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A novel interest message update method based on similarity judgment

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Abstract. This work presents a new method for interest message update based on similarity judgment (IMUSJ). To illustrate the process and rules of the method, an example of interest message update is introduced in detail. A simulation experimental study was conducted to validate theoretical results. It is demonstrated that fixed node deployment density, node sensing area, mobile node trajectory can significantly affect the number of interest message update times. It is also shown that IMUSJ has better decrease performance with increasing fixed node deployment density. In addition, it is found that changing node sensing area and mobile node trajectory have less impact on fluctuations in the number of interest message update times. Finally, it is shown that IMUSJ can significantly decrease the number of interest message update times and reduce node energy consumption, thus extending the network life cycle effectively.

Key words. Wireless sensor network, interest message update, mobile node, anisotropy, similarity.

1. Introduction

Wireless sensor network is a network system composed of a large number of inexpensive and tiny sensor nodes deployed within sensor field in an autonomous or multi-hop manner [1], where the sensor nodes collaboratively sense, collect and process the information about the monitored object in the area covered by the network and send it to an observer [2]. The initial research of wireless sensor network is mostly based on the hypothesis of node being stationary [3]. However, as the application scope of wireless sensor network continues to expand, mobile wireless

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sensor network is also attracting more and more attention [4]. The introduction of mobile nodes has brought new challenges to the research of wireless sensor network, together with many new problems worth studying [5]. For example, the routing paths pre-created through routing algorithm for traditional wireless sensor network is highly vulnerable in a mobile environment, and it costs a lot to re-create these routing paths, so it is necessary to improve or redesign the routing protocol so as to adapt to the mobile environment. Node movement causes network topology to be constantly changing, so it is necessary to adopt a new method for topology management.

Query routing is a commonly used form of routing in wireless sensor network, where user's request is sent to a node in the target area in the form of an interest message to create a routing path [6]. However, after the node moves, the original nodes in the target area may move out of the target area, while those outside the target area may move in. These nodes need to interact with their surrounding nodes in order to obtain the interest messages in the area where they are currently located in a timely manner. This process is called interest message update. This paper studies how to efficiently update interest message in a mobile wireless sensor network.

This paper proposes a new method for interest message update based on similarity judgment (IMUSJ). It first determines whether a mobile node overlaps with the sensing area of any fixed node during movement. If no overlap occurs, interest message update is not performed; if overlap occurs, it calculates the similarity between the interest messages of the mobile node and the fixed node in the overlapping sensing area, and then determines whether the similarity is greater than the set threshold; if so, it performs interest message update to update the message of the mobile node into that of the fixed one. The simulation results show that compared with traditional method for interest message update, this method can significantly decrease the number of interest message update times and reduce node energy consumption, thus prolonging the life cycle of wireless sensor network.

2. Related work

L. Niu et al [7] proposed an interest message update protocol, which used triggered update to enable interest message update to adapt to node moving path, thereby avoiding aimless timed update and decreasing update frequency. However, this protocol failed to consider the influence of the deployment environment in the target area on the sensor node communication model, and lacked an interactive merging mechanism for interest message between neighboring nodes. In addition, interest message update is also part of the routing algorithm for mobile wireless sensor network. Z. G. Lin et al [8] proposed a routing algorithm for wireless sensor network with sink nodes. This algorithm divided network based on grid theory and selected cluster head according to the weighted sum of the residual energy of a node and its distance to the cluster's center of gravity, thus preventing nodes with low residual energy from being selected as cluster head; network energy consumption could be reduced by scheduling the data collected by the receiving cluster head of sink nodes through controllable mobile strategy. Query based routing is a classic routing protocol in wireless sensor network [9]. A sink node sends a query task to the network, and the query task is sent to the node which is related to the task through interest message [10]. Then the node executes the specified task after caching the interest message. This paper studies the problem of interest message update for moving nodes.

3. Algorithm design

3.1. Interest message update method

When the sensing areas of mobile node and fixed node overlap, the similarity of message content is calculated; if the similarity is greater than a set threshold, then interest message update is performed; otherwise, if the sensing areas of mobile node and fixed nodes do not overlap, interest message update is not performed. In addition, what needs to be stressed is that the set threshold is artificially predetermined according to the requirement of information exchanging rate. If the information is more important, information exchanging rate must be higher, and the threshold should be smaller; otherwise, if the information is less important, information exchanging rate is lower, and the threshold should be larger.

Interest message similarity function $D(M, N)$ is expressed as follows:

$$D(M,N) = \sqrt{\sum_{i=1}^{n}(M_i - N_i)^2} \times \left(2 - \left|\sum_{i=1}^{n}(M_i - N_i)\right| / \sum_{i=1}^{n}|(M_i - N_i)|\right), \quad (1)$$

Where, M, N are two sensor nodes, $M=(M_1, M_2, \ldots, M_n)$, $N=(N_1, N_2, \ldots, N_n)$ are respectively the interest messages of sensor nodes M, N, n is the number of dimensions of interest message.

In this section, we present each of steps used to update interest messages with our proposed algorithm. The automated approach is motivated based on the traditional update method.

(1) The network system sets the mobile node and fixed nodes with the same interest message capacity, and the larger the value of the interest message, the higher the priority. Meanwhile the interest message of mobile node is initially empty.

(2) The mobile node enters the target area along a certain path and completes the location at a fixed time interval. The network system compares the distance between nodes with the sum of sensing radius of theirs, then obtains the overlap of sensing area of each node.

(3) The network system distinguishes the overlap types of mobile node and fixed nodes, and divides into the following two categories. The first category is that mobile node overlaps only with the sensing area of a single fixed node. In this case, Interest message similarity function $D(M, N)$ should be adopted to calculate the similarity of message content directly. If the similarity is greater than the set threshold, then the interest message is updated, otherwise it not. The second category is that mobile

node overlaps with the sensing areas of multiple fixed nodes, which can be divided into three specific cases respectively.

In the first case, the sensing areas of these multiple fixed nodes overlap completely, i.e. their interest message contents are the same, either node can be used for calculating the similarity of message content, and compared with the set threshold to judge whether the interest message is updated.

In the second case, the sensing areas of these multiple fixed nodes don't overlap at all, i.e. their interest message contents are no correlation. Each fixed node should use interest message similarity function $D(M, N)$ to calculate the similarity of the message content with mobile node, and determine if interest message updates are needed according to the set threshold.

In the third case, the sensing areas of these multiple fixed nodes overlap each other, and their interest message contents are not exactly the same. In the circumstances, the network system first arranged the shared messages of the fixed nodes in random order, which is considered as the highest priority. Secondly, the rest message contents of these fixed nodes are sorted by priority from high to low until the information capacity of the interest message is filled. Finally, the reassembled interest message calculates the similarity of interest message with the content of mobile node. After a comparison with the set threshold, it is determined whether the interest message of mobile node needs to be updated.

3.2. System model

The basic process of query routing is as follows: when user makes a query request, the sink node converts the request into an interest message, and forwards this message to a node in the target area through the routing channel self-created by the network [11]. For mobile wireless sensor network, when a node in the target area moves out of the area, the monitoring task for this interest message may be directly stopped; when a node outside the target area moves into the area, the node needs to obtain and update interest message in a timely manner and start the corresponding monitoring task. Exploration of an appropriate algorithm for interest message update helps reduce the update frequency of interest messages and decrease the number of messages and the amount of communication data in the update process, thus improving the life cycle of the network.

To generalize the discussion for this problem, this paper makes the following assumptions:

1. All nodes in the wireless sensor network are randomly distributed in a two-dimensional rectangular area, each node has a similar transmission radius, and all connections are bi-directional;

2. A mobile node may enter or leave the two-dimensional rectangular area at any of its boundary;

3. Query request is strictly limited to within the two-dimensional rectangular area, and sink nodes are located outside this area.

The initial research of wireless sensor network is mostly based on some ideal assumptions such as sufficient energy in the node itself and consistent environmental factors around the node, which means that the sensing area in each direction is identical and distributed in a regular circle [12]. However, the residual energy of node is generally not exactly the same as its surrounding environment in actual deployment [13], leading to difference in the sensing area in all directions, i.e. anisotropy. Apparently, sensing area is not a regular circle in anisotropic condition.

The sensing model of sensor node is an irregular circle with node S_i as the center of sensing area and anisotropic detection distance R_S as radius, $R_S = (1-\sigma)\cdot R$, where R is the radius of node sensing area when it is a regular circle, and σ is the anisotropic influence factor; assuming that the influence amplitude of σ on R is not greater than 20%, then $0 < \sigma < 0.2$.

Assuming that the anisotropic influence factor σ of the node sensing area in different directions does not change with time, then this factor can be expressed as:

$$\sigma = \int_{-\frac{1}{4}|\sin(l\theta+l)|}^{\frac{1}{4}|\sin(l\theta+l)|} \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} du, \tag{2}$$

Where, $0 < \theta < 2\pi$, l is a random number greater than 1, and variable $u \in (-0.25, 0.25)$. By this definite integral function, the σ values in different directions of the circle can be obtained randomly, which ranges between 0 and 2.

Assuming that the anisotropic influence factor σ' of the node sensing area in different directions changes with time, then this factor can be expressed as:

$$\sigma' = \int_{-\frac{1}{4}|\sin(l\theta+tl)|}^{\frac{1}{4}|\sin(l\theta+tl)|} \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} du, \tag{3}$$

Where, $0 < \theta < 2\pi$, l is a random number greater than 1, time t >0, and variable $u \in (-0.25, 0.25)$. Applying this equation, the σ'values in different directions of the circle can be calculated at different times.

4. Simulation and discussion

In order to test the performance of IMUSJ, MATLAB is used to carry out corresponding simulation experiments. In the simulation scenario, the size of the target area is 200 m × 100 m, the fixed nodes are randomly distributed in the target area, and the mobile nodes enter the target area at coordinate $(0, 0)$. Considering the regularity of sensor node's actual movement, Gauss Markov mobility model is used to describe the movement of mobile nodes to overcome the defects of sudden stop and turn with random direction mobility model. The equations of Gauss-Markov model are defined as follows:

$$v_k = \beta v_{k-1} + (1-\beta) v_{avg} + (\sqrt{1-\beta^2}) w_{v_{k-1}}, \tag{4}$$

$$d_k = \beta d_{k-1} + (1-\beta) d_{avg} + (\sqrt{1-\beta^2}) w_{d_{k-1}}, \tag{5}$$

$$x_k = x_{k-1} + v_{k-1} \times \cos(d_{k-1}), \tag{6}$$

$$y_k = y_{k-1} + v_{k-1} \times \sin(d_{k-1}), \tag{7}$$

Where, $v_k$and d_k are the speed and direction at time k; v_{avg} and d_{avg} are the average speed and average direction; β is a random controlling parameter and belongs to [0, 1]; $w_{v_{k-1}}$ and $w_{d_{k-1}}$ are random Gaussian variables; (x_k, y_k) is the position coordinate of the node at time k.

Set the capacity of fixed node's interest message to 5, and its content is a random combination of any 5 numbers in 1, 2, ..., 10, where 1, 2, ..., 10 correspond to different monitoring tasks. The effective time of interest message is the length of time from the moment mobile node enters the target area to the moment it leaves the area.

(1) Influence of fixed node deployment density on the number of interest message update times

When the parameters of the corresponding Gauss Markov mobility model of mobile node meet the following conditions: $\beta = 0.3$, $v_{avg} = 1\,\mathrm{m/s}$, $d_{avg} = \pi/2$, the radius of node sensing area $R = 10$ m, and l is a random number greater than 1 and less than 10, fixed node deployment density is changed for an overlapping test. Simulation is performed 100 times under the same simulation conditions, and the average number of overlapping times is calculated for different fixed node deployment densities. The result is shown in Figure 1. It can be seen that when fixed node deployment density belongs to $[1/1000\,\mathrm{m}^2,\ 1/100\,\mathrm{m}^2]$, the number of overlapping times increases continuously, indicating that there is a positive correlation between fixed node deployment density and the number of overlapping times. The result of comparing TUM, TURIR with IMUSJ is shown in Figure 2. It can be seen from the figure that as deployment density increases, the number of update times tends to rise regardless of which method is used. As compared to TUM and TURIR, IMUSJ can reduce the number of messages by 51%–81%, is not sensitive to deployment density, and is of great significance for saving network energy consumption.

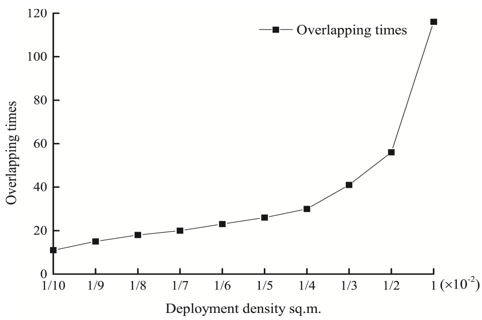

Fig. 1. Influence of fixed node deployment density on the number of overlapping times

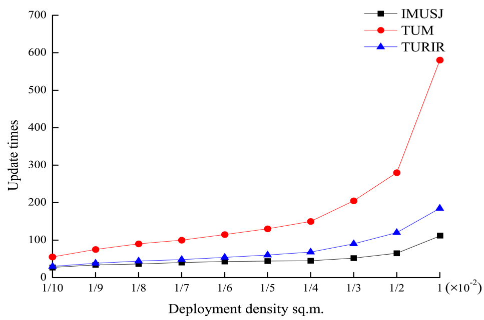

Fig. 2. Comparison of IMUSJ and TUM, TURIR

(2) Influence of node sensing area on the number of interest message update times

When the parameters of the corresponding Gauss Markov mobility model of mobile node meet the following: $\beta = 0.3$, $v_{avg} = 1\,\mathrm{m/s}$, $d_{avg} = \pi/2$, fixed node deployment density is $1/200\,\mathrm{m}^2$, and l is a random number greater than 1 and less than 10, the radius of node sensing area is changed for an overlapping test. Simulation is performed 100 times under the same simulation conditions, and the average number of overlapping times is calculated for different radii of node sensing area. The result is shown in Figure 3. It can be seen that when the radius of node sensing area belongs to [10m, 35m], the number of overlapping times increases continuously; when fixed node deployment density belongs to [35m, 55m], the number of overlapping times is constant at 100, indicating that there is a positive correlation between the radius of node sensing area and the number of overlapping times, and when node sensing area is greater than or equal to 19.24% of the target area, the number of overlapping times is equal to the product of area and node density. The result of comparing TUM, TURIR with IMUSJ is shown in Figure 4. It can be seen from the figure that the number of update times rises rapidly as the radius of node sensing area increases; when the radius of node sensing area increases to a certain extent, the number of update times tends to stabilize. IMUSJ outperforms TUM, TURIR to a great extent, which is consistent with the nature of this method as analyzed above.

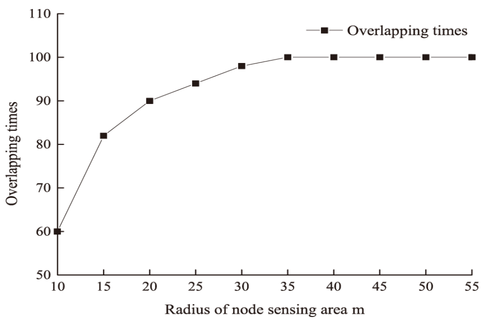

Fig. 3. Influence of node sensing area on the number of overlapping times

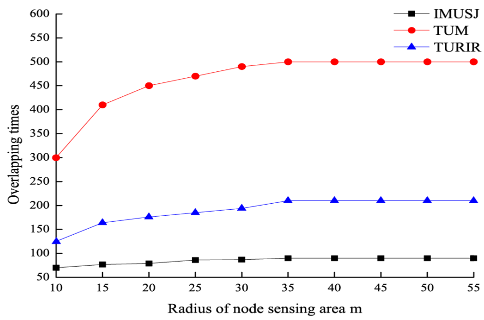

Fig. 4. Comparison of IMUSJ and TUM, TURIR

(3) Influence of mobile node trajectory on the number of interest message update times

When fixed node deployment density is $1/400\,\mathrm{m}^2$, radius of node sensing area $R = 10\,\mathrm{m}$, and l is a random number greater than 1 and less than 10, the parameters of Gauss Markov mobility model are changed for an overlapping test. Ten groups of simulation are performed under the same simulation conditions, and the number of overlapping times for different mobility model parameters is counted. The result is shown in Figure 5. It can be seen that as the mobility model parameters change, the number of overlapping times maintains at a relatively stable level, with maximum value being 35, minimum value being 21, average value being 26.3, and coefficient of variation being just 0.1980, indicating that the influence of mobility model parameters is not significant on the number of overlapping times. The result of comparing TUM, TURIR with IMUSJ is shown in Figure 6. It can be seen from the figure that the number of update times is less influenced by path selection, which only increases slightly as the number of overlapping times increases. After IMUSJ is used, the number of update times decreases significantly, indicating its better adaptability and ability to better accomplish the task of interest message update in a mobile environment.

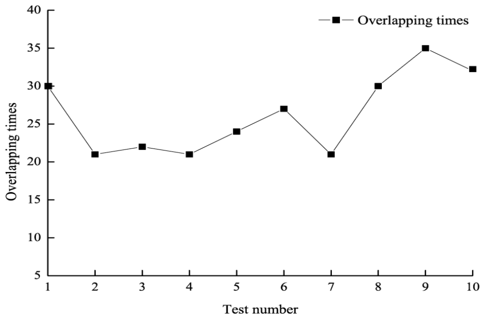

Fig. 5. Influence of mobility model parameters on the number of overlapping times

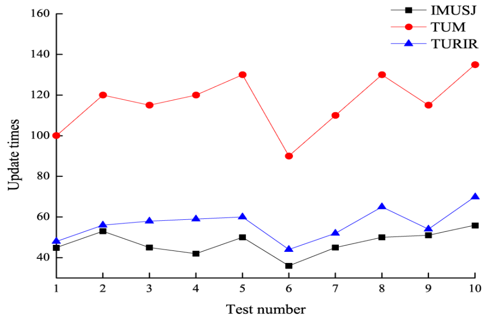

Fig. 6. Comparison of IMUSJ and TUM, TURIR

5. Conclusion

This paper proposes a new method for interest message update based on similarity judgment (IMUSJ), conducts a simulation to compare the performance of IMUSJ with TUM, TURIR. As a result, the following conclusions are made.

(1) The effects of three key parameters including fixed node deployment density, node sensing area, mobile node trajectory on the number of interest message update times are studied. Results of simulation analysis indicate that IMUSJ can significantly decrease the number of interest message update times and reduce node energy consumption, thus extending the network life cycle effectively.

(2) As fixed node deployment density increases, IMUSJ has better operational efficiency on reducing the number of interest message update times to TUM, TURIR. By increasing node sensing area, the number of update times is not obviously changing, and tends to stabilize. Changing mobile node trajectory has less influenced on the number of interest message update times.

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