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Prediction - Based Protocol, Clustering Algorithm and Recovery Mechanism for Target Tracking in Wireless Sensor Networks (WSNs)

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Abstract

Target tracking is one of the most important and complicated applications of wireless sensor networks. In this application, temporal and spatial information of mobile object is continuously investigated at particular times. Energy saving is one of the main challenges in target tracking sensor networks. In this paper, we present a Clustering, Prediction-Based Protocol, recovery mechanism with virtual grid and the base station as a fundamental element for target tracking in wireless sensor networks. Hence, we introduce an efficient protocol namely (PEBSOTT). In this algorithm we use two parameters, distance from predicted location and remaining energy of nodes, for selection sensor nodes for tracking. Also, using virtual grid reduces time of decision which causes to the object retaining and faster recovering. For evaluation, we compare the proposed protocol with the PES and EBSOTT algorithms. The simulation results represented desirable performance of the presented protocol.

Keywords: *Clustering; Prediction; Recovery; Target tracking; Virtual grid; Wireless sensor network.*

1. INTRODUTION

Recently, the rapid developments of various technologies for sensing, computing and communication have brought a lot of momentum to the research in wireless sensor networks (WSNs) [1]. Due to their low cost and capabilities for pervasive surveillance, sensor networks and their applications have tremendous potential in both commercial and military environments [2].

Wireless sensor networks (WSNs) is a new network paradigm that involve the deployment of hundreds even thousands of low-cost, energy-limited, small, and application-specific sensor nodes to create applications for factories monitoring and control, disaster response, military sensing intelligent house control, and, etc.

Target tracking is one of the most important applications in WSNs. In a target tracking system, we can track a moving target like a person or a vehicle that is traveling a WSN with sensing capability of sensors. In this application, locational and positional information of a moving target is constantly studied in each time instance.

Also, energy saving is one of the main challenges in WSNs. It is because of the energy of a sensor node which is limited and replenishment of its battery is usually impossible. So the lifetime of a sensor node is strongly dependent on its battery lifetime and the lifetime of a WSN is directly related to the lifetime of its sensor nodes. Thus, if we can preserve sensor nodes more time in the network, we will increase the network lifetime.

Object tracking sensor networks have two critical operations: 1) monitoring: sensor nodes are required to detect and track the movement states of mobile objects; 2) reporting: the nodes that sense the objects need to report their discoveries to the applications.

In this paper, a tracking protocol was presented based on a new clustering method, prediction and new recovery mechanism with virtual grid had Base Station (BS) tracing as the basis for performing tracking application of moving targets in wireless sensor networks.

This proposed protocol exploit BS as a powerful resource from both energy and computation perspectives. Using new technologies like RFID and new antennas long range transmission with small antenna size have been possible [3]. In our approach BS undertakes management of cluster formation, active nodes rotation and part of transmissions needed for tracking the target. In our protocol, all sensors are equipped with 3Dcubic antenna that allows them to receive information from long distances at 915 MHz radio frequency [3]. Since BS manages the clustering and recovery mechanism, it has a good knowledge of nodes energy level.

In proposed protocol, we use a new tracker sensor nodes selection algorithm that uses from two parameters, distance from predicted location and remaining energy, for selecting tracker sensor nodes. Current existing prediction-based methods for target tracking often use only distance parameter for tracker sensor nodes selection algorithm. By considering energy parameter as second parameter for tracker sensor nodes selection algorithm, we increase the lifetime of sensor nodes that are located near the predicted location and therefore improve the network lifetime. This improvement is especially when target moves slowly or target traverses a route several times. Also, it improves virtual grid ideas to

divide each network into M×N square area and uses the nodes in each grid, so that the less number of sensors can be used in recovery operations.
The proposed protocol was simulated and compared with other existing tracking methods. Simulation results show that our protocol improves network lifetime.
Rest of the paper is organized as follows: In section 2, literature survey of clustering algorithms, target tracking and recovery algorithms are presented. In section 3 assumptions during network deployment are presented. In Section 4 we discuss proposed protocol. Simulation and performance comparison between existing and proposed approach is discussed in section 5. Section 6 concludes the paper with summary and future work.

2. LITERATURE SURVEY

Moving object tracking using WSN has received considerable attention in recent years and intended solutions can be mainly classified into five schemes, which are: tree-based tracking, cluster-based tracking, prediction-based tracking, mobicast message-based tracking and hybrid methods.
In tree-based target tracking, nodes in a network may be organized in a hierarchical tree or represented as a graph in which vertices represent sensor nodes and edges are links between nodes that can directly communicate with each other. Examples of tree-based methods include STUN (Scalable Tracking Using Networked Sensors) [4], DCTC [5] and OCO (Optimized Communication and Organization) [6].
In cluster-based methods, network is divided into clusters. A cluster consists of a cluster head (CH) and member sensor nodes. A CH is responsible for collecting data from its cluster’s members, calculates the current target location and sends it to the sink. Cluster-based methods are divided into 2 categories, static clustering and dynamic clustering. In static clustering methods, clusters are formed at the time of network deployment and remain unchanged until the end of network lifetime. But in a dynamic clustering algorithm, clusters are formed dynamically as target moves. Examples of cluster-based methods are presented in [7], [8], [9] and [10].
Prediction-based methods are built upon the tree-based and the cluster-based methods, with added prediction models. These algorithms are methods that with a prediction mechanism predict next location of target and with attention to estimated location, only select some nodes that are near to this location for tracking and other nodes remain in sleep mode for energy saving. Examples of prediction-based algorithm are PES (Prediction-based Energy Saving) [1], DPR (Dual Prediction-based Reporting) [2] and DPT (Distributed Predicted Tracking) [11].
Mobicast protocols are designed to predict object moving direction. Appropriate nodes are wake up to detect the object before it arrives.
Some protocols fulfill the requirements of more than one types of target tracking which are termed as hybrid tracking methods. Other methods like binary sensor nodes and clustering based method in [12] and [13] have disadvantages such as higher energy consumption, traffic and increased collision probability and consequently increased energy consumption.
In Base Station Based Target Tracking (BSOTT) protocol, (see [14] and [15]) BS is used as a powerful source from two aspects; energy and calculation, to be able to provide the possibility of BS's intervention in tracking process using new antennas.
All above described tracking algorithms may suffer from loss of target as WSN have limited resources. Also, if there are more numbers of failed nodes around, target may go undetected. For next nodes, which were supposed to be active in tracking, may not have the trace of target, causing the situation of loss of target. Other issues like communication failures during transmission of information, localization errors during tracking, and abrupt change in target velocity may also cause loss of target. Following reasons may result in loss of target:

a) Communication failures: Nodes may not be able to communicate due to obstacle like tree, specially, in case of forest WSN. Packet loss and delay in response can also be considered in this case.
b) Node failures: As sensor nodes have limited battery power and if they remain active for a long time, battery may drain faster leading to failure. Physical capturing of node and hardware failure are also the reasons of node failure.
c) Sudden change in target speed: As speed of target changes suddenly, the difference between actual and predicted location of target becomes large, resulting in loss of target.

Therefore, various recovery mechanisms (RMs) are proposed by researchers.RM for wild life tracking is presented in [16] where a simple recovery mechanism for wild life, tracking based on popular places is considered. Popular places, they are the places where animals (targets) frequently visit for water, shelter and rest. If target is lost then by checking their presence at these places recovery can be done. Another RM for wild life tracking using hierarchical clustered WSN is studied in [17]. In paper [18], a lightweight target tracking protocol (LTTP) with three levels of RM is discussed. RM for target recovery using static clustered WSN is discussed in [19]. Also, in this paper, we propose an efficient approach with less communication overhead for successful recovery.

3. Overview

3.1 Assumptions

Our algorithm considers dynamic clustered architecture for target tracking. Following assumptions are made about the sensors and the sensor network in the development of the proposed target tracking algorithm:

1- It is assumed that sensors are binary sensors and each sensor is aware of its own location and they are stationary. Also, BS knows the topology of the WSN.

2- It is assumed that BS is outside of the surveillance field, plugged to an unlimited energy source and capable of long range transmissions through higher transmission power at 915 MHz frequency.

3- Sensing ranges (RS) for all the sensors are the same and communication range (RC) is double the sensing range.

4- All sensors are equipped with 3-D cubic antenna to be able to receive BS packets at 915 MHz from a long distance.

5- All have the same battery power.

6- The sensor network environment is divided cells with dimensions of 100 × 100.

3.2 Sensing and Communication Model

In this paper, binary sensors' sensing disk has a radius of RS and binary sensing model is considered [14]. Sensors can detect the target once it enters to the sensing range of the sensor. Formally, the mode is as follows:

$$S_i(T) = \begin{cases} 1, & if\ d(S_i, T) \le R_s(i) \\ 0, & otherwise \end{cases} \qquad (1)$$

Where S_i(T) is the sensed data of the sensor S_i and d(S_i, T)isthe distance between the sensor S_i and the target T. Fig.1 shows how S_1 senses the target T but S_2 does not sense the target T.

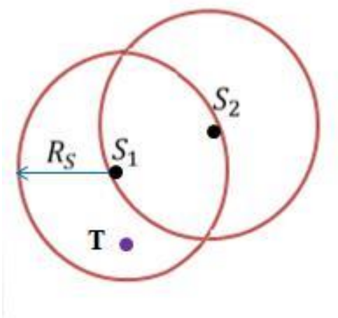

Fig.1. Illustration of the Sensing region.

An important assumption made in this paper is equipping sensors with 3-D cubic antenna. Using this antenna, it is possible to have both RFID technology and miniaturized wireless communication equipment at the same time. The frequency of operation lies in the UHF RFID band, 902 MHz–928 MHz (centered at 915 MHz).

The ultra-compact cubic antenna has dimensions of 3cm × 3cm × 3cm, which features a length dimension of λ/11. The cubic shape of the antenna allows for "smart" packaging, as sensor equipment may be easily integrated inside the cube's hollow interior.

Binary sensors have minimal assumptions about sensing capabilities. At this frequency long range transmission for BS is possible. However, sensors use 2.4 GHz for inter sensor transmissions and merely BS uses 915 MHz to send its data in one-hop and for long range. Fig. 2 shows how BS transmit command message to lead the clustering, and CH replies target location hop by hop. Binary reporting, smart sensors also can act as binary sensors. So, proposed tracking algorithm is applicable to both binary and smart sensor networks.

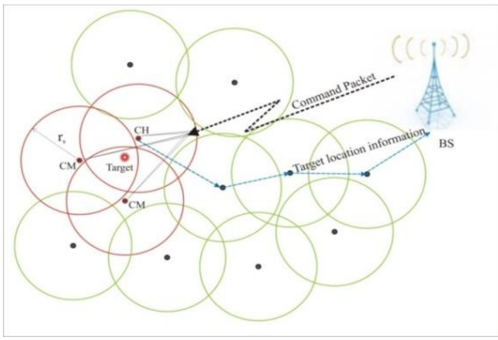

Fig.2. Illustration of the BS and sensors communication.

3.3 Localization

Assuming target T has the coordinate of (XT, YT), all the sensors located in a circle centered at the point (XT, YT) with a radius RS can detect the target. Generally, the centroid of the sensors that can detect the target can be a fair approximation for target location. The location of the target can be estimated using the centroid approach [14]:

$$\begin{cases} \bar{X} = \dfrac{1}{n_{sd}} \displaystyle\sum_{i=1}^{n_{sd}} X_i \\ \bar{Y} = \dfrac{1}{n_{sd}} \displaystyle\sum_{i=1}^{n_{sd}} Y_i \end{cases} \qquad (2)$$

Where (X_i, Y_i) and $n_{sd}$is the coordinate of the sensors and the number of sensors that detect the moving target respectively. The estimated coordinate of the target T is ($\bar{X}$,$\bar{Y}$).

4. PROPOSED ALGORITHM

Our algorithm is divided into three stages, prediction, clustering and recovery.

4.1 Prediction mechanism

Prediction-based algorithms in target tracking are algorithms that predict next location of target (using a prediction mechanism). Then with attention to predicted location, they activate specific nodes for tracking and other nodes of network remain in sleep mode for energy saving.

Prediction mechanism in proposed algorithm is a linear prediction method. This mechanism predicts next location of target with attention to current and previous location of it. In this prediction we assume that fixes speed and direction of target. So we can estimate the target's speed as

$$v = \frac{\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}}{t_i - t_{i-1}} \quad (3)$$

While the direction is given by

$$\theta = \cos^{-1} \frac{x_i - x_{i-1}}{\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}} \quad (4)$$

Based on this information, the predicted location of target after a given time t is given by

$$x_{i+1} = x_i + vt\, cos\theta \quad (5)$$
$$y_{i+1} = y_i + vt\, sin\theta \quad (6)$$

After calculation (x_{i+1}, y_{i+1}), if this location is placed in the current cluster, active CH selects three or five (cluster number) sensor nodes for target tracking in the next interval time, via the tracker sensor node selection algorithm, and wakes up them with sending a message. Otherwise if the next location of target is placed out of the current cluster, active CH selects nearest CH to that location as next active CH and with sending a message informs it from arriving the target and gives the tracking task to the new active CH [20].

4.2 Clustering

Clustering is one of the most needed important operations of aggregation and data fusion. Dynamic clustering algorithms problem is that when target frequently changes its location, reclustering must be invoked and with the course of time communicative overhead imposed by clustering, which makes clustering to lose the initiative. In our proposed algorithm clustering overhead is minimized by using BS. Whenever reclustering is needed, BS broadcasts a command message to announce the new CH and cluster members (CMs). The base station uses the following methods to select the cluster heads and cluster members. In this method, BS calculates, for each nod that can sense the target, a selection parameter as follows:

$$selection_i = \frac{energy_i}{{distance_i}^2} \quad (7)$$

In this relation $distance_i$ is the distance of node i from predicted location of target, and $energy_i$ is the remaining energy of nod i. Then, active CH selects three or five (cluster number) nodes that have maximum selection parameter as tracker sensor nodes in the next interval time. Using both of these parameters, distance and energy, for tracker sensor node selection algorithm caused that nodes with lower energy remain more time in network and so network lifetime increases. Especially in situations that target remains in a cluster for a lot of time or target traverses a route several times or target moves slowly, using proposed tracker sensor node selection algorithm can prolong network lifetime significantly.

Then, BS forms a command packet including clustering information such as CH and CMs IDs and transmits the packet over the WSN through a long range transmission. It is noticeable that BS sends its data in one hop at 915 MHz and with a high power. Also, sensors use 3-D cubic antennas to receive BS data. Activated sensors of the field receive the packet and extract the information and clustering is over. Using received information about target new location, BS decide which sensor must be the new CH. BS lets the sensors to be informed of the new CH and CMs. If any node failure causes missing the target, recovery operation is invoked. This phase continues until BS finds the target.

4.3 Recovery

Recovery mechanism needs to be initiated to find the exact location of the lost target. In this paper, we are proposing an efficient recovery mechanism. In this method, the sensor network environment is divided cells with dimensions of 100 × 100. Each sensor node is located within this field, resulting in one of these cells. The BS estimates target location and saves which cell is the target location [21]. Detail of recovery process is as given below:

Step 1: The last cell, which the target is located, is saved in a list.
Step 2: We search target in the list.
Step 3: If the target was found, therefore, the recovery process is finished.
Else
Step 4: All its neighboring cells are add to the list.
Step 5: Go to Step 2.

Using our recovery process causes that less number of nodes participates in recovery operations, therefore, nodes consume less energy and will increase the network lifetime. As a result, our mechanism works as follows:

At the beginning of this algorithm, all nodes are in sleep mode except border nodes. When a border node finds a target in its sensing range, it waits for a random time called back off time to avoid collision. Then, the border node sends its sensed data to the BS. Upon receiving sensed data from border nodes, BS estimates target location and predicts the probable location of mobile target and determines a cluster of sensor nodes, in which probable location of the target is in its identification area, as “Target Cluster”, to assist target tracking.
According to the clustering algorithm presented in this section, the BS selects the cluster heads. Since, all sensors autonomously return to sleep mode after a period of time, BS needs to trigger CH and CMs to awaken them and make them ready for receiving command message. BS broadcasts command message containing new CH’s ID, over the WSN to inform sensors about the new CH, subsequently other awakened sensors that are not CH will be CMs. Sensors work in two distinct modes shown in Fig. 3 [14].

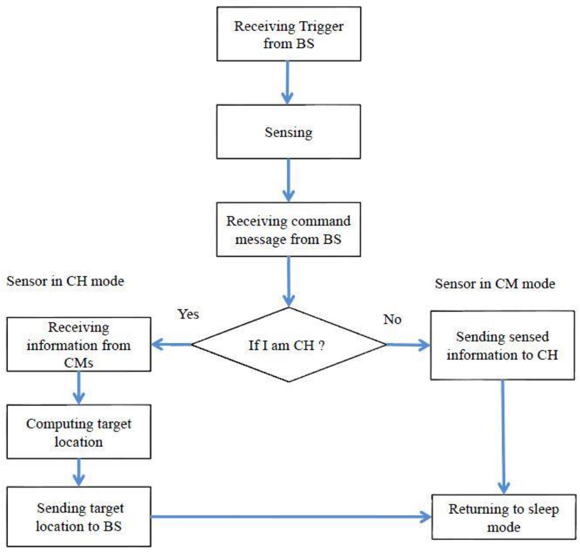

Fig.3. Working stages for sensors.

However, if new CH and the latest CH are the same, BS won’t transmit any command message indicating that everything is as the same. Then, the very last CH again is CH for the new round, CMs just transmit their sensed data. Once a member detects the target, it sends its scan data (its location and the time finding the target) to the CH. CH performs data fusion to get the location of the target, and reports to the BS periodically. Receiving tracking information from sensor field, BS starts to evaluate target location. Then, if target is not in the sense range of the current CH, BS dismisses current CH and choose a new CH as mentioned before.

Therefore, BS broadcasts Command message containing new CH’s ID, over the WSN to inform sensors about the new CH, subsequently other awakened sensors that are not CH will be CMs. Target cluster performs sensing operation for (X) seconds and then CH collects the data from CMs and reports them to BS. It should be noted that BS predicts movement of target for next (T-X) seconds and would form the target cluster again and inform its sensors. After (T-X) seconds, all sensors of the target cluster are awakened to trace the target. BS repeats the process described above so that other sensors could go to sleep state. Fig.4 shows working stages of the BS in two conditions; normal condition and target miss condition.

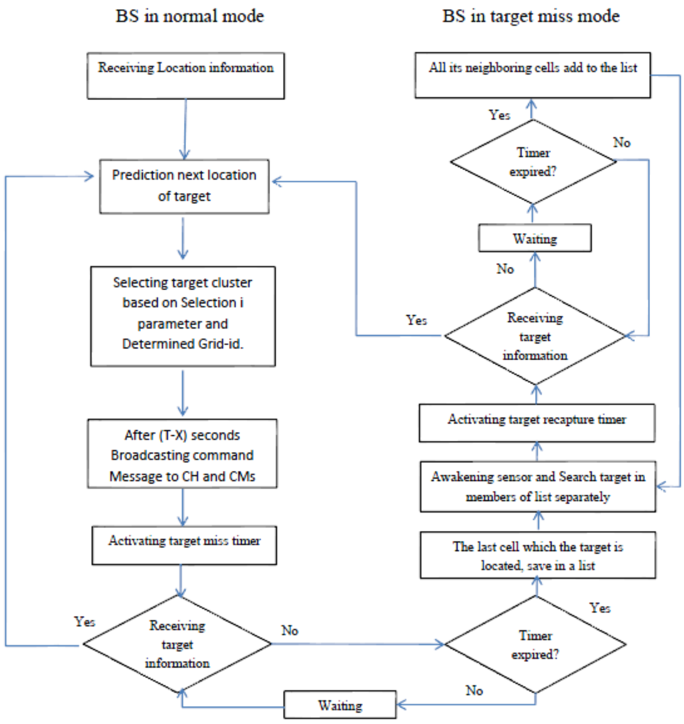

Fig.4. Working stages for base station (BS).

So far BS leads tracking process. However, any failure needs to be handled. It is possible that, when sensors of the target cluster are awakened, the target is not located in their identification area (Fig.5)[2].

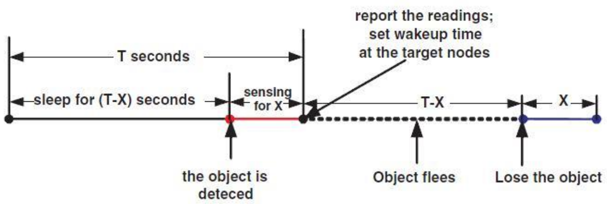

Fig.5. Miss the target.

In this condition, although the target is inside the network, BS would not receive any report regarding the

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target. In this case, presented recovery operation is invoked .If BS succeeds to capture the target, then tracking process starts from the beginning, otherwise BS does recovery process until it finds the target or reach to end the of the network lifetime.

Being triggered by BS, sensors change their state to sensing state and wait to receive command message. After receiving command message, they check to see if they have been announced as CH or not. If a sensor is not announced as CH, then it is CM. CM broadcast sensed information and CH receives the information from all CMs. Then, CH computes exact location of the target using (2). Finally, CH sends target location to BS. Due to energy conservation, CH and CMs return to sleep mode at this point.

5. SIMULATION

In this section, using computer simulation, we evaluate performance of proposed algorithm and compare our proposed method with two other algorithms, PES [2] and EBSOTT [21]. In this review, all algorithms have been simulated in two different cluster member numbers. In fact we changed cluster members from 5 to 7, to investigate impact of this variant on different network parameters. Our simulation has done in c# simulator (Microsoft Visual Studio 2010).

Three below parameters for evaluate performance of our algorithm with others.

1- Network lifetime: The time that the first node of network dies.
2- Transmitted Packets.
3- Number of Target Miss.

5.1 Simulation Environment

The PEBOSTT algorithm described in the previous section was simulated a wireless sensor network consisting of a set of sensor nodes randomly deployed in a field of 1000×600m^2. The sensor network environment is divided into cells with dimensions of 100 × 100. Each sensor node is located within this field, resulting in one of these cells (see Fig. 6).

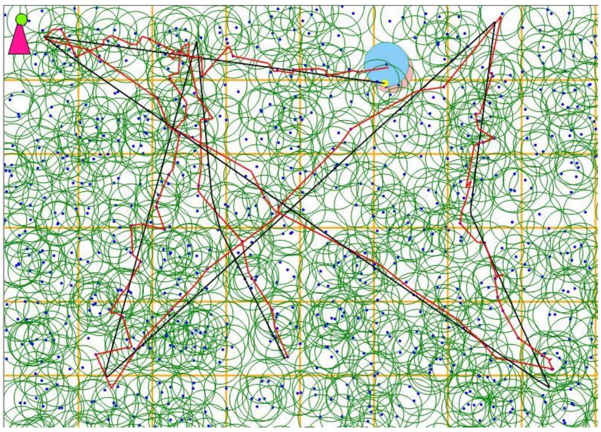

Fig.6.Simulation environment.

Also, the simulation model is considered a network which the number of its nodes is varied between 1000 and 4000. Target motion model is random waypoint and target is moving with the maximum velocity of V_{max} =10m/s. Each sensor node is able to detect the existence of nearby moving target communicate with other sensor nodes in the vicinity and do some simple computation. Sensor nodes are aware of their location. Sensing range (R_S) is considered 30m and communication range (R_C) is 60m. Each sensor begins with an initial energy of 3 J. The transmission energy is 0.175 J and reception energy is 0.035 J, and the sensing energy is 1.75 μJ[22].Basic information of each sensor node is considered as Table1 [22].

Table1: Basic information of each sensor node.

Parameters	Value of parameters
field size (m^2)	1000×600
size of grid	100×100
number of sensors	1000 – 4000
maximum speed of a mobile target: V_{max} (m/s)	10
sensing range (R_S)	۳۰(m)
communication range (R_C)	۶۰(m)
initial energy	۳J
transmission and reception energy	۰.۱۷۵J
sensing energy	1.75 μJ
reception energy (J)	0.035

5.2 Simulation Results

In this section, we evaluate performance of our algorithm and compare our algorithm with PES and EBSOTT in the network lifetime, transmitted packets and number of target miss. Performance of the proposed algorithm was compared with cluster members 5 and 7 with changing the number of nodes.

5.2.1 Network Lifetime

Network lifetime is the most important parameter in comparison of majority of WSN's applications. For more comparison, we run our simulation in many different scenarios, with different node number and two different cluster member numbers, and calculate the network lifetime. We considered time that the first node of network dies as network life time. The lifetime of a sensor node is strongly dependent on its battery lifetime and the lifetime of a WSN is directly related to the lifetime of its sensor nodes. Thus, if we can preserve sensor nodes more time in the network, we will increase the lifetime of the network.

Fig.7 shows effect of increasing number of sensors and cluster members respectively on the network lifetime. As this diagram shows, network lifetime in proposed algorithm is more than other methods and this time increases as the nodes number of network increase.

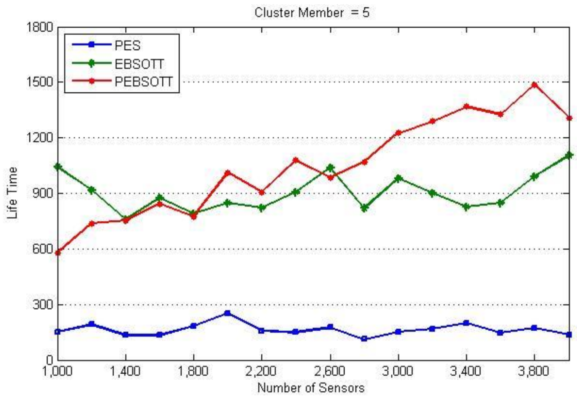

Fig.7. Effect of number of sensors on network life time.

Fig.8 illustrates effect of cluster members on the network life time. Increasing cluster members again leads to growth of message transmission. Hence, cluster head battery drains mush faster and it shortens the lifetime.

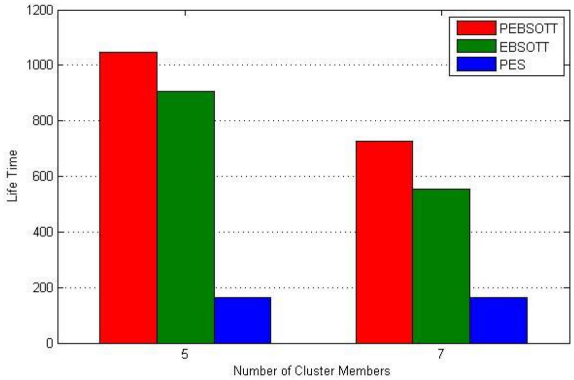

Fig.8. Effect of cluster members on network lifetime.

5.2.2 Transmitted Packets

Number of transmissions during tracking process in the field of WSN is an important factor mostly known as radio silence. Number of transmitted packets must be kept low for both energy and radio silence reasons. Number of transmitted packets in the proposed method is less than the PES and closest EBSOTT. Transmitted packets shown in Fig.9, is an average number and shows the ratio of actual transmitted packets to network life time.

Obviously raising cluster members results in more message exchange between cluster head and cluster members to form and manage a cluster. Thus, the more member a cluster have, the more transmissions it needs (Fig.10).

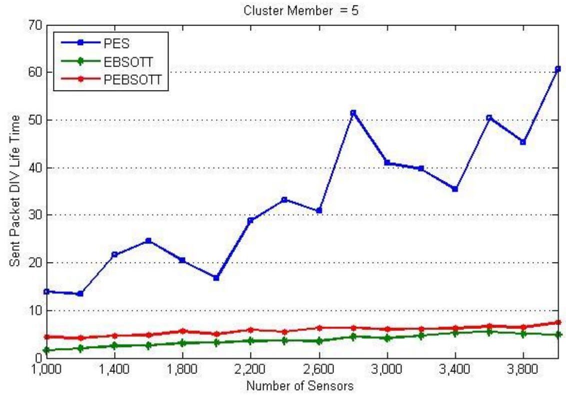

Fig.9. Effect of number of sensors on transmitted packets.

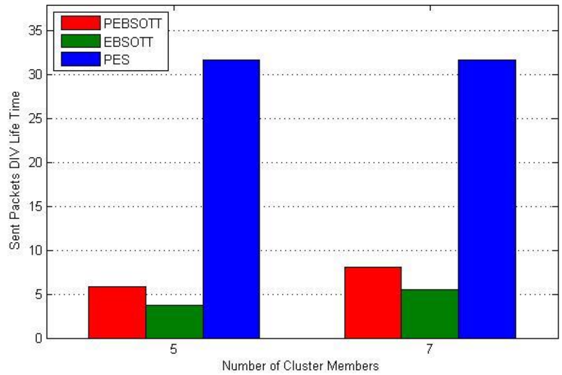

Fig.10. Effect of cluster members on transmitted packets.

5.2.3 Number of Target Miss

This parameter should be kept as low as possible in rescue applications and generally in applications sensitive to target miss considering that number of target miss is a parameter that should be evaluated in time scale. Number of target miss in the proposed method is less than the PES and EBSOTT. Number of target miss shown in Fig.11.

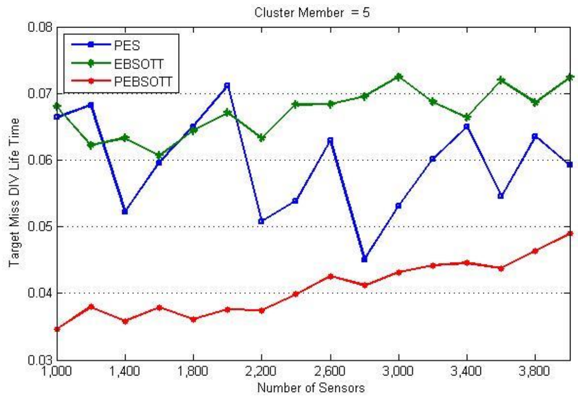

Fig.11. Effect of number of sensors on target miss.

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It is clear that, increasing the number of cluster members again leads to decrease the number of target miss (Fig.12).

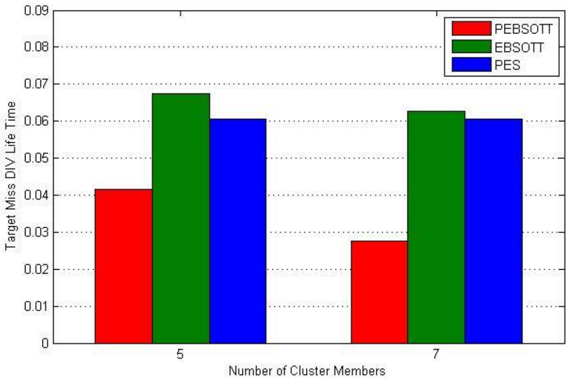

Fig.12. Effect of cluster members on target miss.

6. CONCLUSION AND FUTURE WORK

One of the main limitations of WSN is the limited power of sensor nodes. This limitation affords that saving energy and increasing network lifetime become two main issues in WSN's applications and protocols.

In this paper, we presented a Prediction Based Protocol, Clustering and recovery mechanism with virtual grid for target tracking in WSNs. Proposed protocol uses from an efficient clustering algorithm, Prediction Based Protocol and recovery mechanism with virtual grid. Our protocol considers both energy and distance parameters for clustering. Also, it improves virtual grid ideas to divide each network into M×N square area and uses the nodes in each grid, so that the less number of sensors can be used in recovery operations. Also, we used the prediction-based algorithms for target tracking. They are algorithms that predict next location of target. Then with attention to predicted location, they activate specific nodes for tracking and other nodes of network remain in sleep mode for energy saving. Therefore, this method for target tracking led to reduce number of target miss and increase the network lifetime too. In the future, the methods should be extended to multiple targets tracking in wireless sensor networks.

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