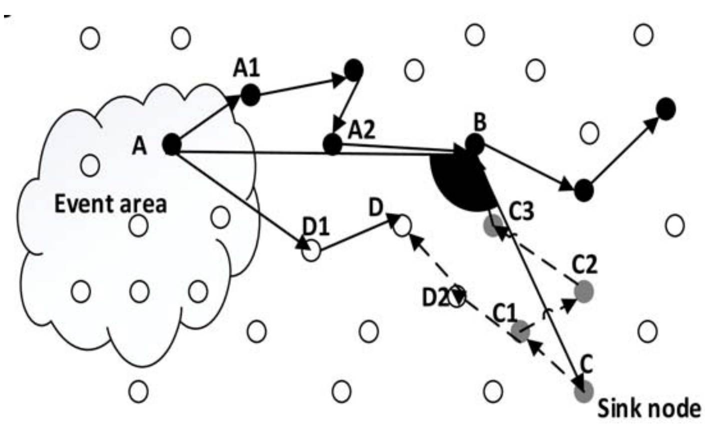

Figure 3. Idea of Improved Protocol

In figure 3, solid line with arrow represents event message path, and dotted line with arrow represents query message path. Circle nodes represent normal nodes and solid nodes represent the nodes in the routing path. Using Rumor Routing protocol, network will establish a routing path as R1={A, A1, A2, B, C3, C2, C1, C} which is the one from the agent node A of event area to the sink node C, and we link lines between A and B, B and C. If $\angle ABC$ is less than a threshold, especially that it is an acute angle, the energy consumption of routing path R1 can be large. However, if $\angle ABC$ is more than a threshold the energy consumption of it can be small. Then, we calculate COS $\angle ABC$ and set a threshold to modify the routing path to reduce the energy consumption of the routing path. The calculation of COS $\angle ABC$ is shown in equation 5.

$$COS\angle ABC = \frac{|AB|^2 + |BC|^2 - |AC|^2}{2|AB|*|BC|} \tag{5}$$

From equation 5, we can find out that $\angle ABC$ can indicate the degree of curve of the established routing path, and then we can find out the energy consumption that is affected by the quality of routing path. The routing path R1 is tortuous including 9 nodes in the path, and $\angle ABC$ is much more than π. Therefore the routing path R1 is high energy consumption path. Agent node A need find the next node to which the event agent message sending according to the direction which is rotated clockwise about node A, and find out a new angle with less cosine value. Otherwise, sink node C need find the next node to which the query message is sent according to the direction which is rotated anticlockwise about node C, and then network can get two path. One is the event agent path, and the other is query path. Each path contains some nodes which record an event list, a neighbor node list and a path list. If a node is both in the event agent routing path and in the query routing path, the routing path between event area and sink node is established. If a node find its neighbor node with a query for its event agent message, the node connects itself with its neighbor node and the routing path between event area and sink node is established. In figure 3, path R2 = {A, D1, D, D2, C1, C} is the new routing path established by our improved protocol which is named as Clustering Routing Protocol Based on Optimized Intersection Angle Rumor Routing and Localization Technology (CR-OIARL protocol). The work-flow of CR-OIARL protocol is as follows:

Step1: Each sensor node records a neighbor list, an event list and a routing path list. Event list records event name, event properties, event area ID and the hops to the event area; neighbor list records neighbor node ID, agent node ID of its area; routing path list records event area ID, sink node, query ID and the nodes in the relevant routing path. When a sensor node detects an event it will generate an agent event message and send it to the agent node of this area, and the agent node sends the agent message outside randomly by unicast way with a hop-lifecycle in the message.

Step 2: Sink node sends a query message towards a specific area randomly by unicast way and sets a hop-lifecycle in the message.

Step 3: Each node inspects the event agent message and the query message reaching it. If two messages match the routing path is established and this node is marked as the cross node. If two messages do not match the node will transmit the message to its neighbor node randomly by unicast way and reduce the hop-lifecycle by 1.

Step 4: The agent node of an area calculates the intersection angle between the line linked by the cross node with the agent node and the line linked by the cross node with the sink node. If the angle is less than a threshold, the agent node and the sink node will change the direction of transmitting messages to find out a more suitable routing path. If not, the routing path is stable. Furthermore, if the sink node cannot find the event area in the hop-lifecycle of the query message, the query message will be retransmitted.

Simulation Experiments and Analysis

Simulation experiments are executed to verify the effectiveness of CR-OIARL protocol in MatLab R2011b. The monitoring area is 100m * 100m; 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 40m; the initial energy is 0.5J; the amount of experiment rounds is 3000. The routing path established by Rumor Routing protocol and that established by CR-OIARL protocol are shown in figure 4.

In figure 4, the event area locates on 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 CR-OIARL protocol; the red thick line represents the query message path of CR-OIARL protocol. It can be concluded that the routing path established by CR-OIARL protocol is straighter than that of RR protocol. According to the routing path, we perform simulation experiments to study the energy consumption of the two protocols.

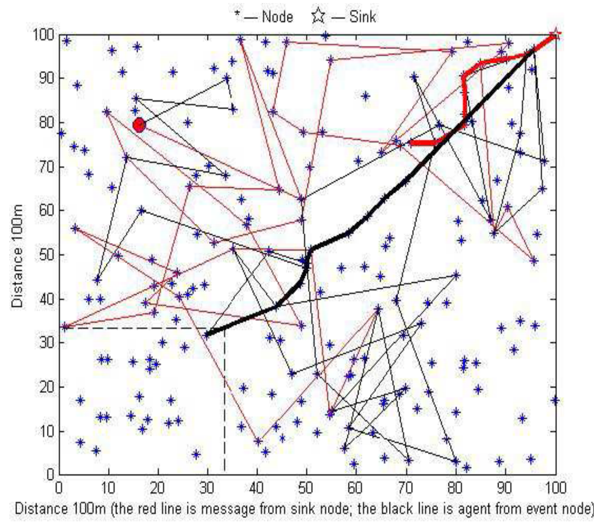

Figure 4. Routing Paths of the Two protocols

In the simulation experiments, we replace the invalid agent node with the one closest to it in the event area. The experiment is terminated when all the sensor nodes in the event area are invalid because of energy being exhausted. We investigate the left energy of network by comparing RR protocol with CR-OIARL protocol. The experimental result is shown in figure 5. furthermore, we analyse the amount of alive nodes of network, comparing the two protocols. The experimental result is shown in figure 6.

In figure 5, the thick line represents the left energy of each round of applying CR-OIARL protocol and the thin line represents the left energy of each round of applying RR protocol. It can be seen that all the sensor nodes in the event area are invalid due to energy being exhausted at about 2000 rounds The left energy of RR protocol is 44Jwhile the left energy of CR-OIARL protocol is 82J.

In figure 6, the thick line represents the amount of alive sensor nodes of each round of using CR-OIARL protocol and the thin line represents the amount of alive sensor nodes of each round of RR protocol. In the same simulation experiment, all the sensor nodes in the event area are also invalid due to energy being exhausted at about 2000 rounds. The amount of alive sensor nodes of RR protocol is about 100 while the amount of alive sensor nodes of CR-OIARL protocol is more than 160. Compared with RR protocol, the left energy is increased by about 35%, and the amount of alive nodes is increased by about 30%.

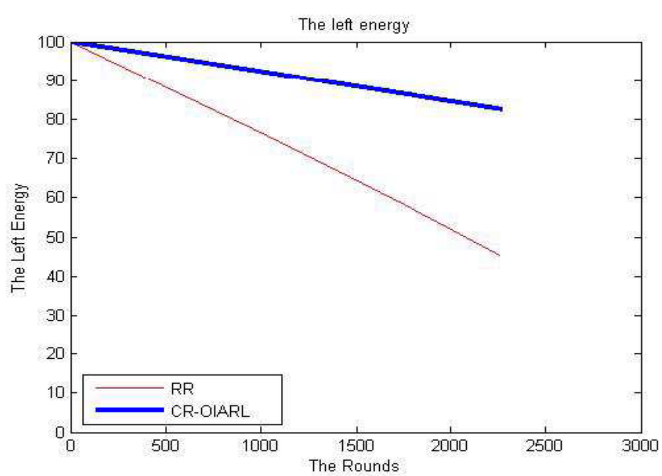

Figure 5. Comparison of Left Energy

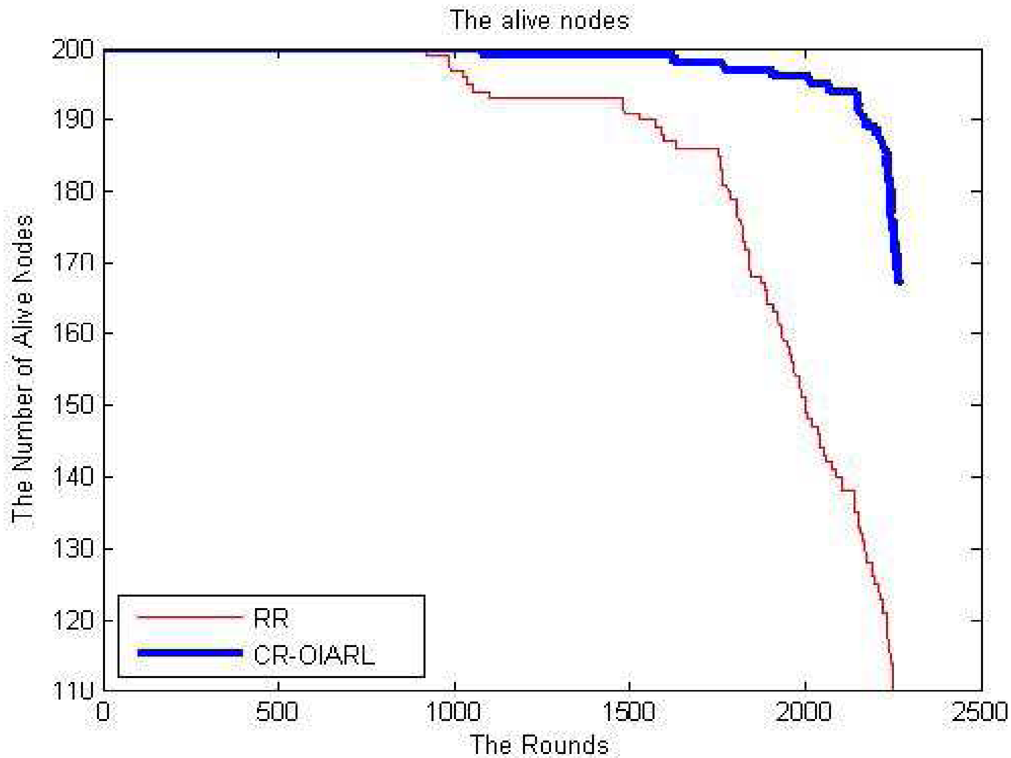

Figure 6. Comparison of the Amount of Alive Nodes

Then, we set different initial energy of sensor nodes and investigate the operation rounds to compare RR protocol and CR-OIARL protocol. That all sensor nodes of event area are invalid due to energy being exhausted can indicate the energy consumption of the two protocols. The parameters of the comparison experiments are shown in table 1, and the experimental result is shown in figure 7.

Time	1	2	3	4	5
Initial Energy	0.1J	0.3J	0.5J	0.7J	0.9J
Operation Rounds of RR Protocol	453	1356	2063	3040	4047
Operation Rounds of CR-OIARL Protocol	486	1475	2469	3175	4087

Table 1. Comparison of Operation Rounds

In figure 7, the line with rhombus represents RR protocol, and the line with circle reprensents CR-OIARL protocol. It can be considered that the rounds are in direct proportion to the initial energy.

Each time when comparing the operation rounds that all sensor nodes are valid due to energy being exhausted in the event area, CR-OIARL protocol is better than RR protocol.

From the experiments and the analysis above, we can draw a conclusion that CR-OIARL protocol is more efficient than RR protocol in reducing energy consumption and extending the network lifecycle.

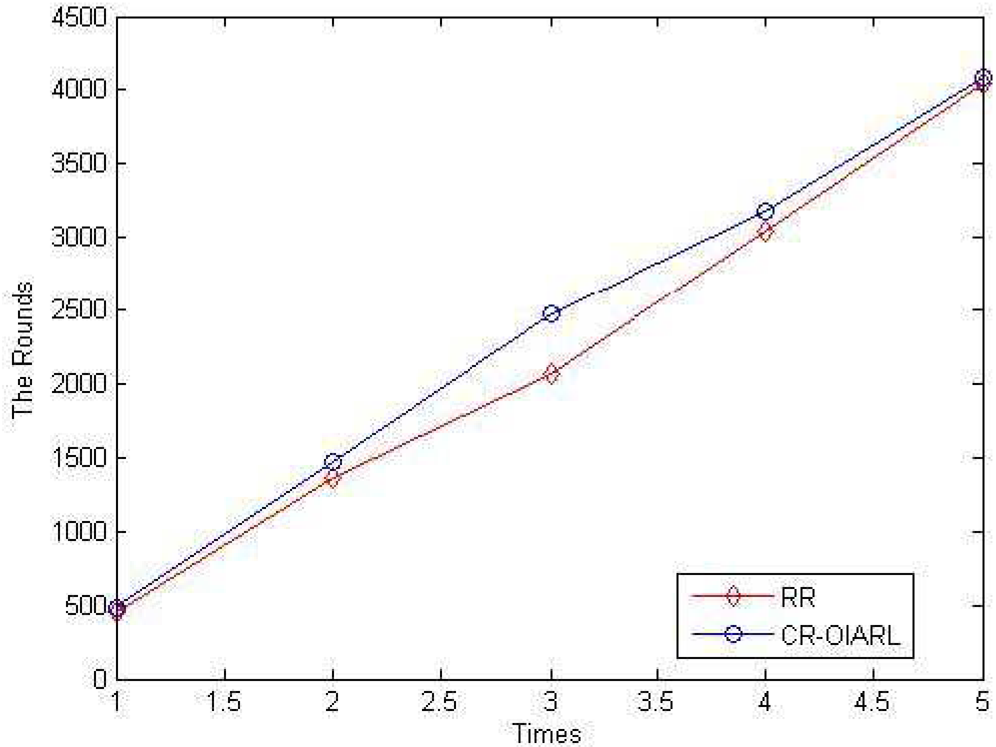

Figure 7. Comparison of Operation Rounds

Conclusion

In this paper, we analyze routing protocols of WSN to solve the problem of the limitation of the energy. A new energy-efficient protocol is proposed to reduce the energy consumption and prolong the network lifecycle. Rumor Routing (RR) protocol is a classical routing protocol in WSN, in which the network generates and transmits two messages from resource node and target node respectively by random and unicast way. If the two messages meet each other the routing path is established. RR protocol can reduce energy consumption by avoiding flooding broadcast which is used in other protocols. But the routing path established by RR protocol is tortuous, which lead to more energy consumption. Therefore we propose an improved protocol according to RR protocol based on clustering routing theory, optimized intersection angle theory and localization technology to reduce the energy consumption and extend network lifecycle. The new protocol can find out more optimized routing path than that of RR protocol by localization information and calculating the intersection angle between event agent message path vector transmitted from event area and query message path vector transmitted from sink node. The message transmission can be limited to approach more suitable direction. Simulation experiments have shown that the improved protocol reduces the energy consumption and extends the network lifecycle efficiently.

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