Designing an Energy Efficient Prediction-based Algorithm for Target Tracking in Wireless Sensor Networks

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Abstract- **Energy saving in wireless sensor networks (WSNs) has received a great deal of attention in recent years due to its wide applications. Target tracking is one of the most important of these applications. Using prediction-based methods for target tracking in WSNs, can improve energy consumption highly in these networks. Prediction-based methods, with prediction the target trajectory and its next location, only activate special nodes of network for tracking and rest of nodes remain in sleep mode for energy saving. In this paper we propose an energy efficient prediction-based method for target tracking. In this algorithm we use two parameters, distance from predicted location and remaining energy of nodes, for selection three sensor nodes for tracking. Moreover, in our algorithm localization of target is done locally. Simulation results show that the proposed algorithm has better performance in energy efficiency which leads to higher lifetime.**

Keywords: ***Target tracking; Wireless sensor network; Clustering; Prediction-based; Energy efficient; Localization.***

I. INTRODUCTION

Wireless sensor networks are systems that consist of small, low-power networked sensing devices with limited sensing, processing and communicating capabilities. These nodes are deployed in environment densely and randomly.

Target tracking is one of the most significant applications in WSNs. In a target tracking system, we can track a moving target that is traversing a WSN with sensing capability of sensors. The type of interested signals includes temperature, sound, light, magnetism and seismic is determined based on the type of targets to be tracked.

Energy saving is one of the main challenges in WSNs. It is because of the energy of a sensor node 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 lifetime of the network.

In this paper, we propose an energy efficient prediction-based algorithm for target tracking in WSNs. Prediction-based algorithms in target tracking are methods which predict the next location of the target (using a prediction mechanism). Then, using a tracker sensor node selection algorithm, only activate some nodes of network for tracking and the other nodes stay in sleep mode for energy saving.

In proposed algorithm 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.

Moreover our algorithm performs localization of target locally. This method attempts to decrease transmission distance for sending localization packets. By decrease transmission distance, energy consumption for sending packets will be decreased. Simulation results show that our algorithm improves network lifetime.

The rest of this paper is as follows: In section 2 we have an overview on some of the existing algorithms for target tracking. The proposed algorithm will be presented in section 3. Then in section 4 we simulate proposed algorithm and evaluate its performance, and in last section we conclude the paper.

II. RELATED WORKS

According to [5], there exist three main approaches for target tracking in WSNs: tree-based, cluster-based and prediction-based algorithms. Tree-based methods organize the network into a hierarchy tree. Examples of tree-based methods include STUN (Scalable Tracking Using Networked Sensors) [6], DCTC (Dynamic Convoy Tree-based Collaboration) [7], OCO (Optimized Communication & Organization) [8] and LFFT (Large Frequency First Tree) [9]. In STUN, the network is considered as a graph. Each edge of this graph is assigned a cost, which is computed from the Euclidean distance between the two nodes. Construction of the tree is based on the costs. The leaf nodes are used for tracking and sending collected data to the sink through intermediate

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nodes. The main idea in DCTC algorithm is that the tree structure is dynamically configured to add some nodes and prune some nodes as the target moves. OCO includes 4 phases. In the position collection phase, the sink collects positions of all reachable nodes in the network. In the processing phase, it applies image processing techniques to clean up the redundant nodes, detect border nodes, and find the shortest path from each node to the sink. In the tracking phase, moving objects are identified and tracked. Finally the maintenance phase reconfigures the network when a node dies or network topology changes. Authors in [9] proposed an efficient object tracking tree based on the physical structure of a WSN. This tree is named LFFT and is designed using the greedy method.

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. Then it 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 [10, 11, 12, 13]. In [10] authors proposed a dynamic clustering algorithm for acoustic target tracking in WSNs. In this method, in each interval time, a CH, that is nearest to target, is selected as active CH. This algorithm constructs a voronoi diagram for CHs and nearest CH to target in each time is the CH that the target is placed in its cell. When an active CH was selected, broadcasts a packet and nodes that receive this packet reply and send the information that have sensed from target for it. Then active CH, based on this information, calculates current target's location and sends it to the sink.

Paper [11] describes an auction-based dynamic coalition for single target tracking in WSNs. In this algorithm when a sensor node finds a target in its vicinity and there is no leader node in the network, it promotes itself coalition leader candidate and sends a broadcast message. Then with evaluation received messages from sensor nodes selects appropriate coalition members.

Algorithms proposed in [12] and [13] use a static clustering scheme for target tracking. In [12] the proposed system is consisting of three main procedures, target detection, acoustic source localization and target state estimation and tracking. RARE method [13], is an energy efficient target tracking protocol is based on two algorithms, RARE-Area and RARE-Node via static clustering. RARE-Area reduces number of nodes participating in tracking and RARE-Node reduces redundant information.

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) [14], DPR (Dual Prediction-based Reporting) [15] and DPT (Distributed Predicted Tracking) [16]. These methods focus on reduction of energy consumption by keeping most of nodes in sleep mode. In DPR the next location of target is calculated at both sensor nodes and sink. When the difference between real location and predicted location is acceptable, no update message send to sink and therefore the number of packets transmitted decrease. DPT uses separate algorithms for nodes and CHs. The CH uses the target descriptor to identify target and predicts its next location.

III. Proposed Algorithm

Proposed algorithm uses a prediction-based method in a clustered network. Our algorithm is divided into two stages, clustering and tracking. Clustering stage is in the start of network deployment. For more simplicity, we use a static clustering method in this algorithm. In clustering stage CHs form their clusters. CHs are specific nodes of network with higher energy and range than other nodes. To doing clustering task, each CH broadcasts a hello message. Each node that receives the hello message from a CH, considers that CH as its father and replies to that CH with a message that inserts the ID, location and energy of itself in it. If a node receives this message from more than one CH, only replies the first message and discards other messages. In the end of this stage, network is divided into clusters and can start tracking stage.

In the start of tracking stage only CHs are awake and other nodes are in sleep mode. When a target enters the network, the first CH that detects the target becomes active. This CH selects three sensor nodes of its members, using tracker sensor node selection algorithm, for tracking. These nodes sense the target and current location of target is calculated from this sensed information. In the future sections proposed algorithm is described with more details.

A. 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, 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 with current and previous location of target, predicts next location of target. So we can estimate the target's speed as

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

While the direction is given by

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

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

$$x_{i+1} = x_i + vt\cos\theta \qquad (3)$$

$$y_{i+1} = y_i + vt\sin\theta \qquad (4)$$

After calculation (x_{i+1}, y_{i+1}), if this location is placed in the current cluster, active CH selects three 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. In the next section, we describe tracker sensor node selection algorithm.

B. Tracker sensor node selection algorithm

For tracking in one interval time, active CH, after prediction the next location of target, should selects three sensor nodes from its cluster as tracking sensor nodes in the next interval time and activates them with sending a wake up message before target arrives to that location.

Current prediction-based methods often consider nearest nodes to predicted route or location as tracker sensor nodes. Proposed algorithm uses two parameters, distance and energy, for tracker sensor node selection algorithm. In this method active CH calculates, for each node in its cluster, a selection parameter as follows:

$$selection_i = \frac{energy_i}{{distance_i}^2} \quad (5)$$

In this relation $distance_i$ is the distance of node i from predicted location, and $energy_i$ is the remaining energy of node i. Then, active CH selects three 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 of proposed tracker sensor node selection algorithm can prolong network lifetime significantly.

As transmission power is directly related to the distance, to prevent high power consumption, we used power 2 for distance in relation 5. This caused distance parameter has been more influence from energy parameter in selection parameter calculation.

C. Localization method

One of the main ideas of proposed algorithm is that localization of target is done locally in sensor nodes not centrally in CHs.

In our method active CH after selection three sensor nodes for tracking, selects one of them that is nearest to itself as leader node. Then sends a wake-up message to the leader node that inserts the predicted location of target in it. Also active CH sends wake-up messages to two other selected nodes. These messages contain the ID of leader node. By using this method two selected sensor nodes (except leader node) for tracking in each interval time send their distance from the target to leader node (distance message). Leader node after receiving distance messages does localization.

As transmission power is directly related to the distance, by using our method energy consumption of network will be decreased. This is because three selected sensor nodes for tracking are often close to each other and consumed energy for sending a message between them is lower than consumed energy for sending a message from one of them to CH. Figure 1 shows the difference between running localization algorithm using active CH and leader node.

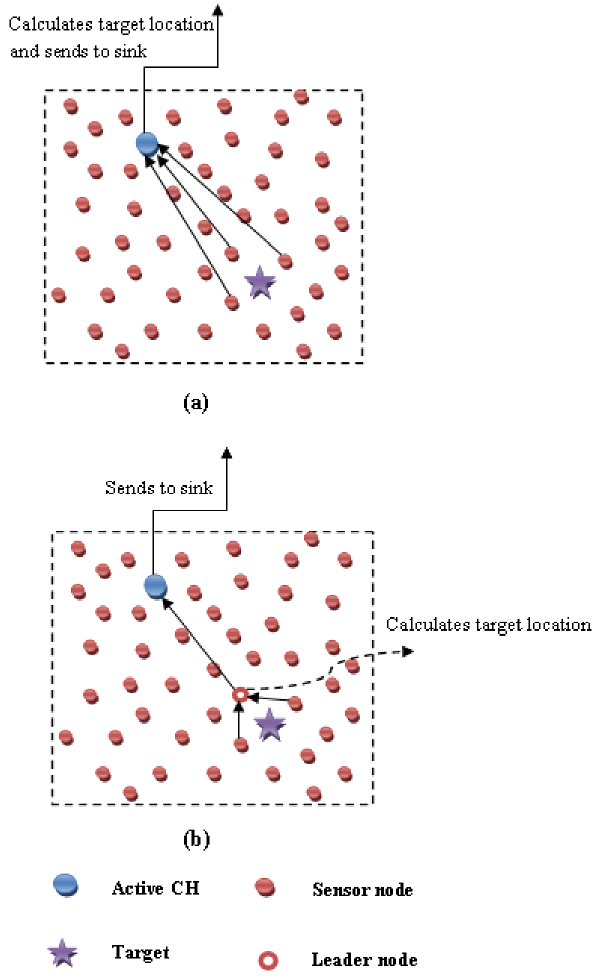

Figure 1. (a) Localization in active CH (b) Localization in Leader node

After leader node receives distance messages from two other selected sensor nodes, calculates current location of target. For this purpose, we use trilateration algorithm for localization. This algorithm has been shown in figure 2.

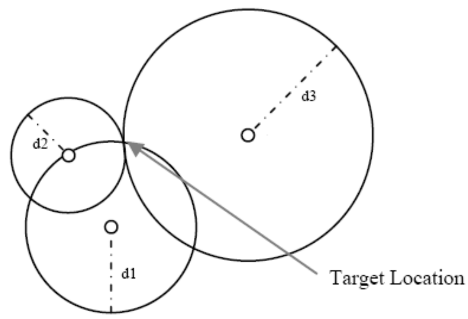

Figure 2. Trilateration localization Algorithm

Trilateration algorithm forms relation 6 for three nodes and from solving three formed relations, obtains coordinate of target.

$$(x_i - x_t)^2 + (y_i - y_t)^2 = d_i^{\ 2} \ , (i = 1,2,3) \qquad (6)$$

In this relation, (x_i , y_i) are coordinate of node i, (x_t , y_t) are coordinate of target and d_i is distance of node i from target.

Leader node, after calculation the current location of target, compares it with the predicted location of target. If the difference between predicted location that has received from active CH and calculated current location is more than error threshold defined by user, sends calculated location using a location message to active CH. Otherwise no message is sent to active CH. In each interval time if active CH receives a location message from leader node, sends the calculated location to the sink. Otherwise predicted location of target will be sent to the sink. By using this method the number of transmitted packet and directly energy consumption of nodes will be decreased.

Figure 4 shows the pseudo code of proposed algorithm in active-CH and leader node.

```
Define:
    PL: Predicted Location
    CRL: Current Location
    PRL: Previous Location
    CCL: Calculated Current Location
    Thr: User-defined threshold
    Send (Transmitted Message, Receiver)
    Receive (Received Message, Transmitter)
    Predicted Next Location= Predict (Current Location, Previous
    Location, Δt)

Active-CH:
    PL= Predict (CRL, PRL, T)
    For each sensor node i
        If father[i] = Active-CH
            Selection[i] = RemainingEnergy[i] / DistanceFromPL[i]^2
        End If
    End For
    (s1, s2, s3) = Three sensor nodes with highest selection[i]
    Leader= Sensor node from (s1 & s2 & s3) with lowest distance from
    Active-CH
    (m1, m2)= Two other sensor nodes from (s1, s2, s3) except Leader
    Send (WakeupMsg, Leader & m1 & m2)
    PRL= CRL
    If receives LocationMsg(CCL) from leader
        CRL= CCL
    Else
        CRL= PL
    End If
    Send (LocationMsg(CRL), Sink)

Leader Node:
    Receive (DistanceMsg, m1 & m2)
    CCL= Localization (m1, m2, Leader)
    If (|CCL – PL| > Thr)
        Send (LocationMsg(CCL), Active-CH)
    End If
```

Figure 3. Pseudo code of proposed algorithm

IV. SIMULATION

In this section, using computer simulation, we evaluate performance of proposed algorithm. Our simulation has done in OPNET simulator.

We compare our proposed method with previous prediction-based algorithms. We use three below parameters for evaluate performance of our algorithm with others:

1. The number of dead nodes of network over time.
2. Network lifetime: The time that the first node of network dies.
3. Average Energy Consumption (AEC) of nodes.

A. Simulation Environment

The simulation model is considered a network which the number of its nodes is varied between 100 and 500. This network has 8 CHs. CHs are uniformly and other nodes are randomly distributed between (x = 0, y = 100) and (x = 400, y = 300) with sink at location (x = 50, y = 50). The initial energy of each normal node is 0.5J. Target trajectory is chosen randomly and the target speed is varied between 0 and 3m/sec. For more accuracy, tracking period is set to 1sec. User-defined threshold is considered 1 meter and simulation is done in 3600 seconds (60 minutes).

The energy model used in our simulation is the same as the one used in [17]. In this model, the energy consumed to transmit a packet to a distance d (E_{Tx}) and energy consumed for receiving a packet (E_{Rx}) are as follows:

$$E_{Tx}(k,d) = E_{elec} + E_{amp} * d^{\alpha} \qquad (7)$$

$$E_{Rx}(k) = E_{elec} \qquad (8)$$

Often in short distance free space model is considered. In free space model α= 2. Whereas in proposed algorithm we use a cluster-based architecture, transmission distance between nodes is short. So we consider α=2. As in [17] we used E_{elec} = 50 nJ/bit and E_{amp} = 10 pJ/bit/m^2, in our simulation.

B. Simulation Results

In this section, we evaluate performance of our algorithm. Figure 4 shows the average number of dead nodes of network during simulation in different scenarios with 300 sensor nodes. The trajectory of moving target in each scenario is different from the others.

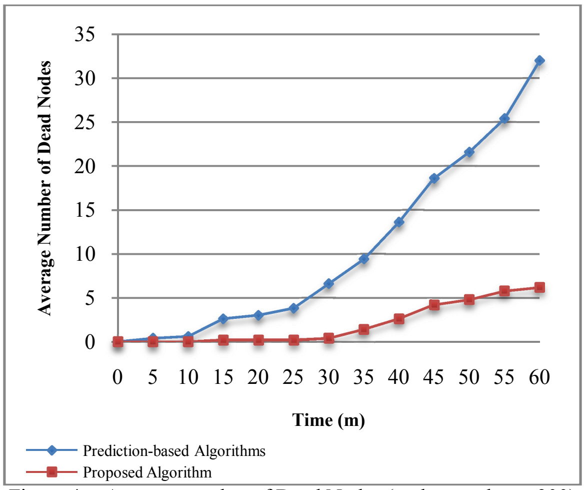

Figure 4. Average number of Dead Nodes (nodes number = 300)

As we expect, in proposed algorithm the number of dead nodes over time are less than other prediction-based algorithms. This is because, proposed algorithm selects tracker sensor nodes with attention to distance and energy parameters but previous prediction-based algorithms only have used distance parameter for tracker sensor nodes selection algorithm. Our method, sometimes may select nodes with higher energy but further from predicted location as tracker sensor nodes. So nodes with lower energy can remain more time in the network and network lifetime will be increased.

Moreover proposed algorithm uses a localized localization method that performs localization algorithm in leader node. As describe in previous section, by using this method for localization, we can decrease consumed energy by nodes. By reduction the network energy consumption, nodes lifetime and directly network lifetime will be increased. Figure 5 shows AEC of nodes versus time in compared algorithms.

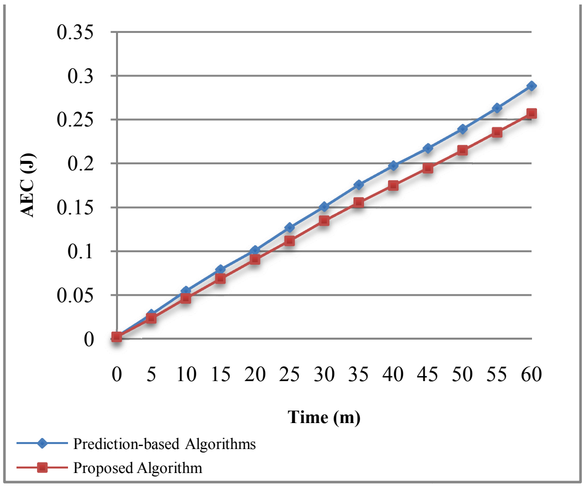

Figure 5. Average Energy Consumption (AEC) of nodes

For more comparison, we run our simulation in many different scenarios, with different node number. Figure 6 shows average number of dead nodes of network in simulation time (60 minutes) versus nodes number. In figure 7 we depict average lifetime of network versus nodes number in these scenarios. As mentioned before we considered time that the first node of network dies as network lifetime. This diagram shows that average network lifetime in proposed algorithm is more than other prediction-based methods and this time increases as the nodes number of network increase.

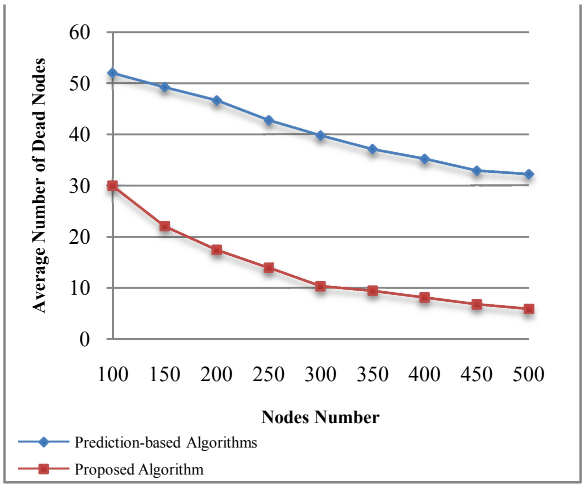

Figure 6. Average Number of Dead Nodes (60 minutes)

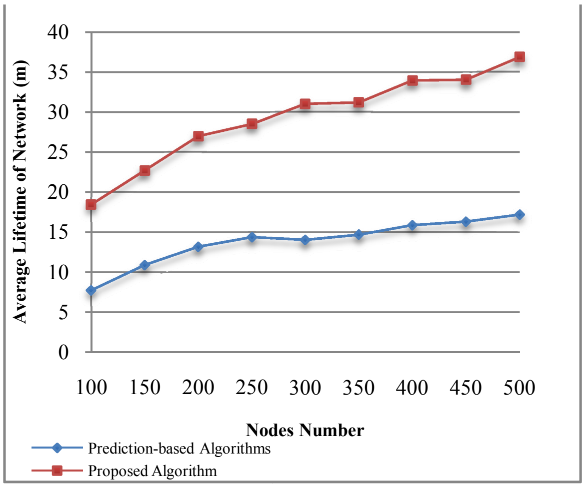

Figure 7. Average Lifetime of Network

As said before, the user-defined threshold in our simulation is considered 1 meter. In last section we compare the difference between three different user-defined thresholds. Figure 9 shows mean tracking error versus time in different scenarios. In these scenarios the nodes number is considered 300. Average number of dead nodes versus time in these scenarios is depicted in figure 10. As these diagrams show by increment the user-defined threshold, mean tracking error increases and the average number of dead nodes decreases. So we can increase tracking accuracy by decreasing user-defined threshold which leads to increment average dead nodes of network.

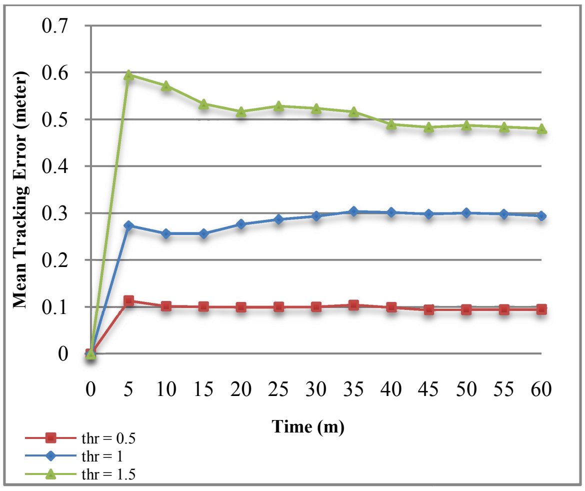

Figure 8. Mean Tracking Error

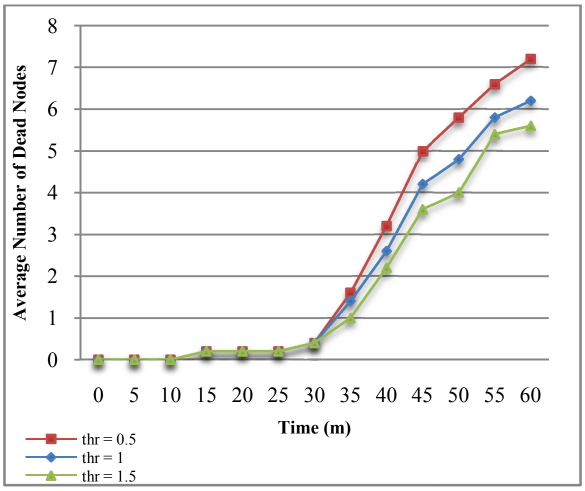

Figure 9. Average Number of Dead Nodes

V. CONCLUSION

One of the main limitations of sensor networks 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 algorithms. Target tracking is one of these applications.

In this paper we presented an energy efficient prediction-based algorithm for target tracking in WSNs. Proposed algorithm used a tracker sensor nodes selection algorithm that considers both energy and distance parameters for selecting tracker sensor nodes. Also our method performs localization algorithm locally in sensor nodes not centrally in CHs. Simulation results show that proposed algorithm decreases the network energy consumption and therefore increases lifetime of network by remaining nodes with lower energy more time in the network in comparison to other prediction-based algorithms.

In this paper, we used trilateration localization algorithm. However, using other localization methods that have lower computation overhead could be of interest for future works.

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