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Designing a Clustering and Prediction-based Protocol for Target Tracking in Wireless Sensor Networks (WSNs)

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Abstract

Target tracking is one of the applications of wireless sensor network which is set up in the areas of field surveillance, habitat monitoring, and intruder tracking. Energy saving is one of the main challenges in target tracking sensor networks. In this paper, we present a Clustering and Prediction-Based Protocol (CPBP) for Target Tracking in Wireless Sensor Networks (WSNs). Also, the Base Station (BS) was exploited as a cluster formation manager and target movement predictor. Our protocol uses two parameters, distance and energy, for clustering algorithm. For evaluation, the proposed protocol was compared to a number of protocols in terms of network lifetime, number of transmitted packets and number of target miss during network lifetime. Performance of the proposed protocol was compared with cluster size 5 and 7. The simulation results represented desirable performance of the presented protocol.

Keywords: *Wireless Sensor Networks, Target Tracking, Base Station, Prediction, Clustering.*

1. Introduction

Sensor networks are composed of a large number of sensor nodes that are densely deployed either inside the phenomenon. These sensor nodes have sensing, processing and communicating capabilities. Wireless sensor networks (WSNs) are a new pattern of networks which include establishment of hundreds or thousands of low cost, low consumption sensor nodes with special application to be used in military-security and monitoring-surveillance applications like factory control, reaction against disasters and military intelligent room control. A sensor networks are composed of a large number of sensor nodes that are densely deployed either inside the phenomenon. These sensor nodes have sensing, processing and communicating capabilities.

A sensor node usually has specifications like small physical size, limited energy, limited process power, short board wireless communications and low memory. 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 traversing 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. Energy saving is one of the main challenges in design and implementation of target tracking sensor networks. Also, limited process power and low memory size are of factors which restrict protocol design of the networks.

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 clustering and prediction (CPBP) had Base Station (BS) tracing as the basis for performing tracking application of moving targets in wireless sensor networks.

CPBP 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 [7]. 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 (Figure 1) [7]. Since BS manages the clustering and prediction processes it has a good knowledge of nodes energy level.

Current existing prediction-based protocols for target tracking use only distance parameter for clustering algorithm, but our protocol uses two parameters, distance and energy, for clustering algorithm.

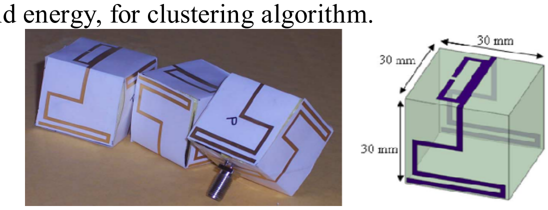

Fig. 1 A view of the antenna used in the proposed protocol.

The proposed protocol was simulated and compared with other existing tracking methods. Simulation results show that our protocol improves network lifetime. This improvement is because, in our method, tracking task is divided between nodes of a cluster and therefore nodes with less energy remain more time in the network and so network lifetime will be increased.
The rest of this paper is organized as follows: In Section 2, a summary of previous works is presented. Then, the proposed protocol is described in Section 3. Simulation model and simulation results are presented in Section 4. Final section of the paper includes conclusion and future works.

2. Related Works

The presented approaches could be categorized to five designs including: tree-based tracking, cluster-based tracking, prediction-based tracking, mobicast message-based tracking and hybrid methods [1].
Scalable Tracking Using Networked sensors (STUN) [2], [3] and Dynamic Convoy Tree-Based Collaboration (DCTC) [4] protocols are of tree-based tracking approaches. In these protocols, network nodes could be organized as a hierarchical tree or could be demonstrated as a graph, the vertices of which show sensor nodes, and, edges of which indicate communication between nodes that could directly communicate with other nodes. Also, a cost is assigned to each communication. Leaf nodes are used for mobile target tracking and transmission of the collected information. Nodes send the collected information to sink through intermediate nodes.
In traditional clustering approach, clusters are formed statically during network development and specifications of each cluster like number of members, regional coverage, etc. are constant. In dynamic clustering, depending on the occurrence of specific events, clusters are dynamically formed. Dynamic clustering has several advantages; for example, when a node with sufficient battery and computational power identifies an event, it volunteers to be a Cluster Head (CH). CH invites adjacent sensor nodes and make them members of that cluster. Since sensors do not statically form cluster, they can belong to different clusters simultaneously. In [5], authors studied an energy-efficient target tracking protocol based on two Reduced Area Reporting (RARE-Area) and (RARE-Node) algorithms through static clustering. RARE-Area algorithm reduces the number of nodes participating in tracking, which occurs by preventing the involvement of farther nodes in tracking process. RARE-Node algorithm reduces excessive information by identifying the overlapped sensors.
Prediction-based tracking [6] happens on the basis of tree-based or cluster-based tracking in addition to a prediction mechanism. In these models, it is assumed that the moving target keeps its current speed and direction for the next few moments. These models process history data to guess next movements of the moving target. Prediction-based Strategies for Energy Saving (PES) protocol [8] attempts to approach ideal patterns through minimizing both frequency and number of the nodes involved in target tracking. The main objective of the presented mechanism in Dual Prediction-based Reporting (DPR) protocol [9], which is a prediction-based target tracking protocol, is to reduce consumption power through decreasing radio transmissions from sensor nodes to BS. In DPR both sensor nodes and the base station predict the future movements of the mobile targets. Consequently, energy consumption decreases in each node and network lifetime increases.
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 [10] and [11] 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 [12] and [13] 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.

3. The Proposed Protocol

3.1 Network Model

For our proposed model, we adopt a few reasonable assumptions of the network model as follows:

1. BS is outside of the surveillance field and is plugged to an unlimited energy source and is capable of long range transmissions through higher transmission power at 915 MHz frequency. Also, BS knows the topology of the WSN.
2. Sensors are binary sensors and sensors are homogeneous and each sensor is aware of its own location and sensors are stationary.

3. Sensing ranges (R_S) for all the sensors are the same and communication range (R_C) 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.

3.2 Sensing and Communication Model

In this paper, binary sensors' sensing disk has a radius of R_S and binary sensing model is considered [12], [15]. Sensors can detect the target once it enters to the sensing range of the sensor. Formally, the mode is as follows:

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

Where S_i (T) is the sensed data of the sensor Si and d (S_i, T) is the distance between the sensor Si and the target T. An important assumption made in this paper is equipping sensors with 3-D cubic antenna [7]. 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. The prototype fabrication was performed on six (planar) sides on liquid crystal polymer (LCP) substrate, and then folded into the cubic structure. The geometry of the design is inspired by the RFID inductively coupled meander line structures, which are folded around the sides of the cube. The structures on the top and bottom of the antenna are identical. 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. Figure 2 shows how BS sends the "cluster formation" message after predicting next location of the target to manage clusters and CH reports target location with hop by hop transmissions. So, proposed tracking algorithm is applicable to both binary and smart sensor networks.

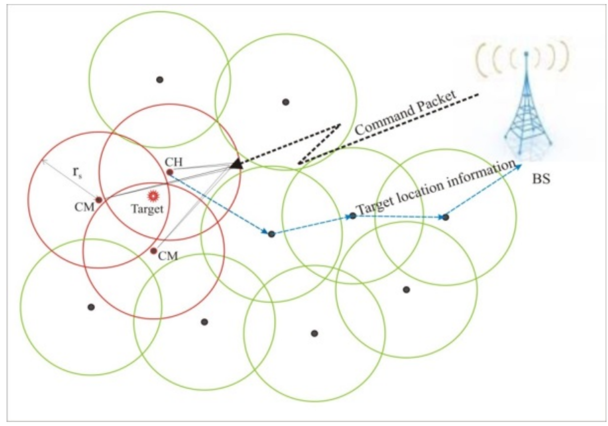

Fig. 2 Sensors and base station during target tracking.

3.3 Localization

Assuming target T has the coordinate of (X_T, Y_T), all the sensors located in a circle centered at the point (X_T, Y_T) with a radius R_S 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 [12], [16]:

$$\begin{cases} \bar{X} = \frac{1}{k}\sum_{i=1}^{k} X_i \\ \bar{Y} = \frac{1}{k}\sum_{i=1}^{k} Y_i \end{cases} \quad (2)$$

Where k is the number of sensors which can detect the target. The coordinate of sensor nodes s_i are (X_i, Y_i). x,¯ and Y,¯ are the estimated location of the target.

3.4 Working Stages of the Proposed Protocol

Due to broadcasting nature of BS transmissions, all sensors are capable of hearing transmitted information; but, only the sensors receive information that have been previously triggered and changed their status to awake state; thus, in BS transmissions, only those sensors consume the received energy that are in awake state. Since sensor nodes periodically report the estimated location of target, possessing wireless sensor network arrangement and estimated location of the target, BS is able to undertake a part of tracking process load, participate in operation of predicting next location of the target and cluster formation and direct the tracking process using ability of long transmissions. Clustering is one of required operations in data aggregation. Since the BS is in charge of cluster formation and directing the tracking, it has a good knowledge about energy level of

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each node. BS uses this knowledge for clustering and avoids selecting nodes with low energy level as CH. It is notable that BS transmits its information in one hop and with high power at 915 MHz frequency. Also, sensors use 3-dimensional cubic antennas to receive BS information. In the proposed protocol, in order to optimize energy consumption, both frequency and number of sensors involved in target tracking were decreased. This protocol consisted of three parts; a prediction model which predicted future movement of the target and therefore only sensors that were expected to identify the target were awakened, an awakening mechanism which determined that cluster of sensors and when they were activated and a recovering mechanism which only started when network lost a target trace.

A sensor that does not perform the tracking action (meaning that there is no target in its identification area) should stay in sleep state as long as possible. According to the used model, BS 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. BS predicts the next location of the target. Nearest sensor to target’s predicted location is the candidate of being CH, however its energy level must be upper than a predefined energy level we call it α here. If candidate node energy level doesn’t satisfy α then the next nearest node to target will be candidate of being CH. This process continues until a candidate node satisfies α condition, otherwise BS decides to lower α to half of its current value. Then, BS starts to examine candidates one by one to find the appropriate CH. Also, BS chooses the farthest sensors to predict location of the target, which have the ability to sense target, as cluster members (CMs). In proposed clustering method, the area covered by CMs would be greater and it would help the target to be identified by cluster and the probability of losing target trace would decrease. All the sensors which are not a member of target cluster become inactive after transmission of the message by BS to target cluster. Figure 3 shows the proposed clustering method with cluster size 3. 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.

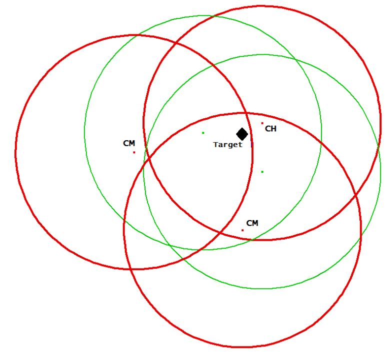

Fig. 3 The proposed clustering method.

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. Figure 4 shows working stages of the BS in two conditions; normal condition and target miss condition.

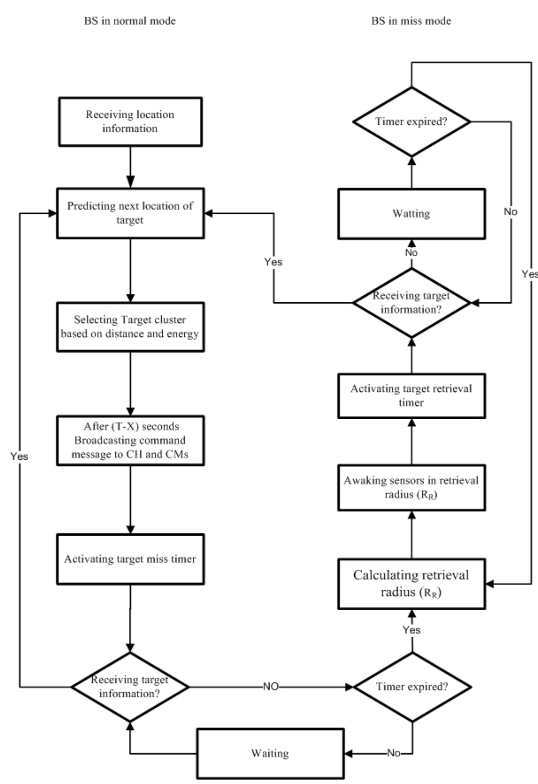

Fig. 4 Working stages of base station.

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It is possible that, when sensors of the target cluster are awakened, the target is not located in their identification area (Figure 5).

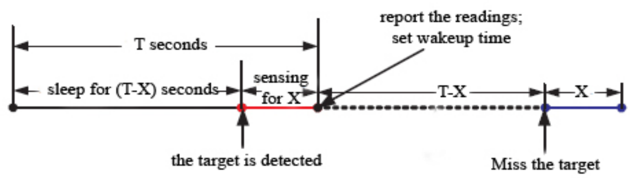

Fig. 5 Miss the target.

In this condition, although the target is inside the network, BS would not receive any report regarding the target. Therefore, the important problem is: how to locate the target again in case of losing it. The process of target miss retrieval is so that the BS activates the target miss counter after broadcasting the "target cluster formation" message. If BS does not receive any report from CH before expiration of counter, a target miss event has happened. BS awakens all sensors existing in retrieval radius (R_R) from last reported location of the target which would be regarded as "target miss" status. In case BS succeeds in target retrieval, normal tracking process would be started over, otherwise BS doubles the retrieval range to its current value and keeps seeking the target until it finds the target or reach to end of the network lifetime. Each sensor separately transmits its sensing information to BS as multi-hop transmission in case of identifying the target in its sense range. After receiving sensor reports, BS calculates the target location and then changes its status to normal state. Figure 6 shows working stages of the sensors.

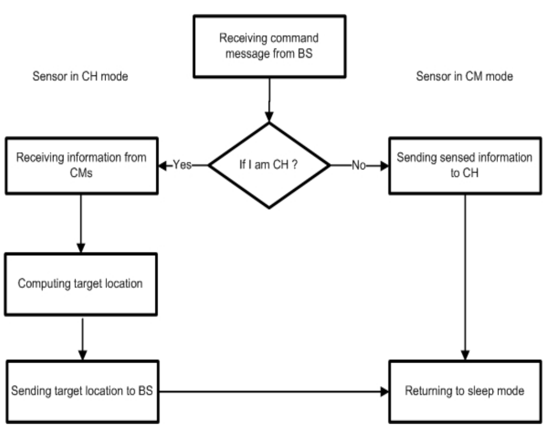

Fig. 6 Working stages of sensors.

3.5 Prediction Mechanism

Prediction based protocols [6], [14] are mainly used to predict the next location of the target. CPBP in target tracking is protocol that predicts 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 CPBP is a linear prediction method. This mechanism predicts next location of target with the current and previous location of target. In this prediction we assume that fixes speed and direction of target. So the target speed is calculated 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}), BS selects sensor to target's predicted location, as CH. Also, BS selects the farthest sensors to predict location of the target, which have the ability to sense target, as cluster CMs. In proposed clustering method, the area covered by CMs would be greater and it would help the target to be identified by cluster and the probability of losing target trace would decrease.

4. Performance Evaluations

4.1 Simulation Model

To validate and characterize the performance of our protocol, simulations are performed. We developed a simulation environment in C#. In this paper, we simulate a wireless sensor network consisting of a set of sensor nodes randomly deployed in a field of 1000×500 m2. 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 [17]. The parameters used in our simulations shown in Table 1.

Table 1: Simulation Parameters

Parameter	***Values***
field size (m)	1000×500
number of sensors	1000 – 2000
maximum speed of a mobile target: V_{max} (m/s)	10
sensing range: R_S (m)	30
communication range: R_C (m)	60
transmission energy (J)	0.175
reception energy (J)	0.035
sensing energy (μJ)	1.75

4.2 Simulation Results

We compared our proposed approach with PES and BSOTT protocols in terms of network lifetime, number of transmitted packets and number of target miss during network lifetime. Performance of the proposed protocol was compared with cluster size 5 and 7.

4.2.1 Network Lifetime

Network lifetime is the most important parameter in comparison of majority of WSN's applications. We run our simulation with different node number, and calculate the network lifetime. We considered time that the first node of network dies as network lifetime. 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. In comparison, it was shown that lifetime of the network increased in case of using the proposed protocols. Figure 7 and Figure 8 present the effect of increasing number of nodes on network lifetime.

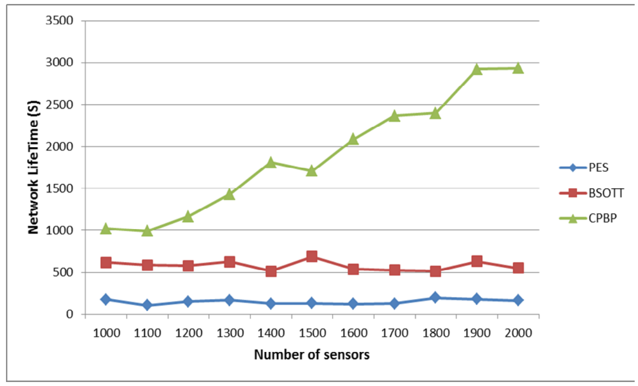

Fig. 7 Effect of increasing the number of nodes on network lifetime. Cluster size = 5

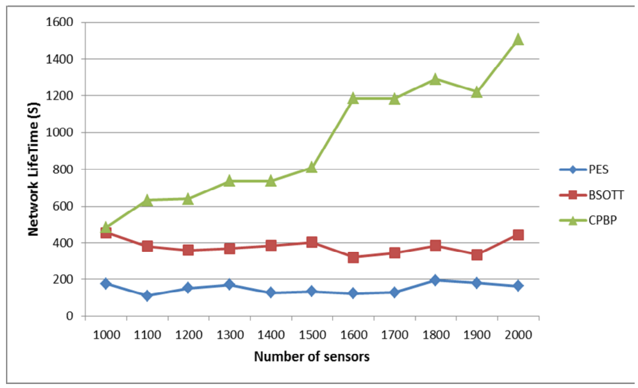

Fig. 8 Effect of increasing the number of nodes on network lifetime. Cluster size = 7

4.2.2 Number of Transmitted Packets

Number of transmissions during tracking process in the field of WSN is one important factor mostly known as radio silence. Number of transmitted packets must be kept low for both energy and radio silence reasons.

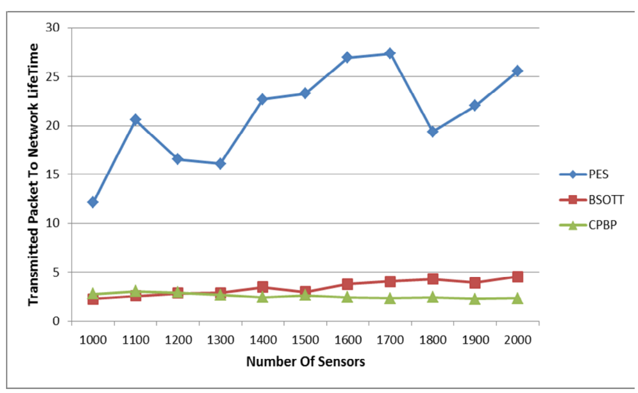

Fig. 9 Effect of increasing the number of nodes on number of transmitted packets. Cluster size = 5

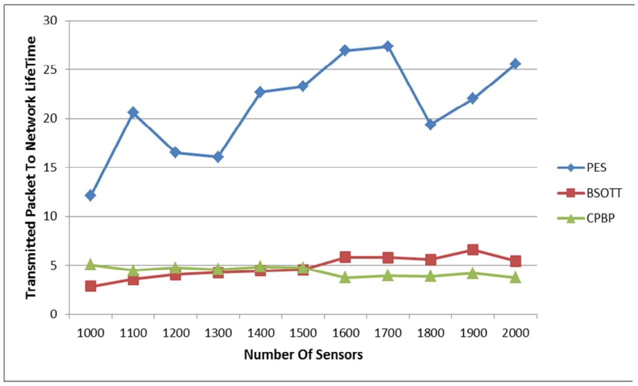

Fig. 10 Effect of increasing the number of nodes on number of transmitted packets. Cluster size = 7

4.2.3 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.

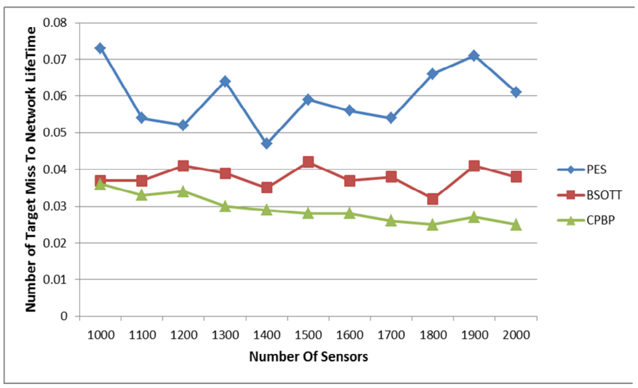

Fig. 11 Effect of increasing the number of nodes on number of target miss. Cluster size = 5

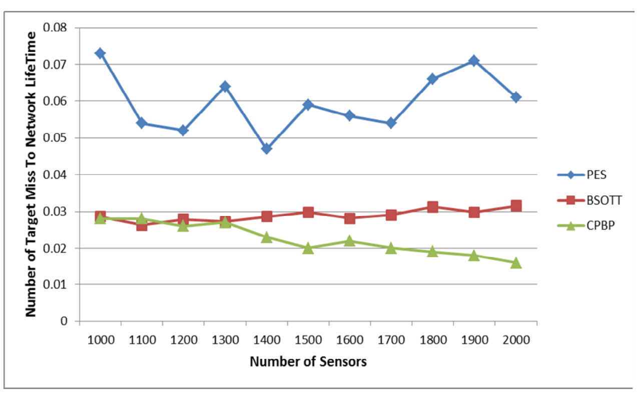

Fig. 12 Effect of increasing the number of nodes on number of target miss. Cluster size = 7

5. Conclusion and Future Works

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. Target tracking is one of these applications. In this paper we presented a Clustering and Prediction Based Protocol (CPBP) for target tracking in WSNs.
Proposed protocol used from a new clustering algorithm. Our protocol considers both energy and distance parameters for clustering. The simulation results represented desirable performance of the presented protocol. The proposed protocol could be considered for improvement of PES and BSOTT protocols.
In the future, the methods should be extended to multiple targets tracking in wireless sensor networks; also, the accuracy in prediction algorithms could be increased using more intelligent prediction algorithms.

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