Grid-based Mobile Target Tracking Mechanism in Wireless Sensor Networks

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Abstract—**The target tracking is one of the main issues in wireless sensor networks (WSNs). In the WSNs, the energy consumption is the most important factor for the network lifetime. In this paper, we utilize the advantage of the grid-based sensor networks to prolong the lifetime of the network. Therefore, we propose Grid-based Mobile Target Tracking Mechanism in Wireless Sensor Networks (GMTT). By the simulation results, we validated the proposed mechanism could efficiently reduce the energy consumption for target tracking.**

Index Terms—**Wireless sensor network, Sink, mobile target, Grid-based network, tracking.**

I. INTRODUCTION

In recent years, because of the great process of wireless communication technologies, which make the applications of the wireless communication becomes increasingly popular. Thus a number of wireless network technology have been developed, including Wireless Sensor Networks (WSNs) [1-2], which attention of everyone most. For WSNs, sensor node can do data sensing and data processing, even do wireless communication. WSNs are often used to replace mankind with sensor nodes to obtain the information which is unable for human beings. Hence its applications is widespread, such fields in environmental, health, military and learning.

The sensor node has qualities of low-cost, small size and power-saving. However, these qualities put bonds to the energy, storage capacity and computing ability. The most influential factor is the restriction to energy. In order to solve the biggest problem - the shortage of energy restrictions, researchers have made various studies of wireless sensor network, and many of the literature also proffer the corresponding approaches in accordance with the mentioned problem. [6][7]

In the wireless sensor network environment, one of the most important tasks is the monitoring and tracking to the target [5]. Under this situation, the basic solution is to put the entire network into sleep mode. It makes the sensor node in monitoring can enter sleep mode in order to save energy after a period of time. But such an approach is still unable to achieve the better energy usage, the sensor node that does not track target in WSNs, will still stay in awaking status and keep continuing waste energy.

For this reason, researchers have made related information in advance which took down the moves of target (such as: speed, direction, movement path, and so on), we hope that the prior record of the target information could help decide to the less sensor node to track the target to resolve this issue. However, the shortcomings of this method are the beforehand preparation work consumes amount of resources. In addition, the target is usually moving at random. If the tracking information gathered inadequate, then the rate of tracking error would be higher.

In this paper, we proposed mechanism could fully utilize the power of sensor node. Under the premise of acceptable tracking error, we hope to be able to wake up the sensor node only when it needs to work in WSNs. The focus of this paper is to design a method in tracking target which can be applied in grid-based [8]. And under this framework, we hope to prolong the WSNs's lifetime by elected the less sensor nodes to track the target.

This paper is divided into five chapters; Chapter two will introduce the common target-tracking technology in recent studies, we classify systematically and analyze them and comparison of the advantages and disadvantages. Chapter three is about the method proposed in this paper. In the context of this chapter we will describe in detail how to actually operate our approach. Chapter four will introduced the simulated settings in the first, and then based on our approach, we operate actual simulation with other relevant methods accordingly, and further analysis by comparing the effectiveness of the methods. Chapter five is the conclusions and future works of this paper.

II. RELATED WORK

On the subject to tracking mobile target, most of the researches focus on how to save sensor node's limited energy[9-11], and they wish the entire WSNs can track the target for long by saving energy. In the current study, the sensor nodes tracking target work usually is added

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the wake-up mechanism (schedule). The major purpose is saving the energy consumption with turning the sensor node working a span of time into sleep mode. We will detail descript the way how the above two types of the wake-up mechanism (schedule) design. In the section A, we will introduce synchronous wake-up [12-14], and the asynchronous wake-up will presented in the section B [15-16].

A. Synchronous Wake-Up

There are two types in synchronized wake-up mechanism, the periodic wake-up mechanism [13] and random wake-up mechanism [14]. We use the chart as shown in Fig 1 to explain the mode of two mechanisms.

In Fig. 1, the Δt represents the length of time interval, the Δs represents the wake-up time length of the sensor node; the T_t represents the period of sending signal of target, T_s represents the wake-up period of sensor node.

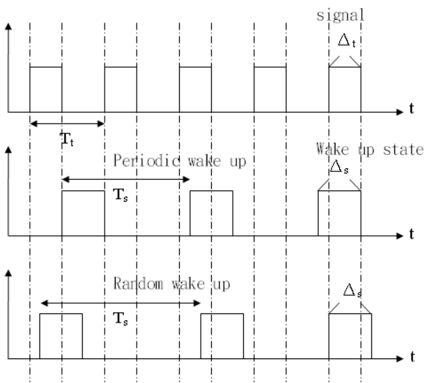

Figure 1. The Periodic Wake-up And Random Wake-up Mechanisms.

In the Synchronous Wake-Up, either the periodic wake-up or the random wake-up, there exist great shortcomings: waste the energy. All sensor nodes have to be waked up each time. However, not all of the nodes will sense the target. For those sensor nodes which cannot sense the target, they will waste the energy and decrease the entire WSNs' life time.

B. Asynchronous Wake-up

There are two categories of the asynchronous wake-up mechanisms which are based on record to predict location of target and direct predict location of target. We will describe the PES Protocol [15] and EST Protocol [16] here.

B-1 PES Protocol

In this tracking mechanism, it determines which nodes should be awaked according to the traveling records. It is the reason why the amount of the awaked sensor nodes is less and reducing the average energy consumption of the WSN substantially. At the same time, if the traveling information is not enough, it will bring a lot of tracking errors because of the prediction. On the contrary, the enough information will need consuming a lot of energy for the tracking. As shown in Fig. 2, when the sensor node A senses the target, it will query the database to get the target's movement information. It will awake the sensor node B and all of the sensor nodes on the path between A and B, which is recorded as the most frequently traveling path, to continue tracking the target. Moreover, it will awake the neighbor nodes beside the path in the meantime to avoid the prediction error.

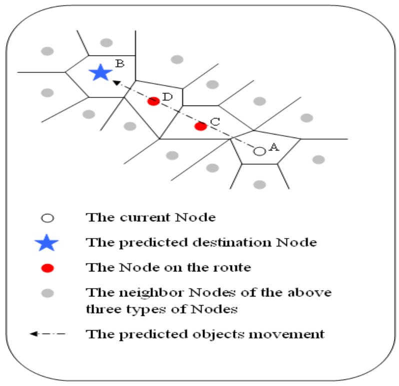

Figure 2. PES Protocol

B-2 EST Protocol

When the sensor node sensed the target, it would directly predict the moving scope of the target. The EST protocol uses the hierarchy-based network architecture. In EST protocol, the sensor nodes at the two outer most levels will awake alternately. The other nodes will stay in the sleep mode until the signal from the external nodes is arrived.

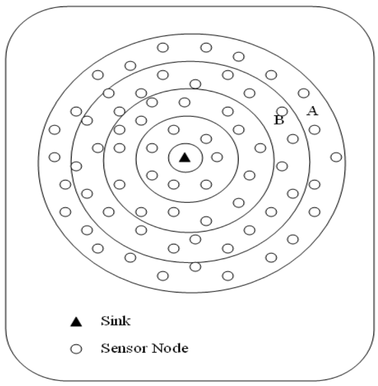

Figure 3. Network Architecture Of EST Protocol

As shown in Fig 3, if the nodes which are located at level A sensed the target, it will send the signal to awake the nodes located at level B immediately. When the target move into level B, the nodes located at level B will awake the nodes located at next level. This tracking procedure will continue until the target exit the network. The restricted number of the awaked nodes could sense the target in one level so that the utility rate of the energy is inefficiently.

III. Grid-Based Mobile Target Tracking Mechanism In Wireless Sensor Networks

The proposed mechanism is divided into three phases: Griding Phase, Tracking Phase and Data Dissemination Phase. The system enters into the griding phase after the sensor nodes were deployed randomly and uniformly in the network. Each grid will select the grid head to transfer the information of the nodes in the same grid and communicate with the grid heads of the neighbor girds. After that, the tracking phase will be triggered. We will categorize the tracking task into two cases, namely: initial tracking task and normal tracking task. When the target is tracked, the system gets into the dissemination phase. The flowchart of the GMTT is shown in Fig. 4:

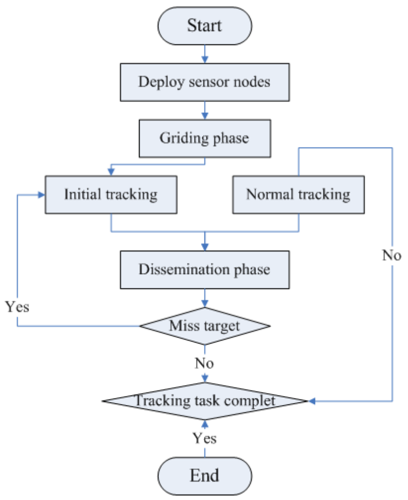

Figure 4. Flowchart of the GMTT

A. System Environment

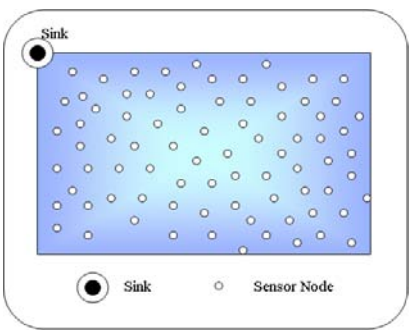

Figure 5. The network deployment of the GMTT

All of the sensor nodes are deployed randomly and evenly in the network. We assume that each node will be fixed and know its position after the deployment. The sink is deployed at the position (0,0) of the network, as shown in Fig. 5. Besides, all the sensor nodes know their own energy capacity.

We assume that the entire network is time synchronization. We could utilize the time which is the sensor node sensed the target, to assign an order to each node while the time is synchronized. According to the order, we can determine the next task of the sensor nodes. Under this environment, all the sensor nodes are equal in terms of sensing ability, computing ability, storage capacity and the maximum energy. The target velocity (V_t) is fixed, and the initial velocity is unknown. At the same time, the direction that the target moves to is random. After the environment settings, we will enter the first phase – Griding Phase through the phrase, we use several grids to divide the entire WSNs.

B. Griding Phase

When the sensor nodes have been deployed, we will divide the network into several grids. There is a head node in each grid, and the length of the each edge is R. Sink will randomly select the grid head node for each grid because of the energy of the nodes is equal in initial state. From now on, the grid head node will be decided again after each round of the tracking task. As the grid head node is decided, it will select the relay node at the same time. We will describe in detail how to select the relay node in section 3-3.

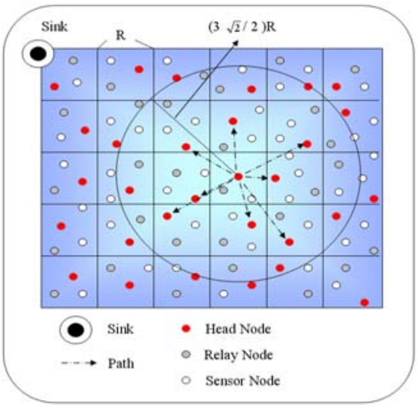

Figure 6. Transmit Range Of The Head Node.

Since the sensor nodes are evenly deployed throughout the network, we assume that the all sensor node in the same grid can mutually sense the covered scope. In other words, there is no unable sensing area per grid in the network. In the aspect of transmit range, we take the edge of a grid (R) as a benchmark. There are two types of the sensor nodes' transmit range, which is the maximum transmit range, $(3\sqrt{2}/2)R$ and the general transmit range, $\sqrt{2}R$. When being the head node or relay node, this node sets the transmit range as $(3\sqrt{2}/2)R$. On the contrary, if the sensor node is he general one, it will set the $\sqrt{2}R$ as its transmit range. The reason to set up the head node's transmit range as maximum transmit range is the head node have to communicate with the neighbor head node, as shown in Fig. 6.

C. Tracking Phase

After the griding phase, we get into the tracking phase. There are two kinds of the tracking works which are initial tracking and normal tracking. Before carrying these two works out, we will give descriptions in detail for some messages which are used in tracking works firstly.

- Query_message (Query_mes) : The sink first will first send to all sensor nodes in entire WSNs. The nodes will begin to sensing when they received the Query_mes packet. The Query_mes packet type as shown in the following Table 1:
  - Address (Xs, Ys) : address information.
  - Tracking Interval : the tracking internal of the target, and the tracking interval initial value is 0.

TABLE 1. TYPE OF QUERY_MESSAGE (QUERY_MES)

Address(X_s, Y_s)	Tracking Interval

- Detection_message (Det_mes) : The nodes will send the Det_mes to the sink as the nodes sensed the target. As our purpose is tracking the target, we do not compute the target's exact address. Thus, we assume that the address of the sensor node sensed the target is where exactly the target was. The following Table 2 is the packet type of Det_mes:
  - Packet_type : the name of pakeage, here it calls Det_mes.
  - Address(X_i,Y_i) : the address of the sensor node, i, who is sending this packet.
  - Sensor_type : the receiver' s identity, S means the Sink, H means the Head Node, R stands for Relay Node,G is for General node.
  - t_i : the time when the i sensor node sense the target.

TABLE 2. TYPE OF DETECTION_MESSAGE (DET_MES)

Packet_type	Address(X_i, Y_i)	Sensor_Type	t_i

- Information_message (Inf_mes) : The nodes send to the head node existing in the same grid whether the sensor node senses the target or not. The packet type of Inf_mes shown as the following Table 3:
  - Inf_mes : the field name of Packet_type
  - Sensor_type : the value of Sensor_type is H here
  - Remain_energy$_i$: shows that the sensor node I' s remained energy.

TABEL 3. TYPE OF INFORMATION_MESSAGE (INF_MES)

Packet_type	Address(X_i, Y_i)	Sensor_Type	t_i	Remain_energy$_i$

- Time_message (T_mes) : The head node picks the time value is the lest from these packets, then transmits to the neighbor grids.
  - Packet_type : the value of the Packet_type is T_mes
  - Sensor_type : H is the value to Sensor_type field
  - Min_t_i : the minimum time to sense the target in this grid

TABLE 4. TYPE OF TIME_MESSAGE (T_MES)

Packet_type	Address(X_i, Y_i)	Sensor_Type	Min_t_i

- Tracking_message (Tracking_mes) : The new head node receives the Tracking_mes, it identify itself as the head node in the next tracking round, and set the maximum transmit range.
  - Packet_type : the value of the Packet_type is Tracking_mes
  - Sensor_type : H is the value to Sensor_type field
  - Wake up Time : the time to wake up all of the sensor nodes in the grid and the neighbor grids.

TABLE 5. TYPE OF TRACKING_MESSAGE (TRACKING_MES)

Packet_type	Address(X_i, Y_i)	Sensor_Type	Wake up Time

- Retracking_message (Retracking_mes) : Determine if the target exists.
  - Packet_type : the value of the Packet_type is Retracking_mes
  - Sensor_type : H is the value to Sensor_type field
  - Time out : the head node notify the sink the time when the target lost, and the value to the Time out field: Wake up Time + 1/2(Tracking Interval)

TABLE 6. TYPE OF RETRACKING_MESSAGE (RETRACKING_MES)

Packet_type	Address(X_i, Y_i)	Sensor_Type	Time out

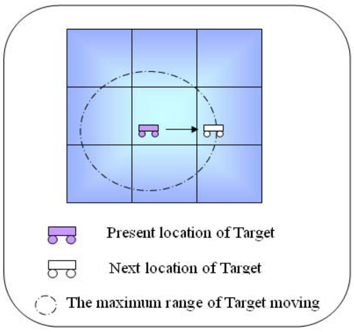

Figure7. The Moving Scope Of Target Within The Tracking Interval.

When the sink receives the Det_mes packets sent by sensor nodes, it computes the target's velocity (V_t) based on the information of the field of Address (X_i,Y_i) and field of t_i. According to the target's velocity (V_t) and the edge of a grid (R), we can set the tracking time interval is R/V_t. The reason why we set the tracking interval time is we hope that the target can just move the longest distance is R in each tracking work. As a result, we can ensure that the target will be within these nine grids in the next tracking, shown in Fig. 7:

C-1 Initial Tracking Work

In the initail tracking work, the sink will replace the field value of Tracking Interval with R/V_t in the Query_mes packet. And then sends it to all of the sensor nodes in entire WSNs. Once the sensor nodes receive this packet, they are doing the initial tracking work. At the same time, all of the sensor nodes begin to sense the target. According to the tracking situation of all the sensor nodes in each grid, we find it can be divided into two situations, namely: sense the target in grid, and none of sensor node sense the target.

Situation 1 : Sense the target in grid:

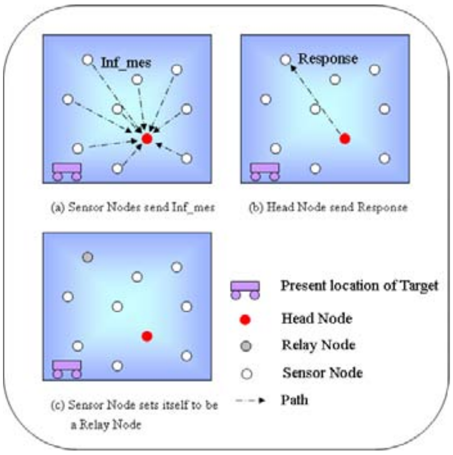

Figure8. The Procedure Of The Relay Node Selection

In this situation, all the sensor nodes shall send a Information_message (Inf_mes) packet to the head node existing in the same grid whether the sensor node sense the target or not. In the tracking target phase, if the sensor nodes do sense the target, this sensor node will record the time sensed the target in the field ti. Or it will set the value ∞ to the Inf_mes packet if it does not sense the target. After receiving the Inf_mes packet sent by the sensor nodes, the head node will look for the furthest sensor node and sends back a Response message to that sensor node. As soon as the one receives the Response message from the head node, it is sure about being the relay identity, and it will set up the maximum transmit range as transmit range setting.

The head node picks the time value is the lest from these packets, then it transmits a Time_message(T_mes) to the neighbor grids. When the head node transmitted the T_mes packet, it computes the wake up time to the neighbor node and the all sensor nodes in its grid for next tracking, which is, $Min\_t_i + Tracking\ Interval(R/V_t)$.

If the head node receives the T_mes packet from the neighbor node, it will compare the time value of the packet with its minimum time value. If its minimum time value is not greater than the received time value, it is going to keep tracking the target. Or the head node will notify the sensor nodes in the same gird turn into the sleep mode except the relay node. The reason to compare the minimum time value is that one situation might occur, which is the sensor nodes sense the target but deployed in more than two grids if the target was at the edge of the grids. As the Figure 9, there are sensor nodes sensing the target in the grids, the head node A and the head node B will transmit the T_mes packet. In this situation, we will choose the grid, the first node sensed the target located in, to do the tracking work.

C-2 Normal Tracking Work

As the head node in the neighbor grids and the new one receive the Tracking_mes, the neighbor head node indicate when the wake up time is. Once the time is up, the sensor nodes will be waked up and start to sense the target. Before tracking target, we must determine if the target exists. The determine way we designed is in each time the head node transmitted the Tracking_mes packet, it would still transmit a Retracking_message (Retracking_mes) packet to the new head node in tracking the target.

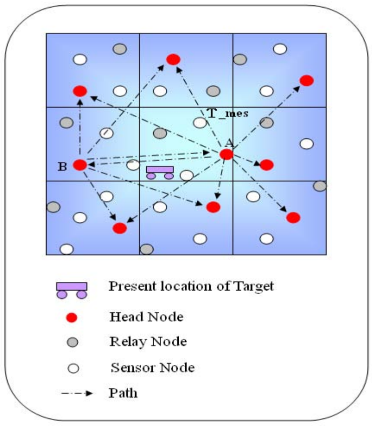

Figure 9. The Multiple Sensor Nodes Sensing The Target.

For the common situation, there would be only two situation in next tracking target, which is: the target is back to this gird again, in the meantime the new head node will know that the sensor nodes sense the target by the Inf_mes transmitted form the same gird; or the target is in the neighbor grid, at this moment the new head node is going to receive the T_mes transmitted by the head node in neighbor gird. The target is missed if the mentioned situations do not occur when the new head node receives the Retracking_mes and the time has run out. And the sink would be notified that the target is lost by this head node. The sink would wake up the all sensor node in entire WSNs and then return to the initial tracking work. If the target does exist, we still can describe the normal tracking work with two situations, namely: sense the target in grids, and there is none of sensor node sensing the target.

The head node will check the maximum value of the $Remain\_energy_i$ field in the Inf_mes packets and sets the sensor node to be the next head node of the grid in the next tracking work. Later, the head node is going to transmit a Tracking_message (Tracking_mes) packet to the neighbor head node and this new head node. After that, the original head node becomes to the general sensor node and set the normal transmit range. As soon as the new head node receives the Tracking_mes, it identify itself as the head node in the next tracking round, and set the maximum transmit range. In the situation one, the first tracking work is over. From now on, we get into the normal tracking work.

Situation 2 : none of sensor node sensing the target:

Under this situation, since all of the sensor nodes do not sense the target in the target tracking process, the sensor nodes transmit the Inf_mes packet to the head node of their grids, the value will be ∞ to the time field. At this point, the head node still chooses the relay node accordingly. When the relay node is chosen, the head node notifies the sensor nodes of its gird put into the sleep mode except the relay node. In the case, the initial tracking work is over.

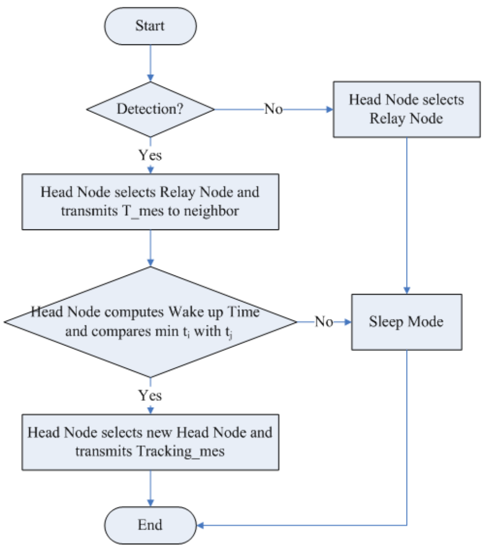

Figure10. Flowchart Of The Initial Tracking Work

Situation 1 : sense the target in grids:

Same as the situation one in the initial tracking work. The head node receives the Inf_mes packets sent by all of the sensor nodes in the grid, picks the relay node accordingly, and transmits the T_mes packet to the head node in neighbor. Differ from the initial tracking work, when the head node transmitted the T_mes packet, it need to replace the Wake up Time field with Wake up Time + Tracking Interval, in accordance with the received Tracking_mes packet and the Interval_mes sent by the sink, in the Tracking_mes.

In the executing period, if the head node receives the transmitted T_mes packet from the neighbor grid, it still needs to determine if the target tracking work is needed to process. Once the target tracking work can not proceed, the head node has to find out the new head node for the tracking round, and then the relative relay node's Inf_mes packet to this new head node. After that, the prior head node transmits the Inf_mes packet to this new head node and sends back the Response to its relay node. As soon as the new head node receives the Inf_mes packet, it knows to become the head node, and the relay node receives the Response will set it's transmit range to the maximum. Then the new head node will notify the sensor nodes in the grid to be in the sleep mode except the relay node. If the head node determines to keep tracking, it has to choose the new head node for the next tracking round, and transmits the changed Tracking_mes packet to this new head node and the one in neighbor grid. For the situation one, the normal tracking work is over and the target tracking will repeat this tracking work.

Situation 2 : none of sensor node sensing the target:

The head node finds the new head node to the next tracking round and notifies it, at the same time, finds out and notifies the relative relay node. And then this new head node is going to notify all of the sensor nodes put into the sleep mode except the relay node.

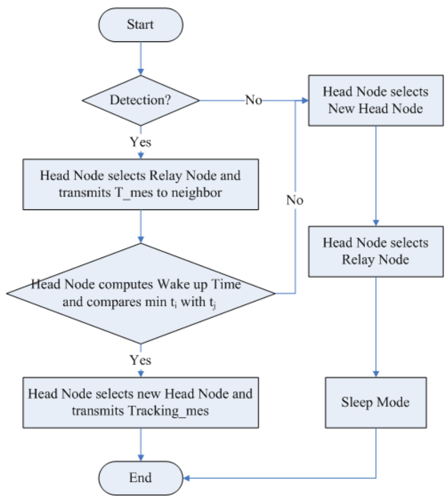

Figure 11. Flowchart Of The Normal Tracking Work

D. *Data Dissemination Phase*

Every time when the target tracking is over, the sensor nodes will transmit the sensed target information to the sink. In this data dissemination phase, there is only the relay node not to put into the sleep mode in entire WSNs. So we transmit data by the head nodes and the relay node.

Finishing each target tracking work, the head node transmits the Tracking_mes packet to the head nodes in neighbor grids. They will send back an Ack_message (Ack_mes) packet for receiving. The head node once receives the Ack_mes packet, it will pick the nearest neighbor head node to the sink, and then transmits the Target_message (Target_mes) packet to that head node.

These above three steps will be repeated until the sink receives the Target_mes packet.

IV. Simulation Reslut

The following are the relevant parameters and the environment settings of WSNs when the simulation is operating:

- The scope of WSNs is 500m × 500m.
- The number of sensor nodes is 750, the deployment way is random with uniform distribution.
- The largest transmission range of the sensor node is 150m.
- The size of packet is 512 bytes.
- The initial energy of the sensor node is 2J.
- The energy consumption of the sensor nodes communicating per unit:50 nJ/bit.
- The energy consumption in sleep mode is 5Mj.

In the first simulation, we set the length of round by the fixed tracking interval. Under this premise, we examine the WSNs could carry out the number of rounds, which is in different tracking interval condition for each round. The result is shown in Fig. 12.

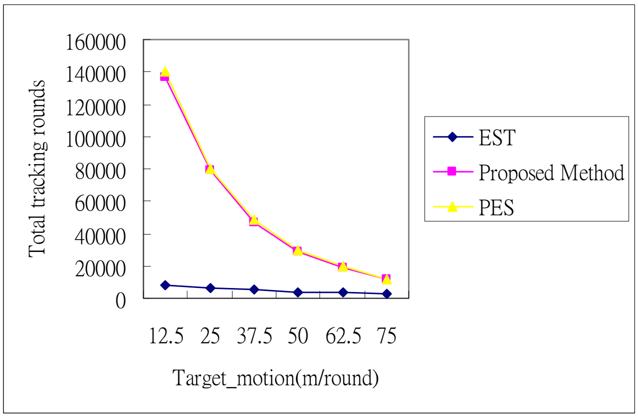

Figure12. The Total Tracking Round

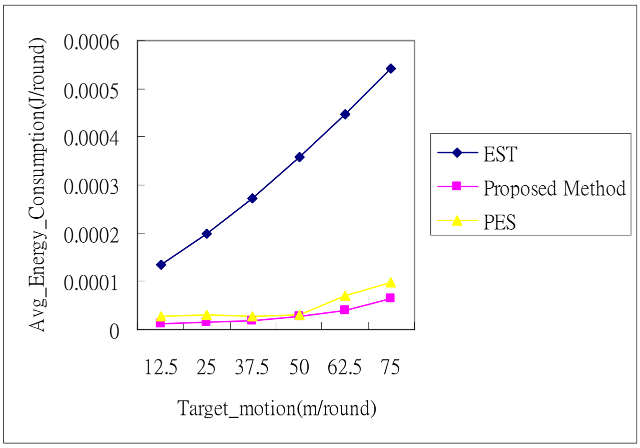

Figure 13. The Average Energy Consumption In The WSNs

Fig. 12 shown GMTT were fell to tracking of round-ratio index, with every round of follow-up time interval increase in the length. For the PES protocol, although it just needs to awake the neighbor node but it will suffer the high tracking error rate. For this reason, the performances between PES and GMTT seem to be equal. However, EST protocol declines in linear proportion. But in every round whose circumstances of tracking interval length is 120 second, the total number of rounds of the GMTT is still five times more than EST protocol. GMTT is based on grid-based, if the tracking interval is short per each round, the size of each grid will be smaller relatively and the amount of sensor node for target-tracking will lessen as well.

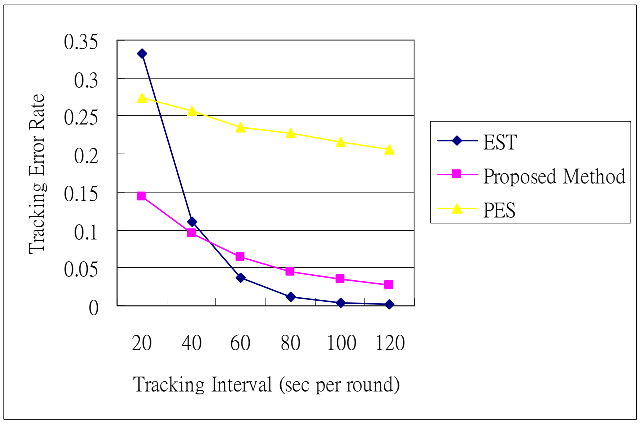

Figure 14. The Rate Of Tracking Error

We analyze and contrast to the average energy consumption of the WSNs to, shown in Fig. 13. Fig. 13 shows that for the whole WSNs, the average energy consumption of the GMTT is much lower than EST protocol. That is because EST protocol's tracking sensor nodes for each round is more than GMTT. We can find out that the breadth of EST protocol's average energy consumption rises higher than our mechanism. It is because that EST protocol wakes up more and more levels while the tracking interval is getting lengthening. And it will wake the 1/6 of sensor nodes in entire WSNs till the tracking interval is at 120 second, so the average energy consumption of EST protocol is worse a lot than our mechanism. For the PES protocol, it suffers the higher tracking error rate than GMTT. So it will waste the energy to recover the tracking tasks.

We have conferred the tracking rate of errors in the third simulation, as shown in Fig. 14. We can find out in Fig 14 when the tracking interval is less than 40 second, the proposed mechanism's tracking errors is lower than EST protocol. When the tracking interval is more than 40 second, EST protocol wakes up a lot of levels, so the rate of tracking error becomes lower than our mechanism. However, EST protocol has slightly better performance in tracking error when tracking interval is more than 40 second. Compared with GMTT, its total number of tracking rounds is pretty less. For PES protocol, it just awakes the predicted neighbor nodes to track the target. So the tracking error rate will higher than the others for the prediction error.

V. CONCLUSION

In the related issues of WSNs, when the sensor nodes are facing many constraints, the most serious restriction is energy. In this paper, we present a mobile target-tracking mechanism adopted the grid-based frame in this paper. We take the surplus energy as a reference, make the sensor node with more energy become the head node of this grid. It will balance the remaining energy to the WSNs, and will further extending the reach of the WSNs' life time. Through the results of our simulation, the tracking mechanism proposed in this paper can be at least five times to the EST protocol in total rounds, even up to 20 times. By the result of the simulations, we can find that

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