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Original Article

A New Method of Target Tracking with Wireless Sensor Networks

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Abstract *- Target tracking is one of the important topics in wireless sensor network (WSN) research. Monitoring enemy intrusions, surveilling wildlife animals and tracking specific people are examples of target tracking. Target Tracing needs to track and collect information about monitoring targets. Many solutions of using WSNs to perform target tracking have been proposed in the research. A common method is to wake up the sensors in a WSN in a predictive manner and only needs to activate a few sensors that could track the next step of a target. However, target tracking requires a trade-off between accuracy and energy saving. In order to save the energy of sensors, the number of wakeup sensors may be too small, and the prediction itself is thus uncertain. On the other hand, the sensors may consume too much energy in order to ensure that the target is not lost. In this paper, we propose a tracking target method called Hexagonal Routing Repair Procedure (HRRP). The method uses regular hexagons to tessellate the entire sensing area, and the sensors route the sensor information back to the base station through Hexagonal Hierarchy. The target's current position and maximum speed can be used to calculate the target's possible range of motion, and we only need to wake up the nearby hexagonal cluster to track targets, thus saving energy as well as preserving the accuracy.*

Keywords *- Wireless sensor networks, Target tracking, Data routing, Cluster networks*

I. INTRODUCTION

The wireless sensor network (WSN) is composed of many sensors. With the rapid development of technology, sensors have developed into small size, low cost, low power consumption, simple computing power, and short-range transmission range. WSN originated from military applications such as battlefield monitoring. The sensor can detect physical properties in the environment within its sensing range, such as temperature, humidity, luminosity, acceleration, pressure, etc. WSN has been used in recent years in ecological environment monitoring, forest fire protection, health care, home care, etc. [1,2]. WSN is composed of a small number of wireless data collectors or sinks and a network system composed of a large number of sensor nodes [3]. The sensors have self-organizing capabilities and communicate wirelessly. These sensors form a network with each other, and a sensor represents a node in the network, working together to transfer data back to the base station.

In the related research of wireless sensor networks, target tracking is a very hot topic. The target to be tracked usually moves around. When we want to continuously track a specific moving target, we need to know the position of the target in order to know the current target state and respond accordingly. However, if the sensor's energy consumption is unlimited, the network's life cycle will soon be exhausted. Target tracking in wireless sensor networks can be divided into three categories: cluster-based, tree-based, and prediction-based.

A. *Cluster-based target tracking*

Cluster-based target tracking first divides the entire sensing area into clusters. After the sensors in the cluster detect the target's information, it forwards the sensed information to the cluster head, which then sends the information to the base station. Usually, to save energy, only the clusters that can sense the target will be awakened for tracking. However, this method usually consumes a lot of energy when setting up and maintaining a cluster.

B. *Tree-based target tracking*

Tree-based target tracking will allow sensors around the target to cooperate to build the tree. As the target moves, the tree will dynamically increase the sensors that can detect the target and pruning the sensors that cannot detect the target. However, this method consumes a lot of energy when constructing and maintaining the tree. At the same time, the structure of the tree is easy to destroy and maintaining the structure of the tree also requires high costs.

C. *Prediction-based target tracking*

Prediction-based target tracking predicts the next position of a moving target to reduce the number of wakeup sensors for accurate and energy-efficient tracking. However, due to the uncertainty of prediction, there will be problems of tracking error and target loss. The algorithm used for prediction also needs to store a large number of parameters, such as position, speed, acceleration, etc., so energy consumption is large.

This paper combines cluster-based and prediction-based methods. First, the sensing area is divided into several hexagonal clusters. When the sensor detects the target, the information is routed to the base station according to the Hexagon Routing with Repair Procedure (HRRP). The base station locates the target position and then predicts the target's moving range based on the target's position and maximum speed and wakes up the clusters within the moving range. The rest of the clusters remain asleep to achieve energy-saving and accurate target tracking.

II. TARGET TRACKING RELATED TECHNOLOGIES AND RESEARCH

In today's wireless sensor network target tracking, GPS-free positioning algorithms already exist [5], which greatly reduces deployment costs. To locate a target, only three or more sensors are needed to know the distance to the target. When the target enters the sensing area, in order to keep all sensors awake and continue to accurately track the target, it is necessary to effectively activate the correct tracking sensor and effectively select the cooperative sensor to detect the moving target.

A. Cluster-based target tracking

A cluster-based approach typically consumes a lot of energy when creating and maintaining a cluster. Taking [6] as an example, this paper proposes a cluster-based object tracking protocol. The state of the sensor itself will switch between sleep, sensing and tracking. The sensor itself calculates weights to switch between these three states. The closer the sensor is to the target, the higher the eligibility to participate in target tracking. One sensor in each cluster will be selected as the cluster head, and it will report the target's information to the base station. Each sensor calculates its own weight based on the speed and direction of the detected target and decides whether to participate in tracking.

B. Tree-based target tracking

Taking the tree-based DCTC algorithm proposed in [7] as an example, this method will establish a cooperative dynamic transmission tree and use sensors to cooperate with each other to track targets. First, the sensors around the target will build a transmission tree and then route the collected sensing information from the leaves to the root of the tree. DCTC constructs a transmission tree to route sensing information from the leaves to the root of the tree and aggregates them one by one. To save energy, only one cluster head in each dynamic cluster stays awake, and other sensors will go to sleep and wake up periodically. When the target enters the sensing range, the cluster head will wake up all the sensors in its cluster, and the sensor will start tracking the target and send the sensing data to the root of the tree. Before the parent sensor forwards its own packet, it waits for its child packets so that it can aggregate the packet hop by hop along the path to the root of the tree.

C. Prediction-based target tracking

In reference [8], in order to achieve energy-saving and accurate target tracking, a target tracking method with a predetermined path is proposed. When using a prediction-based method to track a target, only sensors that sense the target will participate in tracking the target. Therefore, the number of sensors participating in a track will be greatly reduced, which will save a lot of energy and extend the life of the network cycle. This method uses a path structure and can effectively select the next sensor to be activated based on the current moving target position, direction, and path of the tracking target. The sensors are scattered in a predetermined path. The target can move on an unknown trajectory and will be detected by sensors on that trajectory.

D. Distributed Localization

Suppose there are more than three sensors that can detect the distance between themselves and the target and know their location, then these sensors exchange information with each other. The sensor can use a multilateral localization algorithm to locate the position of the target and return the positioning result to the base station. The disadvantage of distributed localization is that the sensors need to exchange information with each other, and representatives are selected for positioning, so this part consumes more energy. The advantage is that the sensor only needs to send a piece of positioning information back to the base station, which will consume less energy [9].

E. Centralized localization

In contrast to distributed localization, the disadvantage of centralized localization is that all sensors must route all information back to the base station, which will consume more energy in this part. The advantage is that the positioning algorithm is executed by the base station, thus saving the energy consumed by positioning, and the sensors do not need to consume energy to exchange information with each other [9].

III. HEXAGON ROUTING WITH REPAIR PROCEDURE

There are cluster-based, prediction-based and tree-based methods for target tracking. Each has its advantages and disadvantages. How to obtain the best solution from these methods is a challenge. The study in this paper is to combine the hexagonal clustering and prediction methods to achieve the best energy-saving effect and accurate target tracking.

A. Hexagonal Cluster

Suppose we want to cover the entire sensing area with the least number of sensors and achieve the maximum target tracking effect with the fewest sensors. We also want to achieve the entire network connection with a minimum of sensors, thereby increasing the entire network life cycle. Reference [10] shows that when the area of the sensing area is F and the sensing range of the sensor is r if the entire area is to be covered, the following number of polygons are needed:

$$\frac{6\mathbf{F}}{(\pi+3\sqrt{3})r^2} \quad \text{triangles} \qquad (1)$$

$$\frac{\mathbf{F}}{2r^2} \quad \text{squares} \qquad (2)$$

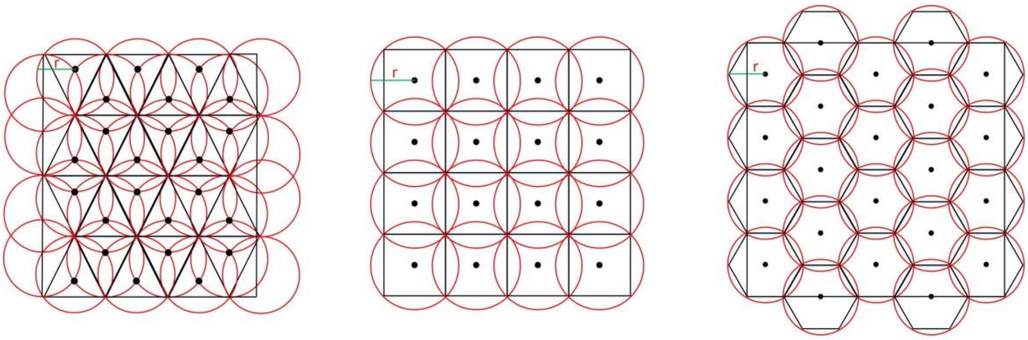
$$\frac{2F}{3\sqrt{3}r^2} \qquad \text{hexagons} \qquad (3)$$

Suppose the sensing area of a sensor is a circle. It can be known from Fig. 1 that the number of sensors required to subdivide the entire plane using a hexagonal cluster is the smallest, so it is decided to use a hexagonal cluster to perform the task of target tracking

B. Routing mechanism and routing repair

Our method is as follows. Each cluster will select a cluster head in turn, and the cluster head must keep awake. When more than three sensors sense the target, the sensor will report information such as its position and the distance to the target to the cluster head, and the cluster head then routes the information to the central base station.

The routing is improved from the HexDD algorithm [4]. First, number each hexagonal cluster as H_k^nWhere n is the number of rings and k is the rank of the hexagons in the ring. Starting from line A, the hexagons are counted counterclockwise from 0, as shown in Fig. 2.



(a) tessellation of triangles (b) tessellation of squares (c) tessellation of hexagons

Fig. 1 plane tessellation with polygons of the same radius of the circumscribed circle

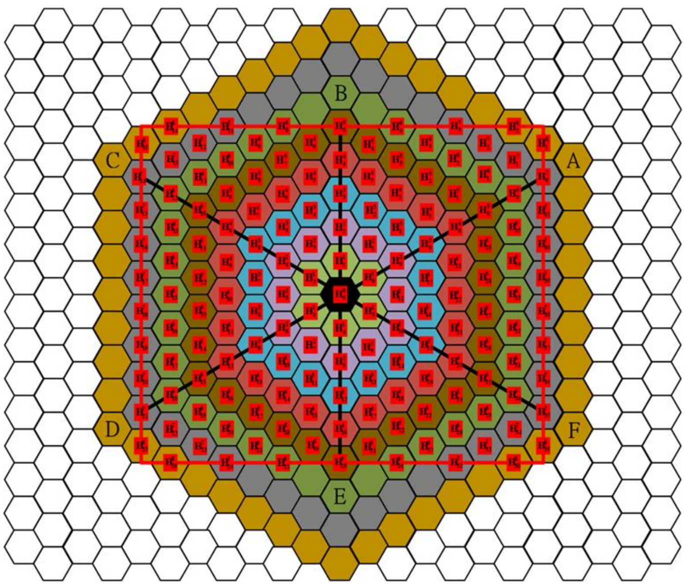


Fig. 2 the index of hexagonal clusters

For the routing, the cluster head will substitute its own cluster number into the following formulas (4) and (5), and then route to the base station step by step. Two examples are shown in Table I and Table II.

$$H^{n-1}_{k-\left\lfloor \frac{k}{n} \right\rfloor}\text{, if } (k \bmod n)=0 \qquad (4)$$

$$\begin{cases} H^{n-1}_{k-\left\lfloor \frac{k}{n} \right\rfloor} \\ H^{n-1}_{k-\left\lfloor \frac{k}{n} \right\rfloor-1} \end{cases}\text{, if} (k \bmod n)\neq 0 \qquad (5)$$

Table 1. Example Of The Steps For Normal Routing To The Base Station

1	Assume that we have reached H^{4}_{18} 18 mod 4 is not equal to 0, so it satisfies the formula (5). $\begin{cases} H^{4-1}_{18-\lfloor\frac{18}{4}\rfloor} & H^{3}_{14} \\ H^{4-1}_{18-\lfloor\frac{18}{4}\rfloor-1} & H^{3}_{13} \end{cases}$ =
2	After calculating these two paths, the cluster head with the larger energy will be taken; if the energy is the same, go to the right.
3	Now suppose the energy of the cluster head is $H^{3}_{14} > H^{3}_{13}$, so the next step will go to H^{3}_{14}.

Table 2. Example Of The Steps For Normal Routing To The Base Station

1	Assume that we have reached H^{3}_{14} because 14 mod 3 is not equal to 0, so it satisfies the formula (5). $\begin{cases} H^{3-1}_{14-\lfloor\frac{14}{3}\rfloor} & H^{2}_{10} \\ H^{3-1}_{14-\lfloor\frac{14}{3}\rfloor-1} & H^{2}_{9} \end{cases}$ =
2	Now suppose that the sensors of clusters H^{2}_{10} H^{2}_{9} have no energy and cannot help routing, so we need to start repairing the routing.
3	Subtract k in H^{3}_{14} by 1. We get $\begin{cases} H^{3}_{14+1} & H^{3}_{15} \\ H^{3}_{14-1} & H^{3}_{13} \end{cases}$ = . After calculating these two paths, the cluster head with the larger energy will be taken; if the energy is the same, go to the right.
4	Now suppose the energy of the cluster head is $H^{3}_{15} > H^{3}_{13}$, so the next step will go to H^{3}_{15}.

Follow the steps of normal routing and repair routing, and it will eventually arrive at the base station in the centre H^{0}_{0}.

C. Prediction mechanism

The base station can locate the current position of the target through the information sent by the sensors. Assuming that the maximum speed of the target is V_{max} and the radius of the circumscribed circle of the hexagonal cluster is R, in order to prevent the target from being lost, formula (6) is used to calculate the number of seconds required for one positioning.

$$\frac{R}{V_{max}} - \frac{R/V_{max}}{3} \qquad (6)$$

Next, calculate the clusters that the target may reach during the next positioning, so the base station will calculate the distance between the current position of the target and the centres of all hexagonal clusters. If the distance between the centre of a cluster and the target is less than the value of formula (7), the cluster will be woken up in preparation for tracking the target. As shown in Figure 3, based on the current position of the target, the blue dotted line indicates the clusters that the distances are less than the value of formula (7) from the target. These clusters will be woken up to prepare for the next round of tracking.

$$R + \left(\frac{R}{V_{max}} - \frac{R/V_{max}}{3}\right) \qquad (7)$$

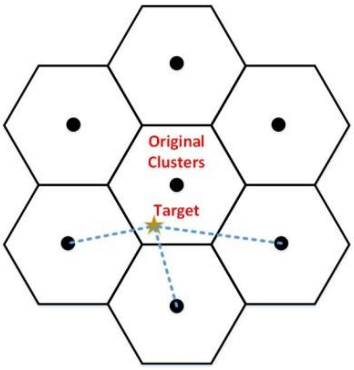


Fig. 3 Prediction mechanism

D. Remedies for Misprediction

When the sensors in each cluster detect the target, in addition to sending information such as their own position and distance to the target to the cluster head, they also send their remaining energy to the cluster head, so the cluster head can know the remaining energy of the entire cluster.

As shown in Fig. 4, assuming that the star is the target, the blue dotted line represents a cluster whose distance from the target is less than $R + \left(\frac{R}{V_{max}} - \frac{R/V_{max}}{3}\right)$. These clusters will be woken up in preparation for the next round of tracking. If the base station does not receive information from the cluster head after $\left(\frac{R}{V_{max}} - \frac{R/V_{max}}{3}\right)$ seconds, it indicates that the target is lost, which also means that some sensors in the three clusters have no energy. At this point, the base station will query the remaining energy information sent by the three clusters and then know which clusters have no energy.

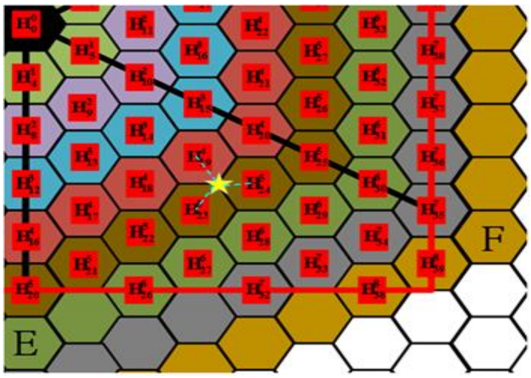


Fig. 4 Predictive remedies -1

Now suppose the cluster H_{19}^{4} has no energy, so all clusters surrounding H_{19}^{4} should be awakened.

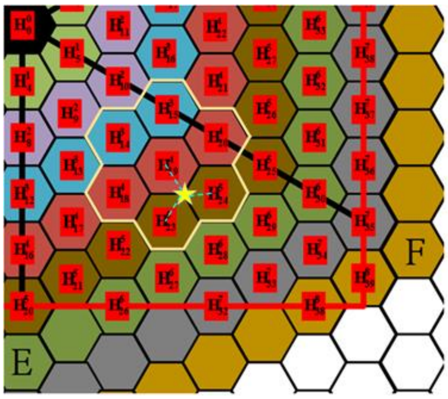


Fig. 5 Predictive remedies -2

E. *How the target moves*

As shown in Figure 12, the entire sensing area is a rectangle of 367,108.168 square meters (divided into 157 small hexagon clusters with a circumscribed circle radius of 30 meters). The target is assumed to be a pedestrian walking randomly in a shopping mall and starting from cluster A in the lower-left corner. Its speed is chosen randomly from 0 m/s to 1 m/s, and the time is randomly chosen between 0 seconds to $(\frac{R}{V_{max}} - \frac{R/V_{max}}{3})$ seconds each time.

Suppose the current position of the pedestrian is at (0,0), and select to walk at a speed of 0.5m / s for 10 seconds, so you can imagine a circle with (0,0) as the centre and 0.5m/s × 10s = 5m as the radius. The entire circumference will be the position the target may reach in the next round, as shown in Figure 6.

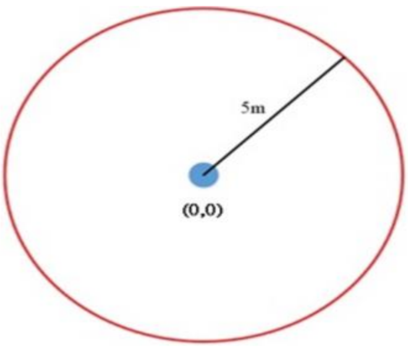


Fig. 6 Diagram of target movement

To calculate the Cartesian coordinates on the circumference of Figure 6, we first move the target using polar coordinates. Suppose the target wants to use polar coordinates (Dis, θ) to move to the destination in the next round. We use the following formulas (8) and (9) to convert polar coordinates (Dis, θ) to Cartesian coordinates (x', y'):

$$\begin{cases} x' = \text{Dis} \times \cos(\theta) & (8) \\ y' = \text{Dis} \times \sin(\theta) & (9) \end{cases}$$

Then, adding the original location (x, y) of the target to the calculated (x', y') is the Cartesian coordinate of the target.

I. RESULTS OF SIMULATION EXPERIMENTS

In the following sections, we will explain the parameters of the simulation environment and the results of the simulation.

A. *Simulation environment*

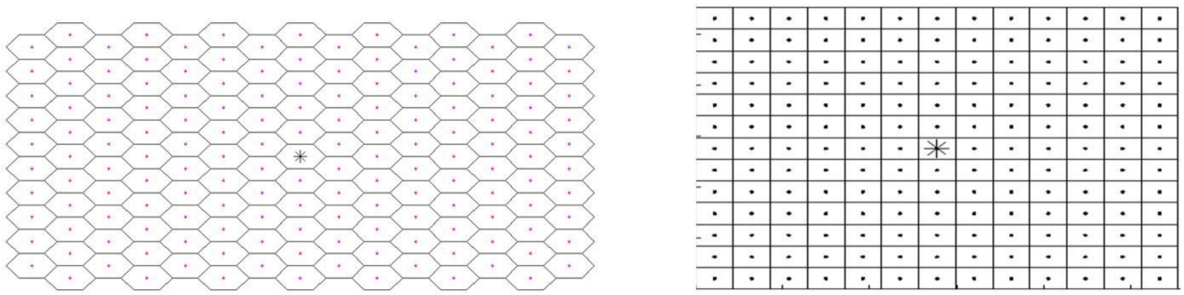
Table 3. Parameters Of Simulation Environment

Parameters	Values
communication range	120 meter
sensing range	30 meter
the radius of the circumscribed circle of cluster	30 meter
sensing area of hexagonal clusters	367108.168 m^2 (divided into 157 clusters)
sensing area of square clusters	551.5433m×551.543m= 304200.01m^2 (divided into 169 clusters)
data packet size generated by sensors	4000 bits
control packet size	100 bits
transmission energy consumption per bit	$50e^{-9}$
receive energy consumption per bit	$50e^{-9}$
distance squared power amplifier	$10e^{-12}$
the distance power amplifier of a fourth power	$0.0013e^{-12}$
data aggregation energy consumption	$5e^{-9}$
aggregation ratio	0.6
base station located at the centre	infinity power
initial energy per sensor	1J
number of sensors	1500
cluster head election	every two epochs
starting position of a target	cluster centre at the lower-left corner
speed of target	choose randomly from 0 m/s to 1 m/s
the direction of target movement	choose randomly from degree 0 to 360
time of target movement	Choose randomly from $0 \sim \frac{R}{V_{max}} - \frac{R/V_{max}}{3}$ seconds

B. Simulation results

As mentioned above, our method is to divide the sensing area into a hexagonal cluster to track the target, and we will compare it with the square cluster-based method. All the mechanisms of the square cluster are the same as the hexagon cluster. The only difference is that the routing mechanism of the square cluster is the shortest path search method. The schematic diagram of the entire sensing area divided into hexagonal clusters and square clusters is shown in Fig. 7.

The target walks randomly throughout the sensing area. We compare the hit rate, the total energy of the network, and the number of active nodes based on the hexagon and square-based methods. We define the following terms.



a. Hexagon-based target tracking　　　　b. Square-based target tracing

Fig. 7 Hexagon-based and square-based target tracking

Table 4. Definition Of Terms

round	The target randomly selects a speed (between 0m / s to 1m / s), and orientation (between 0 degrees to 360 degrees), and a time (between 0 seconds to $\frac{R}{V_{max}} - \frac{R/V_{max}}{3}$ seconds) to walk from the current position to the destination each time. After that, it was called a round.
hit ratio	The target entered the cluster we awakened in the next round. The cluster contains more than three sensors that can route related information to the base station for positioning. This round is called a successful hit. The formula is: $\frac{number\ of\ hits}{number\ of\ round} \times 100\%$ For example, the number of hits is 48, and it is in the 50 round, the hit ratio is $\frac{48}{50} \times 100\% = 96\%$.
The total energy of the network	Sum of remaining energy of all sensors in this round
Active nodes	Number of all sensors with energy greater than zero in this round

We will perform the hexagon-based and square-based methods ten times, respectively. Since the square-based methods will soon lose power when the sensors are close to the base station, the data will not be routed to the base station, so we first record the number of rounds that can be routed by the square ten times, then let the hexagon simulate the number of rounds, and then average the ten times. The number of recorded rounds that can be routed ten times is shown in Table 5, and detailed simulation data is shown in Table 6 and Figure 8.

Table 5. The Number Of Rounds That Can Be Routed By Square-Based Method For Ten Times

	Number of rounds that the square-based cannot route
Simulation 1	17977
Simulation 2	17295
Simulation 3	20229
Simulation 4	16949
Simulation 5	17197
Simulation 6	18022
Simulation 7	17135
Simulation 8	18989
Simulation 9	17273
Simulation 10	19275

Table 6. Simulation Results Of Hexagonal Clusters And Square Clusters

Item / Method	Hit ratio	The total energy of the network(J)	Number of effective nodes
Hexagon	98.922	1293.619	1478
Square	97.591	1308.705	1461

Our method is superior to the square cluster-based method in terms of hit rate and the number of effective nodes, but the total network energy is slightly lower than the square cluster-based method. We further carefully study why the total network energy is poor. Since the total area of the two solutions is not the same, we observed the total route length. The total route length represents the sum of the routes from each cluster to the base station. See Table 7

Table 7. Total Route Length Of Hexagon Cluster And Square Cluster

	Total route length (m)
Hexagon	40009.970
Square	37283.064

Since the total routing length of our hexagonal cluster is larger than the square cluster, our solution will consume more power in this part. Because the sensing area formed by the hexagon-based method and the square-based method is not the same, the total area of the hexagonal cluster-based method is 367,108.168 square meters, while the total area of the square-cluster-based method is 304200.01 square meters, so we take the total area composed of square clusters as the basis, and normalize the entire simulation results. The results are shown in Table 8, Figure 9, and Table 9.

Table 8. Simulation Results Of Normalized Hexagonal Clusters And Square Clusters

Item / Method	Hit ratio	The total energy of the network (J)	Number of effective nodes
Hexagon	99.1067	1329 J	1482
Square	97.591	1308.705 J	1461

Table 9. Total Regular Route Length Of Hexagonal Clusters And Square Clusters

	Total route length (m)
Hexagon	33153.770
Square	37283.064

After normalization, the hit rate, total network energy, and the number of effective nodes of the hexagon-based method are better than those of the square-cluster-based method, and the total route length is shorter than that of the square-cluster-based method.

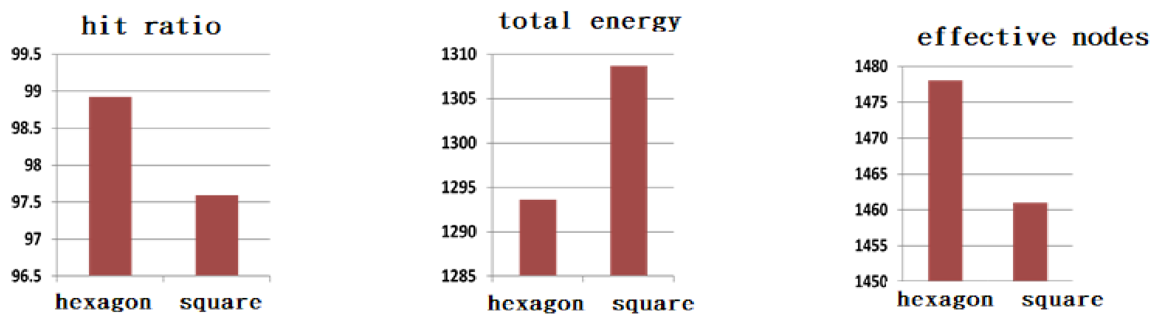


Fig. 8 Simulation results of hexagonal clusters and square clusters (energy is measured in Joule)

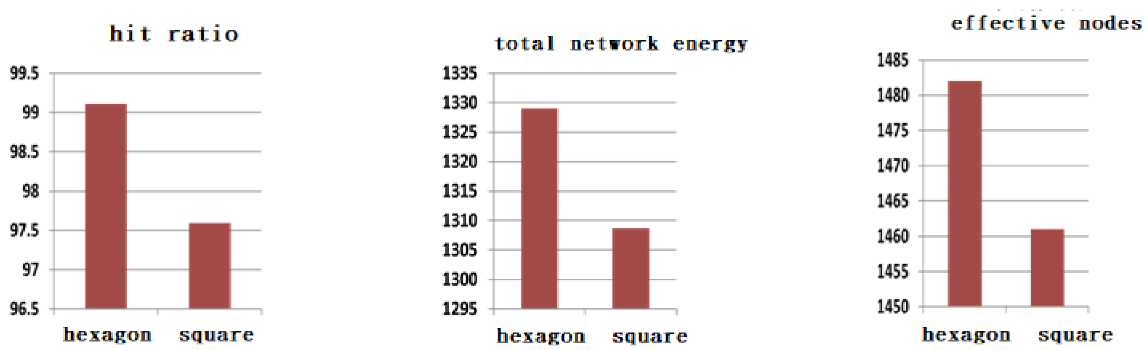


Fig. 9 Simulation results of normalized hexagonal clusters and square clusters(energy is measured in Joule)

IV. CONCLUSION

This paper proposes a target tracking method based on clustering and prediction. We first divide the sensing area into several hexagonal clusters. When the sensor senses the target, the information is routed to the base station according to the Hexagon Routing with Repair Procedure. The base station locates the target's position and predicts the target's moving range based on the target's position and maximum speed. The base station wakes up the clusters within the moving range, and the remaining clusters stay asleep to achieve energy-saving and accurate target tracking. According to our simulation experiments, the proposed method is superior to the method based on square clusters in terms of hit rate, the total energy of the network, and the number of effective nodes.

Regardless of the method based on the hexagon or the method based on a square, the common problem is that after a certain number of rounds, the sensors around the base station will quickly fail, resulting in the inability of routing the sensor information to the base station. In future work, we will increase the number of simulations, compare the number of rounds that cannot be routed, further study the method of the project, compare the advantages and disadvantages of decentralized positioning and centralized positioning, and then enhance their shortcomings.

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